INNOVATION ADOPTION IN NAVAL SHIP DESIGN

BY

REUVEN LEOPOLD

B.S., MASSACHUSETTS INSTITUTE OF TECHNOLOGY
(1961)
M.S., MASSACHUSETTS INSTITUTE OF TECHNOLOGY
(1963)
M.M.E., MASSACHUSETTS INSTITUTE OF TECHNOLOGY
(1965)

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE
DEGREE OF DOCTOR OF
PHILOSOPHY
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
MAY 1977

Signature of Author

Certified by

Accepted by

Thesis Supervisor

Chairman, Department or (Interdepartmental) Committee

SEP 21 1977
INNOVATION IN NAVAL SHIP DESIGN

VOLUME I
INNOVATION ADOPTION IN NAVAL SHIP DESIGN

by

REUVEN LEOPOLD

Submitted to the Department of Ocean Engineering
on May 10, 1977 in partial fulfillment of the requirements
for the Degree of Doctor of Philosophy

ABSTRACT

The objective of this thesis was to develop a set of principles
which govern the process of innovation adoption within a large and complex
organization such as the U.S. Navy. By synthesizing results of research
conducted by sociologists, social psychologists, economists, and political
scientists on the subject of innovation, a set of seven hypotheses were
derived. Two empirical case studies embodying substantially different
technologies were developed as part of this thesis: (1) gas turbines as
propulsion prime movers for warships, and (2) fin roll stabilizers also
for warships.

Despite the differences of these entirely different systems in
terms of their functions in a warship, perceived essentially in terms of
a warship's missions, the character of the industry which produces them,
as well as the character of the Navy's organizations concerned with develop-
ment, procurement, and maintenance of the two systems, both case studies
were found to support all seven hypotheses. Although organization structural changes are not expected to have sufficient impact to simplify the diverse and complex Navy organization so as to radically impact the innovation adoption process, this study does recommend several feasible steps which, if taken, should enhance an increased rate of innovation adoption in new naval ship designs.

Two case studies are clearly insufficient to provide conclusive proof for the validity of the seven hypotheses as generally applicable principles governing the adoption of innovations in complex organizations; however, they and this study do provide a good framework for further validation by future research.

Thesis Chairman: Harvey Sapolsky
Title: Associate Professor of Political Science

Committee Members: Prof. Ira Dyer, Head, Ocean Engineering Department
Dr. Jim Utterback, Center for Policy Alternatives
ACKNOWLEDGEMENTS

This dissertation is the product of years of effort. The idea of the topic itself is a product of a year spent in taking courses on the subject of innovation, at MIT in the Schools of Political Science and Industrial Management and the Harvard Business School, as well as the many years of courses in the technology of ship design in the Department of Ocean Engineering. During that year I was exposed to a fascinating segment of literature unknown to me up to that time – the literature on innovation.

Professors Sapolsky, Utterback, Roberts and Abernathy, as well as Dr. Hollomon and Dr. Dyer were generous with their time and it was as a result of conversations with them in concert with reading the aforementioned literature that the subject of this thesis was born.

Dr. Hollomon and Dr. Utterback of MIT's Center for Policy Alternatives were especially generous with their time and shared with me their tremendous insight into the process of innovation. It has been indeed a privilege to have had the opportunity to have their guidance and advice.

I want to also thank Professor Roberts for consenting to serve on my inter-departmental doctoral committee and, in the many conversations we had, to impart to me his wisdom on the subject of innovation, a field he has contributed to with numerous articles.
Professor Harvey Sapolsky, chairman of my dissertation committee, was the most instrumental in developing my interest in the management of innovation. His influence on my thinking and research has been substantial. I am indebted for his insights, stimulation, and support.

However, I owe most special thanks to Dr. Dyer for my having undertaken work toward a Ph.D. in the first place. It was a major step to take a year off from my work in Washington and embark on the long and treacherous road toward this degree. Had it not been because of Dr. Dyer's encouragement and continuous moral support I doubt that I would have returned to MIT and carried through the work toward this degree.

I am also indebted to the U.S. Navy for having financially supported me in my studies with special thanks to Capt. J. Wilkins for obtaining the Civil Service Commission approval in this matter. In particular, I would like to express my appreciation to Capt. Rasmussen, Capt. Milano and Admiral Jones, Commander, Naval Ship Engineering Center (1972-1974), for both encouraging me to return to MIT and allowing me to leave for a period of 10 months to pursue the studies which led eventually to this dissertation.

I wish also to express my appreciation to the following individuals for the generosity of their time taken to conduct interviews: J. Boatwright, L. Weschler, M. Hauschildt, the late R. Michel, RADM W. A. Brockett (USN, Ret.) F. Welling, Capt. E. Svendson (USN, Ret.), E. MacLeish, J. Doyle, R. Apple, J. Mills, H. Meyer, and T. Sarchin.
Also, I wish to thank the following individuals who were kind enough to review rough drafts and make constructive comments: L. Affanasieff, P. Gale, J. Abbott, W. Schmid, R. d'ArCY.

For editorial help I wish to thank: J. Cramer, L. Brophy, J. Montgomery, C. O'Brien and M. Amir and for typing the final manuscript: JoAnne Hastings and Sue Harding.

Finally, I would like to express my thanks to my family, my wife Dora and children Brigitte and Edward, for the many sacrifices they had to make over the years to make it possible for me to reach this goal. Throughout my graduate education my wife Dora has been a constant source of encouragement, support and love. Among other sacrifices, she was the one who encouraged me to uproot ourselves for one year and move to Boston. Brigitte and Edward were at an age at which it was difficult to accept making new friends in a new state yet they also took it in stride. Therefore, I dedicate this dissertation to Dora, Brigitte and Edward.

Reuven Leopold
Bethesda, Maryland
May 5, 1977
Dedicated To:

My wife Dora, daughter Brigitte,

and son Edward

and to the most successful innovation advocate in naval ship design,

Admiral Hyman G. Rickover.
DISCLAIMER

This thesis reflects views of the author and does not in any way reflect the views of the Department of the Navy.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>3</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>5</td>
</tr>
<tr>
<td>DEDICATION</td>
<td>8</td>
</tr>
<tr>
<td>DISCLAIMERS</td>
<td>9</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>10</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>13</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>16</td>
</tr>
<tr>
<td>1 INTRODUCTION</td>
<td>18</td>
</tr>
<tr>
<td>2 LITERATURE REVIEW ON THE PROCESS OF INNOVATION</td>
<td>22</td>
</tr>
<tr>
<td>3 STATEMENT OF HYPOTHESES AND RESEARCH PLAN</td>
<td>33</td>
</tr>
<tr>
<td>4 THE GAS TURBINE ADOPTION CASE STUDY</td>
<td>44</td>
</tr>
<tr>
<td>4.1 Introduction and Pre-World War II Developments</td>
<td>44</td>
</tr>
<tr>
<td>4.2 Why Destroyers as a Vehicle for Analysis for the Adoption of Gas Turbines?</td>
<td>51</td>
</tr>
<tr>
<td>4.3 A Competitor is Born - The 1,200-psi Steam Plant</td>
<td>58</td>
</tr>
<tr>
<td>4.4 U.S. Naval Gas Turbine Developments of the 1940's</td>
<td>79</td>
</tr>
<tr>
<td>4.5 The Early 1950's - The Work of the Ship Design Coordinating Committee and Its Propulsion Panel</td>
<td>107</td>
</tr>
<tr>
<td>4.6 The Adoption of Medium Speed Diesels for Destroyers: The DE 1033 Class</td>
<td>165</td>
</tr>
<tr>
<td>4.7 The Adoption of Pressure-Fired Boilers (The DE 1040 Class)</td>
<td>177</td>
</tr>
<tr>
<td>CHAPTER</td>
<td>PAGE</td>
</tr>
<tr>
<td>---------</td>
<td>------</td>
</tr>
<tr>
<td>4.8 The Destroyer That Never Was - SEAHAWK</td>
<td>197</td>
</tr>
<tr>
<td>4.9 The Last Failure Preceding the Successful Adoption</td>
<td>241</td>
</tr>
<tr>
<td>4.10 Finally The First Adoption - The DD 963</td>
<td>270</td>
</tr>
<tr>
<td>4.11 The First Five Years of the Post Adoption Period</td>
<td>294</td>
</tr>
<tr>
<td>5 SHIP ROLL STABILIZATION CASE STUDY</td>
<td>311</td>
</tr>
<tr>
<td>5.1 Introduction</td>
<td>311</td>
</tr>
<tr>
<td>5.2 Early History</td>
<td>318</td>
</tr>
<tr>
<td>5.3 The Late 1930's and 1940's</td>
<td>341</td>
</tr>
<tr>
<td>5.4 Prelude to the Adoption Decision</td>
<td>368</td>
</tr>
<tr>
<td>5.5 The Last Experiment Before Adoption</td>
<td>394</td>
</tr>
<tr>
<td>5.6 The Decision to Adopt</td>
<td>410</td>
</tr>
<tr>
<td>5.7 Three More Adoptions Between 1961 - 1963 - But Only for DE's</td>
<td>438</td>
</tr>
<tr>
<td>5.8 Studies, Test and More Studies - But No More Adoptions</td>
<td>447</td>
</tr>
<tr>
<td>5.9 Revival of Interest But Instead of Adoption - Regression</td>
<td>462</td>
</tr>
<tr>
<td>6 SYNTHESIS AND ANALYSIS</td>
<td>500</td>
</tr>
<tr>
<td>6.1 Introduction</td>
<td>500</td>
</tr>
<tr>
<td>6.2 Nature of the Process of Innovation Adoption</td>
<td>504</td>
</tr>
<tr>
<td>6.3 The Role of Organization Structure in Innovation Adoption</td>
<td>552</td>
</tr>
<tr>
<td>6.4 The Effect of Policies and Regulations on Innovation Adoption</td>
<td>600</td>
</tr>
<tr>
<td>6.5 Concluding Note</td>
<td>623</td>
</tr>
</tbody>
</table>
# TABLE OF CONTENTS (CONT'D)

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td></td>
</tr>
<tr>
<td>CONCLUSIONS</td>
<td>627</td>
</tr>
<tr>
<td>7.1 Establish Conditions Which Will Foster Policy-Based Decisions For Innovation Adoption or Transfer the Design Function to the Private Sector</td>
<td>630</td>
</tr>
<tr>
<td>7.2 Provide Stronger Integration Between the R&amp;D and Design Communities</td>
<td>636</td>
</tr>
<tr>
<td>7.3 Make Organizational/Environmental Changes to Encourage the Emergence of Innovation Advocates</td>
<td>639</td>
</tr>
<tr>
<td>7.4 Reduce the Emphasis on Cost and Schedule During Design</td>
<td>644</td>
</tr>
<tr>
<td>8</td>
<td>648</td>
</tr>
<tr>
<td>LIST OF REFERENCES</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>678</td>
</tr>
<tr>
<td>ABBREVIATIONS AND GLOSSARY</td>
<td></td>
</tr>
<tr>
<td>APPENDIX A</td>
<td>681</td>
</tr>
<tr>
<td>THE ORGANIZATION OF THE U.S. NAVY</td>
<td></td>
</tr>
<tr>
<td>APPENDIX B</td>
<td>724</td>
</tr>
<tr>
<td>DEVICES FOR SHIP ROLL STABILIZATION</td>
<td></td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-1</td>
<td>Propulsion Subsystem Acquisition Cost Relative to Other Costs for Four Gas Turbine Ships</td>
<td>54</td>
</tr>
<tr>
<td>4-2</td>
<td>Manning Summaries by Department for Four Gas Turbine Ships</td>
<td>55</td>
</tr>
<tr>
<td>4-3</td>
<td>Propulsion Subsystem Volume Requirements for Four Gas Turbine Ships</td>
<td>56</td>
</tr>
<tr>
<td>4-4</td>
<td>Westinghouse Analysis of Optimum Steam Pressure</td>
<td>65</td>
</tr>
<tr>
<td>4-5</td>
<td>Westinghouse Analysis of Optimum Steam Pressure</td>
<td>66</td>
</tr>
<tr>
<td>4-6</td>
<td>&quot;Free Piston&quot; Gas Generator and Gas Turbine</td>
<td>88</td>
</tr>
<tr>
<td>4-7</td>
<td>Schematic Diagram of a &quot;Free Piston&quot; Gas Generator</td>
<td>89</td>
</tr>
<tr>
<td>4-8</td>
<td>Comparison of Fuel Rates</td>
<td>98</td>
</tr>
<tr>
<td>4-9</td>
<td>Comparison of Weight of Machinery and Endurance</td>
<td>99</td>
</tr>
<tr>
<td>4-10</td>
<td>Fuel Rates for Various Turbine and Compressor Efficiencies</td>
<td>101</td>
</tr>
<tr>
<td>4-11</td>
<td>Pressure-Fired Boiler Cycle</td>
<td>180</td>
</tr>
<tr>
<td>4-12</td>
<td>Design Schemes for DE 1040</td>
<td>186</td>
</tr>
<tr>
<td>4-13</td>
<td>Single Screw Design With Three Base Plant Diesels and One Gas Turbine</td>
<td>205</td>
</tr>
<tr>
<td>4-14</td>
<td>Scheme D - Twin Screw Design Using Two Base Plant Diesels and One Gas Turbine</td>
<td>207</td>
</tr>
<tr>
<td>4-15</td>
<td>Endurance Comparison of Schemes A Through D</td>
<td>210</td>
</tr>
<tr>
<td>4-16</td>
<td>CODAG Machinery Arrangement</td>
<td>213</td>
</tr>
<tr>
<td>4-17</td>
<td>CODAG Plant Design Proposed for SEAHAWK I</td>
<td>218</td>
</tr>
<tr>
<td>4-18</td>
<td>Combined Gas Turbine Propulsion Plant</td>
<td>231</td>
</tr>
<tr>
<td>4-19</td>
<td>Development Schedule</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Estimated RDT&amp;E Funds Required for the Combined Gas Turbine Propulsion Plant Development</td>
<td>232</td>
</tr>
<tr>
<td>4-20</td>
<td>Fuel Consumption Comparison Curves</td>
<td>233</td>
</tr>
<tr>
<td>4-21</td>
<td>Propulsion Plant Weight Comparison Curves</td>
<td>234</td>
</tr>
<tr>
<td>4-22</td>
<td>Steam Plants (600 psi and 1,200 psi)</td>
<td>244</td>
</tr>
<tr>
<td>4-23</td>
<td>Gas Turbine Plants (Simple Cycle and Regenerative Gas Turbine)</td>
<td>245</td>
</tr>
<tr>
<td>4-24</td>
<td>FY-1967 DDG - Comparison of S.F.C. Versus Speed for Steam and COGAG Plants</td>
<td>246</td>
</tr>
<tr>
<td>4-25</td>
<td>DDG Fiscal Year 1976 SCB Project No. 223.67 (Steam)</td>
<td>257</td>
</tr>
<tr>
<td>4-26</td>
<td>SCB Project No. 223.67 COGAG-E</td>
<td>258</td>
</tr>
<tr>
<td>4-27</td>
<td>Elevation of Planned Layout of DDG Machinery Spaces</td>
<td>259</td>
</tr>
<tr>
<td>4-28</td>
<td>Plan View of DDG Machinery Spaces</td>
<td>260</td>
</tr>
<tr>
<td>4-29</td>
<td>Comparison between Steam and Gas Turbine Machinery Space Lengths</td>
<td>261</td>
</tr>
<tr>
<td>Figure</td>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>-------</td>
<td>------</td>
</tr>
<tr>
<td>4-30</td>
<td>Alternative Methods for the Development of Naval Ship Design</td>
<td>271</td>
</tr>
<tr>
<td>4-31</td>
<td>Impact of Ship Design on Propulsion System</td>
<td>274</td>
</tr>
<tr>
<td>4-32</td>
<td>Propulsion Subsystem Selection and Design Procedure</td>
<td>277</td>
</tr>
<tr>
<td>4-33</td>
<td>Propulsion Subsystem Concepts</td>
<td>279</td>
</tr>
<tr>
<td>4-34</td>
<td>Impact of Propulsion Subsystem on Destroyer Size Specific Weight Versus Endurance Specific Fuel Consumption</td>
<td>284</td>
</tr>
<tr>
<td>4-35</td>
<td>Single Screw COGAG</td>
<td>297</td>
</tr>
<tr>
<td>4-36</td>
<td>Single Crew COGOG</td>
<td>298</td>
</tr>
<tr>
<td>4-37</td>
<td>Twin Screw COGAG-E</td>
<td>299</td>
</tr>
<tr>
<td>4-38</td>
<td>Twin Screw COGOG</td>
<td>300</td>
</tr>
<tr>
<td>5-1</td>
<td>The Ship as a Dynamic System</td>
<td>312</td>
</tr>
<tr>
<td>5-2</td>
<td>Royal Yacht LIVIDIA</td>
<td>319</td>
</tr>
<tr>
<td>5-3</td>
<td>The Steamer BESSEMER (Salon Mounted on Gimbals)</td>
<td>320</td>
</tr>
<tr>
<td>5-4</td>
<td>&quot;Water Chambers&quot; as Designed for the Warship INFLEXIBLE</td>
<td>322</td>
</tr>
<tr>
<td>5-5</td>
<td>Impact of Rolling on a Ship of the CORVETTE Class</td>
<td>345</td>
</tr>
<tr>
<td>5-6</td>
<td>General Arrangement of Activated-Tank Installation on USS PEREGRINE</td>
<td>352</td>
</tr>
<tr>
<td>5-7</td>
<td>Denny-Brown Fin Stabilizer System</td>
<td>397</td>
</tr>
<tr>
<td>5-8</td>
<td>Sperry Gyroscope Fin Stabilizer System</td>
<td>398</td>
</tr>
<tr>
<td>5-9</td>
<td>Vosper Ltd. Non- Retractable Fin Stabilizer System</td>
<td>401</td>
</tr>
<tr>
<td>5-10</td>
<td>Frequency Response Curves</td>
<td>405</td>
</tr>
<tr>
<td>5-11</td>
<td>Reduction in Average Roll Amplitudes</td>
<td>408</td>
</tr>
<tr>
<td>5-12</td>
<td>Qualitative Comparison of Roll Angle Envelopes for Stabilized and Unstabilized Conditions for Ships Equipped With Active Antiroll Fins</td>
<td>435</td>
</tr>
<tr>
<td>5-13</td>
<td>Comparison of Stabilized and Unstabilized Roll as a Function of Ship's Roll Amplitude</td>
<td>436</td>
</tr>
<tr>
<td>5-14</td>
<td>Roll-Caused Incidents and Motivation Index for Ships Equipped With Active Antiroll Fins</td>
<td>453</td>
</tr>
<tr>
<td>5-15</td>
<td>Subsystem Effectiveness as a Function of Roll Amplitude</td>
<td>458</td>
</tr>
<tr>
<td>5-16</td>
<td>Comparative Effectiveness of PF Stabilization Systems</td>
<td>466</td>
</tr>
<tr>
<td>5-17</td>
<td>Roll Response as a Function of Roll Stabilized Fin Size in Sea State 6 for the PF 109</td>
<td>468</td>
</tr>
<tr>
<td>5-18</td>
<td>Comparison of Stabilized Ship and Unstabilized Ship Effectiveness During a Lengthy North Atlantic Mission</td>
<td>474</td>
</tr>
</tbody>
</table>
### LIST OF FIGURES (Cont'd)

<table>
<thead>
<tr>
<th>Figure</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-19</td>
<td>Comparative Annual Average Maximum Speed for Destroyer-Type Ships</td>
<td>475</td>
</tr>
<tr>
<td>6-1</td>
<td>Bell Labs: The Myth Versus Reality</td>
<td>582</td>
</tr>
<tr>
<td>6-2</td>
<td>Matrix R&amp;D Engineering Organization</td>
<td>586</td>
</tr>
</tbody>
</table>

### Appendix A

| A-1    | The Navy's Organization from World War II through the Mid-Sixties      | 685  |
| A-2    | Organization of the Bureau of Ships (1940)                            | 689  |
| A-3    | Relative Position of the Naval Reactors Organization                  | 690  |
| A-4    | Organization of Bureau of Ships Design Division                       | 691  |
| A-5    | A Major Change which Affected Both Requirement Definer's (User's) and Ship Designer's (Developer's) Organizations | 694  |
| A-6    | Organization of OPNAV                                                 | 697  |
| A-7    | Bureau of Ships R&D Organization 1965                                 | 702  |
| A-8    | R&D Directorate of the Naval Ship System Command (1966–1975)          | 703  |
| A-9    | Chain of Command for RDT&E Field Activities (1966)                    | 704  |
| A-10   | Decision and Documentation Flow Preliminary Design                    | 709  |
| A-11   | Requirements Specifications Dialogue                                   | 711  |
| A-12   | NAVSEC/NAVSEA Ship Design Project Organization                        | 712  |

### Appendix B

| B-1    | Sketches of Passive Antiroll Tank Stabilizers                        | 728  |
| B-2    | Passive-Tank Stabilizers, USS PENSACOLA and USS NORTHAMPTON           | 729  |
| B-3    | Performance Curves of Tank Stabilized Ship                           | 730  |
| B-4    | Performance Curves of Pin Stabilized Ship                            | 732  |
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3–1</td>
<td>Innovation Adoption, The Hypothesis</td>
<td>34</td>
</tr>
<tr>
<td>3–2</td>
<td>System Innovations for Possible Investigations</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>As Case Studies</td>
<td></td>
</tr>
<tr>
<td>3–3</td>
<td>Post World War II U.S. Cruisers, Destroyers and Frigates</td>
<td>38</td>
</tr>
<tr>
<td>4–1</td>
<td>Preliminary Design Studies—September 1941</td>
<td>60</td>
</tr>
<tr>
<td>4–2</td>
<td>Design Characteristics</td>
<td>63</td>
</tr>
<tr>
<td>4–3</td>
<td>DD 927 Class Characteristics at the End of Preliminary Design</td>
<td>64</td>
</tr>
<tr>
<td>4–4</td>
<td>Estimated Machinery Weight Comparison, Increased Reliability</td>
<td>73</td>
</tr>
<tr>
<td>4–5</td>
<td>Estimated Machinery Weight Comparison, Increased Reliability and Steel Deckhouse</td>
<td>74</td>
</tr>
<tr>
<td>4–6</td>
<td>Comparison of Four Types of Internal Combustion Power Plants to Provide 50,000 shp/ shaft</td>
<td>95</td>
</tr>
<tr>
<td>4–7</td>
<td>Features of the Selected Steam Plants</td>
<td>96</td>
</tr>
<tr>
<td>4–8</td>
<td>Proposed Gas Turbine Program</td>
<td>136</td>
</tr>
<tr>
<td>4–9</td>
<td>Bureau of Ships Gas Turbine Program (1953)</td>
<td>142</td>
</tr>
<tr>
<td>4–10</td>
<td>Comparison of Propulsion Characteristics</td>
<td>156</td>
</tr>
<tr>
<td>4–11</td>
<td>Bureau of Ship Gas Turbine Program (1955)</td>
<td>162</td>
</tr>
<tr>
<td>4–12</td>
<td>Propulsion Machinery Comparison</td>
<td>173</td>
</tr>
<tr>
<td>4–13</td>
<td>Exhausting S.S.T - G Sets into Main Condenser</td>
<td>188</td>
</tr>
<tr>
<td>4–14</td>
<td>Gas Turbine - Waste Heat Boiler Combination</td>
<td>189</td>
</tr>
<tr>
<td>4–16</td>
<td>Comparison of Characteristics</td>
<td>198</td>
</tr>
<tr>
<td>4–17</td>
<td>Characteristics of Minimum Escort Ship</td>
<td>202</td>
</tr>
<tr>
<td>4–18</td>
<td>Cost Summary</td>
<td>208</td>
</tr>
<tr>
<td>4–19</td>
<td>Base Plant Max/Min Speed Capability</td>
<td>209</td>
</tr>
<tr>
<td>4–20</td>
<td>Summary of Characteristics</td>
<td>211</td>
</tr>
<tr>
<td>4–21</td>
<td>Schedule of Key Events Showing Inter-Relationship of Shore/Ship Machinery Prototype Installations</td>
<td>227</td>
</tr>
<tr>
<td>4–22</td>
<td>Propulsion Plant Cost Comparisons</td>
<td>237</td>
</tr>
<tr>
<td>4–23</td>
<td>Propulsion System Evaluation</td>
<td>243</td>
</tr>
<tr>
<td>4–24</td>
<td>Operational Cost Analysis 25-Year Cost ($ Millions)</td>
<td>247</td>
</tr>
<tr>
<td>4–25</td>
<td>R&amp;D Cost Analysis R.G.T Versus Simple Cycle</td>
<td>248</td>
</tr>
<tr>
<td>4–26</td>
<td>Gas Turbine Main Propulsion Applications</td>
<td>252</td>
</tr>
<tr>
<td>4–27</td>
<td>Comparison of the DLG28 and the FY 1967 DDG Characteristics</td>
<td>256</td>
</tr>
</tbody>
</table>
LIST OF TABLES (Cont'd)

<table>
<thead>
<tr>
<th>Table</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-28</td>
<td>Gas Turbine Usage by Other Nations in 1971</td>
<td>291</td>
</tr>
<tr>
<td>4-29</td>
<td>DG/AEGIS Propulsion Plant Trade-Off Study</td>
<td>305</td>
</tr>
<tr>
<td></td>
<td>Characteristic Comparison</td>
<td></td>
</tr>
<tr>
<td>4-30</td>
<td>Aircraft Derivative Gas Turbine Performance Characteristics</td>
<td>306</td>
</tr>
<tr>
<td>4-31</td>
<td>Power/Specific Fuel Consumption Requirements as a Function of Ship Speed</td>
<td>307</td>
</tr>
<tr>
<td>5-1</td>
<td>Chronological List of Stabilization Installations</td>
<td>355</td>
</tr>
<tr>
<td>5-2</td>
<td>Report of Conference, Dated 13 April 1949</td>
<td>361</td>
</tr>
<tr>
<td>5-3</td>
<td>British Ships with Denny-Brown Stabilizers</td>
<td>395</td>
</tr>
<tr>
<td>5-4</td>
<td>British Destroyer Fin Stabilization Adoption in the Late 1950's</td>
<td>425</td>
</tr>
<tr>
<td>5-5</td>
<td>Effect of Stabilization on AN/SQS-26 Sonar</td>
<td>431</td>
</tr>
<tr>
<td>5-6</td>
<td>The Suppliers of Fin Stabilizers for U.S. Navy Destroyers</td>
<td>433</td>
</tr>
<tr>
<td>5-7</td>
<td>Estimated Break-Down of Savings on Nonretractable Fins.</td>
<td>434</td>
</tr>
<tr>
<td>5-8</td>
<td>Merit Values Indicating Fin Effectiveness</td>
<td>449</td>
</tr>
<tr>
<td>5-9</td>
<td>DDG Stabilized and Unstabilized Significant Rolling Motions</td>
<td>455</td>
</tr>
<tr>
<td>5-10</td>
<td>Cost-Effectiveness Study of the Ship with a Beartrap Helicopter Landing Assist System and Various Roll Stabilization Systems</td>
<td>460</td>
</tr>
<tr>
<td>5-11</td>
<td>Examples of Cost Reduction Alternatives Considered in a Recent Program</td>
<td>472</td>
</tr>
<tr>
<td>5-12</td>
<td>Destroyer Fin Stabilizer Installations</td>
<td>484</td>
</tr>
<tr>
<td>5-13</td>
<td>A Comprehensive Fin Stabilizer Program</td>
<td>490</td>
</tr>
<tr>
<td>5-14</td>
<td>ShipAlt Cost Estimates and Priority Listing</td>
<td>492</td>
</tr>
<tr>
<td>6-1</td>
<td>A Summary of the Existing Models of Innovation Process</td>
<td>553</td>
</tr>
<tr>
<td>6-2</td>
<td>Characteristics of R&amp;D and Organizational Implications</td>
<td>583</td>
</tr>
</tbody>
</table>

APPENDIX A

A-1 Laboratories Under the Cognizance of the Bureau of Ships During the War 700

APPENDIX B

B-1 Stabilizing Systems to Quench Rolling Motion 726
CHAPTER 1

INTRODUCTION AND SIGNIFICANCE OF THE STUDY

The objective of this study is to identify the factors which influence the U.S. Navy's adoption of significant innovations, late exploitation of innovations adopted by others or the decision not to adopt innovations used by other navies.

In an effort to identify the adoption decision factors, a set of seven hypotheses were developed which can be thought of as the governing principles of innovation adoption in large public organizations such as the Navy. By researching and tracing the rationale and circumstances surrounding the decision to adopt two particular innovations (the gas turbine and roll stabilization) significant supportive evidence for the validity of the postulated hypotheses was found.

In the U.S. Navy and other military establishments, the innovation adoption process differs significantly from that of other U.S. government agencies or private firms. This difference complicates meaningful research. For example, among the many factors which influence innovation in private industry*, the most important one appears to be understanding "user need." Recent major studies, such as the SAPPHO project [1-1], Myers and Marquis [1-2], and Von Hippel [1-3], specifically highlight understanding "user need" as paramount. A product which is not "tuned-in" to "user need" has only a remote chance for success. An innovation that

* Naturally potential profit is the fundamental underlying reason.
does not satisfy "user need" may financially jeopardize the innovating company because it may have no market value. If there is no demand for a new product, the company cannot recoup research and development (R&D) or marketing expenditures. On the other hand, lack of innovation may have an equally disastrous effect on the company's ability to keep up with its competitors.

In private industry, market value and competition are obvious determining factors in innovation adoption, but in the U.S. Navy, there is no market value and competition takes on a totally different meaning than in the private sector. The decision to adopt an innovation into a new Navy design occurs mostly as a result of the user's direct participation in the decision. In most Navy cases, where the innovation adoption occurs with no user participation, the designer will not have the advantage of feedback information as does the designer in the commercial case. In private industry the firm which fails to properly assess "user need" and translate that assessment into sufficient (but not too much) innovation adoption endangers its existence. In the Navy, on the other hand, there is little or no consequence for the organization that failed to adopt innovations or caused adoption of innovations which, in retrospect, should not have been introduced. The Navy is both innovator and user at the same time.

The innovation process and innovation content in the Navy also differs from that of other government agencies. Many government agencies develop regulations and are, subsequently, concerned with regulation enforcement. To these agencies, innovation means primarily a choice among
alternative policies, i.e., should they subsidize R&D directly, should they create incentive through price support or should they invoke new regulations which will drive the public or private enterprises toward what is considered to be in the public's interest?

Thus, in the case of a private firm, the problem is one of company strategy [1-4] to improve its performance, while in the case of the usual government agency, it amounts to a choice among policy alternatives. The Navy is neither like a private firm nor like the usual government agency; instead it is characterized by the fact that it has no competition, other than at times from another branch of the armed services, at the same time it is responsible for the development and operations of equipments it decides to adopt.

This study is significant because the factors which affect the propensity of the Navy to innovate are identified and factual case studies of innovation adoption by the Navy are provided to support the validity of the identified factors.

It is considered also significant that this study managed to avoid two major pitfalls of many other innovation process studies conducted in the past, such as:

a. Selection of a few quantifiable parameters, (but not necessarily parameters which are clearly surrogates to innovation adoption), treated statistically, with conclusions that fail the "so what" test, e.g.,
the number of patents and/or publications produced by an R&D organization or, the number of advanced degreed personnel in the organization (see literature review section for details).

b. Attempts to understand the process of innovation through segmented lenses of either micro-economists, psychologists, sociologists, or political scientists as opposed to an analysis that integrates these views, thus accounting for synergism produced by these factors acting simultaneously (a more correct view of reality).*

* The underlying misassumption of the segmented approach is that a valid explanation of the principles governing the innovation process can be derived by combining the conclusions obtained from entirely different empirical case studies, each performed through one of the segmented lenses of one of the above mentioned disciplines. (See more detailed discussion on this subject in the literature review chapter.)
CHAPTER 2

LITERATURE REVIEW ON THE PROCESS OF INNOVATION

Within the last decade or so, a substantial amount of literature addressing the mechanics of the innovation process and attempts to manage it has been made available. The literature is divided into various fields, such as:

a. Case studies of successful and failed attempts to innovate [1-1], [1-2], [2-1], [2-2] and [2-3].

b. The sociology of innovation adoption by various societies (more on the individual level than organizational level) [2-5], [2-6], [2-7] and [2-8].

c. The history of innovation in various fields [2-9], [2-10] and [2-11].

d. Principles for selection and development of supervisors to enhance the environment for improved innovation in an organization [2-12], [2-13], [2-14] and [2-15].

e. Alternative business arrangements for improved innovation in the firm [2-16], [2-17], [2-18], [2-19] and [2-20].

f. National policy alternatives to enhance innovation in industry [1-4] and [2-21].

g. Attempts to model the innovation process of a firm [1-5] and [2-22].
h. Attempts to determine resource allocation between science and engineering by tracing the contributions of research to innovation [2-23] and [2-24].

i. Analysis of the work environment of scientists and engineers from a human motivation standpoint in large R&D organizations [2-25], [2-26], [2-27], [2-28] and [2-29].

j. Optimization of organizational design to enhance innovation [2-30], [2-31], [2-32], [2-33] and [2-34].

k. The implications of differing firm sizes and industry market structure on technological innovation [2-35], [2-36], [2-37] and [2-38].

l. The measurement of R&D spending as a surrogate to innovation and its effect on the firm's profitability [2-39] and [2-40].

m. Technological forecasting as a means of predicting worthwhile investment in specific innovations, i.e., as a tool for determining allocation of funds for R&D projects [2-53], [2-54].

The rather extensive literature cited represents only the most significant and recent papers. The current status on research of the process of innovation adoption is that it is not well integrated even though it appears that there are contributions to be made across the above listed boundaries.

Five sources, Becker and Whisler of the University of Chicago [2-41], Rodgers and Shoemaker [2-7], Ross of A.D.L. [2-42], Rosenbloom of Harvard [1-5], and Utterback and Abernathy [2-4] and [2-22], of which the latter three were published in 1974, argue the need for a conceptual model of the innovation process.
Each of these researchers takes a different viewpoint for the problem definition and his proposed solution. This segmented approach is reminiscent of the old Indian fable about the "Six Blind Men of Industan" who were asked to describe an elephant. After touching different parts of the animal each man gave a different description. Their conclusions were diverse since each examined a different part of the animal.

Ross [2-42] was searching the field for an appropriate model of innovation adoption by organizations, in order to apply it for a particular case study of innovation adoption by public school districts. He concluded that:

"It seems fair to say that the literature on organizational behavior in innovation adoption, as compared with the work on behavior of individual adopters, lacks consensus on even a few major conditions affecting innovation adoption, has not worked with care on the indicators of adaptability, and generally fails to test its observations using models, such as mathematical models, relating environmental and internal conditions to organizational behavior in adoption performance."

In reviewing the state-of-the-art of understanding the innovation process, Rosenbloom [1-5] observed that:

"A better understanding of the processes of innovation is necessary if society is to be able to influence them. The existing base of knowledge offers relatively little that is directly useful for policy makers, but it provides an extensive foundation for research that would do so. The 'state-of-the-art' invites a policy-oriented synthesis, one built on a conceptual framework that would interlink currently disparate traditions of inquiry."
Utterback and Abernathy [2-22] proposed, in 1975, a conceptual model for predicting differences in the innovative process and the types of innovations attempted by firms in different stages of maturity of the firm. Their opening statement was:

"Most studies of new product and process technology to date have been descriptive and have attempted to identify consistent patterns in the sources of ideas and problem solutions used, communication processes, and characteristics of successful innovations [2-43]. Past work does suggest central tendencies and systematic variations in the innovative process, but offers no higher level explanation, or theory, of why these tendencies and variations are observed."

In reviewing the existing theory and empirical research in the field of innovation by organizations, Becker and Whisler [2-41] stated that:

"It seems to us that we have, at the moment, only a slender thread of agreement or commonality among the writers on innovation. Badly needed is a theoretical framework which brings together the external and internal factors, the structural and psychological factors, and certain factors which have not even received mention up to this point."

Rodgers and Shoemaker [2-7] have compiled an impressive array of studies of innovation, mostly as related to individuals in a society. In discussion of future research required, they state:

"The sparse research to date on collective decisions has been conducted mostly in communities. To what extent are these tentative results generalizable
across different types of social systems, such as industrial plants, government bureaucracies, and small groups such as the family? We need to find out."

In spite of the confusing picture which emerges from what the earlier mentioned literature search indicates, there are three well-developed streams of inquiry into the differing innovative behavior of firms in industry:

a. By psychologists [1-4], [2-4] and [2-5]  
b. By sociologists [1-1], [1-2] and [1-3]  
c. By economists [1-5], [2-1], [2-3], [2-6] and [2-7].

Consider the implications of the view of the organization being investigated as one which is in continuing interaction with its environment. Clearly, this suggests that external forces, e.g., the behavior of a competitor, the needs of customers, bureaucratic politics and public policies, might explain much of the observable behavior of the organization in the tasks of innovation. However, just as important are internal characteristics of the organization such as organizational structure and the technology the firm is engaged in developing and/or processing.

This view implies that explanations of innovative behavior may be seriously misleading if only characteristics of the internal organization, aspects of the external environment or characteristics of the technology (products/process) alone are considered. All three perspectives must be considered (hopefully simultaneously) since an observable relationship between an
environmental characteristic and innovative behavior may be heavily conditioned by the internal organizational characteristics. Therefore, organization, environment and technology must be treated explicitly and carefully if a good understanding of the innovation process is to be developed.

How can organizational, environmental and technological contexts be brought into the perspective of research on the innovation process simultaneously? In the survey of recent studies of [1-5], [2-4], [2-22] and [2-42] mentioned previously, each study provides its own solution. Rosenbloom's [1-5] answer is "strategy":

"Strategy formulation results in the top management's commitment to a set of goals, policies, and programs that match the organization's distinctive resources to perceived opportunities in a changing environment. Profit objectives are made explicit and the means of financing matched to the implied balance of risks and returns. Commercial goals are set, defining market segments and channels, and the products or services (functionally defined) to be offered. The core idea in the establishment of an economic strategy for the firm is the careful assessment and subsequent matching of (environmental) opportunity and (organizational) capability. The process of implementation creates the organizational conditions necessary for realization of a chosen strategy. It defines the structure of the formal organization, its information and control systems, and the 'style' of management direction. Implementation changes the capabilities of the organization; environmental factors change autonomously and in response to corporate initiatives; both kinds of change create a need for continuing reassessment and reformulation of strategy."

Ross [2-42], found that none of the existing models were general enough to reasonably fit all, or even a major fraction of the innovation
adoption histories which were described to him. As a result, he was forced to develop a general model of his own at the time when he set out to conduct an experiment on eight school districts carefully selected throughout the U.S. Ross's concept consists of what he calls "locations" (inside and outside the organization) and "forces" (initiating, sustaining and feedback). The model assumes that the innovations are created outside the organization and brought in by several different ways. Since he couldn't get data on every parameter of the model, he settled for one expression alone containing two independent variables and one dependent one, i.e.,

\[ a = I \times S \]

where:

\[ a \] = adoption performance

\[ I \] = initiating mechanism

\[ S \] = sustaining mechanism

In order to obtain the data in these three categories, he prepared questionnaires which contained eight measures of initiating mechanisms, eight measures of sustaining mechanisms and six measures for adoption performance. For each measure, he devised several questions. His paper presents two results in graph form. Plotting the eight school districts, one relates to professional staff development and the second to team teaching.

The article leaves one with the suspicion that the results do not support the apparent joy expressed by the author regarding the results.
First, he was forced to drop many of the variables which he postulated. Left with one expression as the model, he made various assumptions without providing any tangible analytical proof of validity. For example, one highly questionable assumption he made was to go from the premise that,

\[ a = f(I, S) \text{ to } a = I \times S \]

Utterback and Abernathy [2-22] present a model which relates innovation patterns within a firm, to the firm's competitive strategy and production process capabilities. The model originates in the integration of two separate but complimentary lines of inquiry pursued independently by each author:

"One such line of inquiry has concerned the relationship between a firm's competitive environment and the pattern of innovation it undertakes, for instance, whether performance-maximizing, sales-maximizing, or cost-minimizing (addressed in [2-43] and [2-45] and in research in progress). The other line of inquiry has considered the relationship between the development of a firm's production process characteristics and the type of innovative activity it undertakes, e.g., the type and source of innovation and its stimuli (addressed in [2-46] and [2-47] and research currently underway)."

They postulate that innovation can be conceptualized by the three stages of product development:

a. **Stage I – Uncoordinated Process**

Product Performance-Maximizing Strategy (Classified on the basis that most innovations are market-need stimulated)
b. **Stage II - Segmental Process**

Sales-Maximizing Strategy (Classified on the basis that most innovations are stimulated by technological opportunities)

c. **Stage III - Systemic Process**

Cost-Diminishing Strategy (Classified on the basis that most innovations are stimulated by production related factors).

In the final version of this working paper [2-4], they somewhat modified this three-stage concept. Nevertheless, while searching for an overall conceptual model, Utterback and Abernathy have linked an individual firm's propensity to innovate only to the various stages of a firm's production process, thus limiting the concept's general applicability to innovation adoption in large organizations.

This brief review illustrates attempts to develop a model combining organizational, environmental and technological factors that have so far been unsuccessful. One significant problem in most studies of the innovation process is the desire of social scientists to achieve the level of rigor reached by the natural sciences. In a few decades, social science has tried to "catch up with" what took natural science several centuries to evolve.

The problem stated above is symptomatic of the research literature on innovation. As a result, many reports, papers and dissertations become involved with methodology and lose sight of the original problem. Studies conducted by political scientists appear to be exceptions to this
rule. Armacost [2-48], Davis [2-49], Perry [2-50] and Sapolsky [2-51] and [2-52] used an approach which is not diluted by methodology and, consequently, reached conclusions which are more comprehensive and more helpful to the innovation practitioner.

Normally, it appears that by necessity and the pressure of time required to complete a study, only factors that can be introduced in questionnaires that are administered impersonally and that only partially represent the complexity of real situations, are chosen as indicators (such as, number of patents, number of publications, the ages and employment histories of scientists, R&D dollars allocated or the number of communications per day between people). Such a narrow focus, in combination with frequent overemphasis on methodology, is largely responsible for the lack of a comprehensive conceptual model for the innovation process.

Criticism of the lack of a model does not indicate that the prime objective today should be to create a universal model for the innovation process. Quite the contrary, the creation of a general purpose model is not envisioned as a result of this study. The complexity of the process through which new technology is adopted requires a multivariate analysis.

The study conducted and described in this thesis is directed to achieving a better understanding of the innovation process within the peculiar confines of the Navy as opposed to enhancing general paradigm development in the social sciences. Therefore, the approach of this
research takes the form of an empirical study. It should be noted that this study was conducted from a unique vantage point as the investigator works within the Navy establishment, and therefore has excellent access to historical files and to those who were actual participants in the innovation adoption process during the Navy's post-World War II warship developments.
CHAPTER 3
STATEMENT OF HYPOTHESES AND RESEARCH PLAN

The following two part research question establishes the direction of this study: Are there similarities in the factors influencing innovation adoption of various naval ship systems in spite of their different engineering features, their operational use, the organizations responsible for their development and adoption, their manufacturing industries, the policies that regulate their procurement and other differences? Do the study results indicate that there are certain conditions which are conducive to innovation adoption? If yes, is it possible to create these conditions to enhance innovation adoption for future naval ship designs?

To enhance the study of the research questions, a number of hypotheses have been advanced by the investigator. These hypotheses are based on the literature concerning innovation adoption, as well as personal insight gained from vantage points both inside the Navy and in industry supporting the Navy in its new ship designs. The hypotheses are listed in Table 3-1.

These hypotheses can be viewed as synonymous to many fundamental laws governing nature in the natural sciences. Though the social sciences had a late start relative to the natural sciences, their developmental process is essentially the same. The laws of natural science also evolved
<table>
<thead>
<tr>
<th>A. NATURE OF THE PROCESS</th>
<th>B. ORGANIZATION STRUCTURE</th>
<th>C. POLICIES AND REGULATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-1 The process of innovation adoption is a political process.</td>
<td>B-1 The greater the diversity of an organization the smaller the proportion of proposed innovations which will be adopted.</td>
<td>C-1 The quantity of R&amp;D funding is not necessarily the decisive factor in innovation adoption.</td>
</tr>
<tr>
<td>A-2 The existence of other viable and technologically mature hardware options is one of the most powerful innovation retarders.</td>
<td>B-2 Separate chains of command for the R&amp;D and design organizations spatially separated and lacking effective integration mechanisms, hinders innovation adoption.</td>
<td>C-2 Personnel policies which create anti-risk taking incentives for the Washington military executive, tend to retard innovation adoption.</td>
</tr>
<tr>
<td>A-3 The lack of an innovation champion strongly retards innovation adoption.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
by a process of observing phenomena first and developing laws (much like these hypotheses) without complete proof. The proof was left to future generations, who attempted to prove or disprove these laws by further experimentation (case studies). At times, they succeeded in showing that some of those laws were only special cases of more universal laws. Conversely, thousands of controlled observations sometimes reinforced the originally postulated laws of nature. There is, however, a differentiating characteristic between the laws of natural science and those of the social sciences. Natural science laws may be stated in precise, straightforward formulae, whereas laws of the social sciences may involve numerous lengthy hypotheses.

Several such hypotheses may be necessary to define the governing factors for the innovation process in this study. Thus there is value in stating the hypotheses of Table 3-1 even if the limited case studies in this thesis would not prove or disprove them conclusively and to suggest that the remaining case studies of Table 3-2 not studied in detail, and others, should be pursued by other researchers. The basis for the derivation of each hypothesis is developed in Chapter 6.

The study encompassed innovation adoption in surface warships with the exception of carriers. This leaves destroyers, escorts, cruisers, corvettes and frigates, i.e., surface warships sized between 1,000 and 20,000 tons. General characteristics of the ships under study are shown
<table>
<thead>
<tr>
<th></th>
<th>SYSTEM INNOVATIONS FOR POSSIBLE INVESTIGATION AS CASE STUDIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Large Bow-Mounted Sonars (payload/platform)</td>
</tr>
<tr>
<td>2.</td>
<td>Ship Roll Stabilization System (platform)</td>
</tr>
<tr>
<td>3.</td>
<td>Helicopters as a Sensor/Weapon on Destroyers (payload/platform)</td>
</tr>
<tr>
<td>4.</td>
<td>Light-Weight Naval Guns (payload)</td>
</tr>
<tr>
<td>5.</td>
<td>Surface-to-Surface Missiles (payload)</td>
</tr>
<tr>
<td>6.</td>
<td>Gas Turbines for Propulsion Prime Movers (platform)</td>
</tr>
<tr>
<td>7.</td>
<td>Controllable Reversible Pitch Propellers (platform)</td>
</tr>
<tr>
<td>8.</td>
<td>Power Transmission Systems (for Main Propulsion) (platform)</td>
</tr>
<tr>
<td>9.</td>
<td>Auxiliary Machinery Systems (platform)</td>
</tr>
<tr>
<td>10.</td>
<td>Electric Power Conversion Systems (from 60 Hz to 400 Hz) (platform)</td>
</tr>
</tbody>
</table>
in Table 3-3. The specific innovations listed in Table 3-2 meet the following conditions:

a. They are systems or major equipments.
b. They represent a cross section of innovations, i.e., they are representative of most subsystems in the ship.

The specific systems to be studied were chosen from this list. Since it was difficult to determine a priori the availability of relevant data, an initial investigation was performed to select a subset of systems of the list as case studies.

The two cases chosen for detailed study in this thesis are the gas turbine and roll stabilization. This choice was arrived at on the following basis: (1) These two major equipments represented sufficiently different technologies, different industries which manufacture them as well as different branches of the Navy's organization dealing with them. (2) An initial survey of available material and access to participants who participated in the innovation process indicated material rich in content. (3) It became clear in the early stages of the research that more than two cases would result in excessive workload as well as too much material for a reasonable size thesis.

One of the unique aspects of the approach taken by this study is that the research was not done from the technologist viewpoint (e.g., a gas turbine specialist). Rather, the approach is strictly from the user viewpoint, i.e., the decision maker who must select from an array of alternative systems one which performs the desired function most effectively.
## TABLE 3-3 POST WORLD WAR II U.S. CRUISERS, DESTROYERS AND FRIGATES

### CRUISERS

<table>
<thead>
<tr>
<th>Class Name</th>
<th>NORFOLK</th>
<th>MITSCHER</th>
<th>COONTZ</th>
<th>LEAHY</th>
<th>BAINBRIDGE</th>
<th>BELKNAP</th>
<th>TRUXTON</th>
<th>CALIFORNIA</th>
<th>VIRGINIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year/Operational</td>
<td>53</td>
<td>53-54</td>
<td>60-62</td>
<td>62-64</td>
<td>63</td>
<td>64-67</td>
<td>67</td>
<td>74-75</td>
<td>76-78</td>
</tr>
<tr>
<td>No. in Class</td>
<td>1</td>
<td>4</td>
<td>10</td>
<td>9</td>
<td>11</td>
<td>9</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Displacement</td>
<td>7,300</td>
<td>4,730</td>
<td>5,800</td>
<td>7,800</td>
<td>8,580</td>
<td>7,930</td>
<td>9,200</td>
<td>10,150</td>
<td>10,000</td>
</tr>
<tr>
<td>Length, OA</td>
<td>540</td>
<td>493</td>
<td>512</td>
<td>533</td>
<td>565</td>
<td>547</td>
<td>564</td>
<td>596</td>
<td>586</td>
</tr>
<tr>
<td>Beam</td>
<td>54.2</td>
<td>50</td>
<td>52.5</td>
<td>54.9</td>
<td>57.9</td>
<td>54.8</td>
<td>58</td>
<td>61</td>
<td>76.6</td>
</tr>
<tr>
<td>Draft</td>
<td>26</td>
<td>25</td>
<td>25</td>
<td>24.5</td>
<td>29</td>
<td>28.8</td>
<td>31</td>
<td>22.3</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>80,000</td>
<td>80,000</td>
<td>85,000</td>
<td>85,000</td>
<td>85,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>Steam</td>
<td>Steam</td>
<td>Steam</td>
<td>Steam</td>
<td>2 Reactors</td>
<td>Steam</td>
<td>2 Reactors</td>
<td>2 Reactors</td>
<td>2 Reactors</td>
</tr>
<tr>
<td>Screws</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Speed</td>
<td>32</td>
<td>35</td>
<td>34</td>
<td>34</td>
<td>30+</td>
<td>34</td>
<td>30+</td>
<td>30+</td>
<td>30+</td>
</tr>
<tr>
<td>Endurance</td>
<td>411</td>
<td>336</td>
<td>375</td>
<td>396</td>
<td>450</td>
<td>318</td>
<td>500</td>
<td>500+</td>
<td>500+</td>
</tr>
<tr>
<td>Complement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Armament:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guns</td>
<td>8-3&quot;/70</td>
<td>2-5&quot;/54</td>
<td>1-5&quot;/54</td>
<td>4-3&quot;/50</td>
<td>4-3&quot;/50</td>
<td>1-5&quot;/54</td>
<td>1-5&quot;/54</td>
<td>2-5&quot;/54</td>
<td>2-5&quot;/54</td>
</tr>
<tr>
<td>Missile Launcher</td>
<td>None</td>
<td>None</td>
<td>1 MK 10</td>
<td>2 MK 10</td>
<td>2 MK 10</td>
<td>1 MK 10</td>
<td>1 MK 10</td>
<td>2 MK 13</td>
<td>2 MK 26</td>
</tr>
<tr>
<td>ASW</td>
<td>ASROC</td>
<td>ASROC</td>
<td>ASROC</td>
<td>ASROC</td>
<td>ASROC</td>
<td>HELO</td>
<td>HELO</td>
<td>ASROC</td>
<td>HELO</td>
</tr>
<tr>
<td></td>
<td>2 MK 32TT</td>
<td>Dash</td>
<td>2 MK 32TT</td>
<td>2 MK 32TT</td>
<td>2 MK 32TT</td>
<td>facilities</td>
<td>facilities</td>
<td>2 MK 32TT</td>
<td>facilities</td>
</tr>
<tr>
<td></td>
<td>SQS 23</td>
<td>SQS 23</td>
<td>SQS 23</td>
<td>SQS 26</td>
<td>SQS 26</td>
<td>SQS 26</td>
<td>SQS 26</td>
<td>SQS 26</td>
<td>SQS 26</td>
</tr>
</tbody>
</table>

* NONE CURRENTLY AUTHORIZED
<table>
<thead>
<tr>
<th>Class Name</th>
<th>SHERMAN</th>
<th>ADAMS</th>
<th>DECATURE</th>
<th>MITSCHER</th>
<th>SPRUANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class No.</td>
<td>DD 931</td>
<td>DDG 2</td>
<td>DDG 31</td>
<td>DDG 33</td>
<td>DD 963</td>
</tr>
<tr>
<td>Year</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operational</td>
<td>56-59</td>
<td>60-64</td>
<td>67-68</td>
<td>68-69</td>
<td>75</td>
</tr>
<tr>
<td>No. in Class</td>
<td>18</td>
<td>23</td>
<td>4</td>
<td>2</td>
<td>30</td>
</tr>
<tr>
<td>Displacement</td>
<td>4,050</td>
<td>4,500</td>
<td>4,050</td>
<td>5,100</td>
<td>7,180</td>
</tr>
<tr>
<td>Length, OA</td>
<td>418</td>
<td>437</td>
<td>418</td>
<td>493</td>
<td>560</td>
</tr>
<tr>
<td>Beam</td>
<td>45</td>
<td>47</td>
<td>45</td>
<td>50</td>
<td>54</td>
</tr>
<tr>
<td>Draft</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>26</td>
<td>22</td>
</tr>
<tr>
<td>Power</td>
<td>70,000</td>
<td>70,000</td>
<td>70,000</td>
<td>80,000</td>
<td>90,000</td>
</tr>
<tr>
<td>Type</td>
<td>Steam</td>
<td>Steam</td>
<td>Steam</td>
<td>Steam</td>
<td>COGAG</td>
</tr>
<tr>
<td>Propeller</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2-CP</td>
</tr>
<tr>
<td>Speed</td>
<td>33</td>
<td>32</td>
<td>32</td>
<td>35</td>
<td>30+</td>
</tr>
<tr>
<td>Endurance</td>
<td>Complement</td>
<td>333</td>
<td>354</td>
<td>335</td>
<td>370</td>
</tr>
<tr>
<td>Armament:</td>
<td>Guns</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3-5&quot;/54</td>
<td>2-5&quot;/54</td>
<td>1-5&quot;/54</td>
<td>2-5&quot;/54</td>
<td>2-5&quot;/54</td>
</tr>
<tr>
<td></td>
<td>4-3&quot;/50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Missile Launchers</td>
<td>None</td>
<td>1-MK 11</td>
<td>1-MK 13</td>
<td>1-MK 13</td>
<td>SEA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(TARTAR)</td>
<td>(TARTAR)</td>
<td>(TARTAR)</td>
<td>SPARROW</td>
</tr>
<tr>
<td>ASW</td>
<td>2-MK 32TT</td>
<td>ASROC</td>
<td>ASROC</td>
<td>ASROC</td>
<td>ASROC</td>
</tr>
<tr>
<td></td>
<td>2-MK 32TT</td>
<td></td>
<td>2-MK 32TT</td>
<td>2-MK 32TT</td>
<td>MK 32TT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>HELO</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>facilities</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SQS 23</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class Name</td>
<td>DEALEY</td>
<td>JONES</td>
<td>BRONSTEIN</td>
<td>GARCIA</td>
<td>BROOKE</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------</td>
<td>--------------</td>
<td>--------------</td>
<td>-------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Class No. (new)</td>
<td>FF 1006</td>
<td>FF 1033</td>
<td>FF 1037</td>
<td>FF 1040</td>
<td>FFG 1</td>
</tr>
<tr>
<td>(old)</td>
<td>(DE 1006)</td>
<td>(DE 1033)</td>
<td>(DE 1037)</td>
<td>(DE 1040)</td>
<td>(DEG 1)</td>
</tr>
<tr>
<td>Year</td>
<td>54-57</td>
<td>59-60</td>
<td>63</td>
<td>64-68</td>
<td>66-68</td>
</tr>
<tr>
<td>Operational</td>
<td>13</td>
<td>4</td>
<td>2</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>No. in Class</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Displacement</td>
<td>1,914</td>
<td>1,750</td>
<td>2,650</td>
<td>3,400</td>
<td>3,426</td>
</tr>
<tr>
<td>Length, OA</td>
<td>314.5</td>
<td>310</td>
<td>371.5</td>
<td>414.5</td>
<td>414.5</td>
</tr>
<tr>
<td>Beam</td>
<td>36.8</td>
<td>37</td>
<td>40.5</td>
<td>44.2</td>
<td>44.2</td>
</tr>
<tr>
<td>Draft</td>
<td>13.6</td>
<td>18</td>
<td>23</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Power</td>
<td>20,000</td>
<td>9,200</td>
<td>20,000</td>
<td>35,000</td>
<td>35,000</td>
</tr>
<tr>
<td>Type</td>
<td>Steam</td>
<td>Diesel</td>
<td>Steam</td>
<td>Steam</td>
<td>Steam</td>
</tr>
<tr>
<td>Screws</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Speed</td>
<td>25</td>
<td>22</td>
<td>24-1/2</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>Endurance</td>
<td>170</td>
<td>175</td>
<td>220</td>
<td>241</td>
<td>248</td>
</tr>
<tr>
<td>Complement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Armament:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guns</td>
<td>4-3&quot;/50</td>
<td>2-3&quot;/50</td>
<td>3-3&quot;/50</td>
<td>2-5&quot;/38</td>
<td>1-5&quot;/38</td>
</tr>
<tr>
<td>Missile</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>1 MK 22</td>
</tr>
<tr>
<td>Launcher</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(TARTAR)</td>
</tr>
<tr>
<td>ASW</td>
<td>2-MK 32TT</td>
<td>2-MK 32TT</td>
<td>ASROC</td>
<td>ASROC</td>
<td>ASROC</td>
</tr>
<tr>
<td>Wep &quot;A&quot;</td>
<td>2-MK 32TT</td>
<td>HELO</td>
<td>2-MK 32TT</td>
<td>HELO</td>
<td>2-MK 25TT</td>
</tr>
<tr>
<td>facilities</td>
<td>DASH</td>
<td>DASH</td>
<td>facilities</td>
<td>facilities</td>
<td>facilities</td>
</tr>
<tr>
<td>QHB</td>
<td>SQS 4</td>
<td>SQS 26</td>
<td>SQS 26</td>
<td>SQS 26</td>
<td>SQS 26</td>
</tr>
</tbody>
</table>
The decision maker (translator of "user need") in this study is the ship designer since he is given the task of choosing among alternative subsystems either available on the shelf or nearing the stage of complete development.

Accepted methods of survey analysis by interview and questionnaires, though appropriate for many cases in social science research, were not deemed applicable for this research task. In the case of election predictions, for example, the subjects responding to questionnaires may not understand the political issues at hand but this lack of understanding does not harm the survey, since the surveyed subjects will behave in a similar manner at the time they actually cast their ballots.

This is not so in the case of a survey on factors influencing the innovation process. The capability of those surveyed varies drastically; even though meaningful statistical findings can be obtained, they may be totally incorrect. In selecting questionnaire respondents for case studies such as the ones in this thesis, a pretest should first be administered to ascertain potential respondents' comprehension, memory and biases on the issues.

The roles individuals played relative to an innovation might bias their views. Whether they confuse the facts may also depend upon the reliability of their memories. Their particular vantage points, education and areas of professional interest during the innovation adoption process might lead to further misinterpretation of facts.
The procedural approach to this thesis was as follows:

First, a literature review was made for each system listed in Table 3-2. Personal interviews with participants in the actual innovation adoption/rejection process supplemented information obtained from the survey of a host of original Navy documents, such as minutes of meetings, memoranda, internal reports, letters and formal presentations to decision-making organizations within the Navy and DOD.

Especially useful were minutes of the Ship Characteristics Board (SCB) meetings which were recorded and transcribed up to the mid-1960's. The Ship Characteristics Board* represented both the requirement-definer organization (OPNAV) and the various designer organizations on the material side of the Navy. These meetings determined the features of each new ship which would be subsequently designed and produced. Prior to 1945, the SCB did not exist and the General Board made these decisions. Between 1945 and 1950, both boards functioned in somewhat overlapping capacities.

Ship design histories were a further source of information. These documents contain correspondence between OPNAV and NAVSEC, NAVSEC and the David Taylor Model Basin and other participants during the actual

* A detailed explanation of the Navy's organization structure in the last four decades is presented in Appendix A. It is strongly suggested that readers unfamiliar with the Navy's day-to-day operations and its organization read this appendix prior to reading the rest of this thesis.
design process. In addition, personal files of various individuals responsible for naval system development over the past 20-30 years were reviewed. The Defense Documentation Center and its computerized filing system provided further research material. Information on all systems listed in Table 3-2 was reviewed before selecting two cases for concentrated analyses, i.e. gas turbines and roll stabilization.

Though this study is limited to adoption of two specific innovations, the other eight systems in Table 3-2 are potential topics for future investigation. It would be worthwhile to determine whether they further substantiate the research hypotheses. These hypotheses may have applicability beyond naval ship design, such as in all DOD branches or other large bureaucracies engaged in applying the products of their R&D efforts to their hardware.
"It has been said "It is a striking fact that
the U.S. Navy is the last major Navy in the
world to go to gas turbine propulsion'. We
are way behind the Soviets and Britain. That
this is not altogether the Navy's fault is
irrelevant; it is the Navy's job to provide
successful leadership."

National Academy of Sciences
Report to the Secretary of the Navy 1971

CHAPTER 4

THE GAS TURBINE ADOPTION CASE STUDY

4.1 Introduction and Pre-World War II Developments

In 1975, the U.S. Navy commissioned the first of the 30 SPRUANCE
class destroyers. These 7800-ton ships are each powered by four 20,000 shp
gas turbine engines. They represent the first class of major warships in
the U.S. Navy to be powered solely by gas turbines. This development comes
some 15 years after other navies have successfully adopted this type of
propulsion plant.

This study will review the events which contributed to the adoption
of the gas turbine for U.S. naval ship propulsion and will emphasize those
factors which delayed its acceptance. No attempt is made in this case
study to prove the hypotheses listed in Table 3-1. This is reserved for
Chapter 6.

Many contemporary studies concerning the motivation behind inno-
vation adoption have shown that, in three-quarters of the cases, it was
the user's need and not technology push which led to successful adoption.
Therefore, to look through the ship designer's lenses and not the machinery
developer's is most appropriate in studying the adoption of gas turbines
for naval ship propulsion.
The approach used in this case study is to examine the events of the last 35 years from two perspectives: (1) an examination of the decisions relating to power plant selection for destroyer designs from the ship designer's viewpoint and (2) an examination of the decisions which led to the development of competitive power plants during the same period.

The following power plant types are in use as main propulsion prime movers of warships:

a. Steam
   1. Conventional (600 psi and 1200 psi steam pressure)
   2. Pressure fired
b. Nuclear (steam)
c. Diesel
d. Gas Turbine
e. Combinations of the above.

At the start of World War II (b) and (d) were not in existence other than in theory or in small scale experimental stages. Diesels had been in use by then for over 20 years in the U.S. Navy, mostly in submarines, but also as small slow speed destroyer propulsors. One of the reasons that the diesel application for warships was limited, and is a reason which holds even today, is that medium and high speed diesels which are small enough in size and weight to be considered for warship application (as opposed to slow speed direct drive), are limited in the U.S. inventory to up to 4000 hp today (there is an 8000 hp medium speed diesel which is a
French design and by license is manufactured in the U.S. but not for naval use) and were even more limited (to about 2000 hp) during World War II.

For the above reason, diesels were not considered as contenders for full size warships (60,000 to 80,000 hp) but only for the normally single screw slow speed escorts (15,000 to 25,000 hp).

Thus the prime type power plant for warships was steam. Until the early 1930's, the steam power plants used fairly low pressure steam (300 psi). Because of the potential of improved efficiency Admiral Bowen, the Chief of the Navy's Bureau of Engineering fought hard against anti-innovation forces in the Navy to increase pressures and temperatures and, succeeded at the cost of his job in developing what became the standard World War II U.S. warship power plant (the 600 psi, 850°F steam power plant) [4-1]. To even further reduce the size and weight of steam power plants, the Swiss developed in the 1930's the so-called Velox cycle (pressure-fired boiler).

"Pressure-fired", as the term is used here, implies a system in which the boiler operates under sufficient pressure on the combustion gas side that the gas upon leaving the boiler performs useful work by expansion through a gas turbine. In other words, a gas turbine is connected in series with the boiler on the combustion gas side. At the outset of World War II there was no marine version of this boiler type and, even for land-based power generation, it was still in an experimental status.
In short, in the late 1930's when the first interest was exhibited by the U.S. Navy in gas turbines, the 600 psi, 850°F steam power plant reigned supreme in the field of warship propulsion.

Since history reveals little or no interest in gas turbines for naval ship propulsion prior to the late 1930's, this study will concentrate on events since that time. A literature survey does reveal various contrivances which may be classified as gas turbines, the earliest appearing almost 200 years ago. The following is a list of early workers and significant developments:

1791 - John Barber [4-2] of England granted a patent on an invention which, primitive in form, contained all of the essentials of a modern gas turbine.

1808 - John Dumbell [4-3] of h-gland granted a patent on a forerunner of the "explosion" type of turbine.

1837 - Bresson [4-3] of France granted a patent on a gas turbine.

1864 - Boulton [4-4] granted a patent on an improved turbine which used a series of induced jets of increasing volume to reduce excessive velocities.

1884 - Sir Charles Parsons [4-5] granted a patent on steam turbines in which he made reference to the gas turbines.

1893 - De Laval [4-6] proposed a system in which compressed air was delivered to a combustion chamber along with liquid fuel. The combustion gases then expanded through a nozzle onto an impulse wheel. Water injection was provided for cooling.
1900-1908 - The Parsons Co. built about 30 axial compressors many of which were exported worldwide.

1903-1906 - Armendgauld and Lemale [4-7, 4-8] experimented to develop practical gas turbines.

1930 - A. Meyer of the Brown, Boveri Co. [4-9] presented a paper on history, development, and prospects of the combustion gas turbine. He discussed the application of this engine to marine propulsion and proposed a combination of gas turbine and diesel engine plants using a mechanical transmission.

1939 - George Jendrassik [4-10] of Budapest reported on a 100-hp combustion gas turbine giving overall thermal efficiencies of 21.2 percent with a regenerative cycle operating at 890°F admission temperature.


1939 - J. L. Ray [4-12] published on the application of the combustion gas turbine to locomotives.


1939 - G. Darrieus [4-14] granted a patent on an air-cooled turbine blade. Brown, Boveri Co. using such a blade, operated an experimental turbine at 1600°F by 1940.

By 1939, about 80 gas turbine units had been built to operate in conjunction with the Velox pressure-fired boiler, and hundreds were in use for the purpose of supercharging diesel engines. Industrial gas turbines were also in use to deliver mechanical force to an electrical generator or other rotating machinery. The British and the Germans had started
development efforts for gas turbine aircraft jet engines as early as the late 1920's and, by the late 1930's, aircraft jet engines were under construction in both countries. However, marine gas turbines were not being developed with the same enthusiasm because there was not the same potential pay-off as was envisioned for aircraft jet propulsion.

The record shows that the U.S. Navy's first real interest in investigating the feasibility of gas turbine propulsion for warships occurred in 1938 after a naval officer returned from an extended European trip and submitted a report regarding his observations of gas turbine technology in Europe. The Bureau of Engineering,* after an in-depth study of this report and review of the state of the art in industrial gas turbines, requested the National Academy of Science in 1939 to investigate gas turbines as naval ship propulsion plants. The Academy appointed a committee of distinguished persons to conduct the study, namely Dr. C.F. Kettering, Prof. Lionel S. Marks, Dr. R.A. Millikan, Dr. A.G. Christie, Dr. Theodore von Kármán, and Dr. Max Mason as Chairmen.

The Academy's report [4-15] summarized the state-of-the-art as follows:

"In its present state, indications are that a gas-turbine-diesel engine combination will weigh about 20 pounds per shaft horsepower when designed specifically for marine-propulsion application."

* The Bureau of Ships was formed in 1940 from the Bureau of Engineering and the Bureau of Construction and Repair (see Appendix A).
"The gas-turbine units built to date have all been intended for land practice and no marine applications are in existence at the present time."

The committee recommended:

"...that a 1,600 horsepower gas turbine unit be purchased by the Navy and subjected to exhaustive shore tests at the present limit of 1,000°F. Selection of this particular unit is suggested as it is of sufficient capacity so that the test results can be readily applied in predicting probable performance and behavior of the larger units contemplated for the destroyer application. Furthermore, upon completion of the shore tests the unit could be installed in a small ship of the Navy's choice and subjected to additional tests at sea."

This can be considered the starting point of serious interest by the U.S. Navy in marine gas turbines.
4.2 Why Destroyers As A Vehicle For Analysis For The Adoption Of Gas Turbines?

Before evaluating the contending prime movers for naval propulsion in the 1940's, it is appropriate to examine briefly the view which the ship designer takes with respect to the choice of propulsion plants for the different types of naval ships which exist in the U.S. fleet. Although the field for gas turbine application is not limited to a specific ship type, certain classes of warships provide conditions that give the gas turbine an edge on its competitors. In other classes the reverse situation is the case, while in yet another class the power plant selection process becomes a fierce competition among many options including gas turbines.

Submarines, because of the large air flow that gas turbines demand, are eliminated from consideration for gas turbines. Since a submarine operates below the surface most of the time, it would have to obtain air through an extended snorkel which would have to be excessively large to satisfy the requirements of gas turbines.

Auxiliaries are another category of naval ships, where, so far, simple-cycle aircraft derivative gas turbines do not compete well with other power sources. In part, this is because in some of these ships, e.g., tankers, repair ships, ammunition ships, volume is plentiful because these ships are weight-limited types. This means that the displacement volume required to carry the high density cargo is more than is required
for the cargo alone and that space required for propulsion equipment is not limited. Thus, in weight-limited ships, larger volume machinery equipment does not penalize the ship as a whole to the same extent that it does in volume-limited ships (i.e., the equipment does not dictate an increase in ship size and cost such as occurs in the case of volume-limited ships). This does not necessarily mean that gas turbines could not win a trade-off with other power sources even for weight-limited type ships, since considerations such as maintenance, manning, and fuel can overshadow the acquisition cost factor, but so far such factors have not prevailed in the tanker, repair ship, or ammunition ship applications.

Aircraft derivative gas turbines do reign without competition in the area of the high performance ships (e.g., Surface Effect Ships (SES), Air Cushion Vehicles (ACV), and Hydrofoils). These ships are not governed by conventional displacement; the factor governing ship performance is the Lift/Drag (L/D) ratio. Therefore the very existence of these ships depends on the availability of lightweight gas turbines as prime movers. Thus, there are no trade-offs to make in this case.

The naval ship types, where the choice of propulsion prime mover becomes an issue, are primarily the conventional 2,000-to-20,000-ton monohull warships, i.e., frigates, destroyers, and cruisers.

The propulsion plant type selection for those ships is a very significant one in the context of the ship as a whole. No single subsystem of the platform part of a ship has greater impact on configuration,
acquisition, and life-cycle cost than the propulsion system. The volume occupied by propulsion system equipment, fuel, and the men required to operate and maintain the equipment represents the most substantial portion of the platform.

Cost of propulsion machinery acquisition and installation is a primary consideration in arriving at the "best" ship. Figure 4-1 shows acquisition costs of four gas turbine ship designs of the 1970's apportioned in accordance with the Ships Work Breakdown Structure and demonstrates that, of the ship platform parts (with Groups 4 and 7 excluded since they are payload), propulsion represents the largest cost segment. The Sea Control Ship falls outside this pattern only because the Navy, for the sake of austerity, was ready to accept a lower speed using the basic Patrol Frigate power plant for a ship with four times the displacement.

Manning of the propulsion plant requires a substantial portion of the crew as shown on Figure 4-2; for destroyers from 3,500 tons to as large as 7,600 tons, the Engineering Department consists of some 20 percent of the total complement. The Sea Control Ship again does not fit the pattern, because its mission (aircraft support) is totally different from that of the other three ships shown; the SCS requires a disproportionately larger number of people to fly and service the aircraft, making the Engineering Department a relatively smaller group than on destroyers.

Figure 4-3 shows the space requirements for the propulsion plant and fuel storage. In addition to these requirements, the propulsion plant
FIGURE 4-1 PROPULSION SUBSYSTEM ACQUISITION COST RELATIVE TO OTHER COSTS FOR FOUR GAS TURBINE SHIPS.
FIGURE 4-2  MANNING SUMMARIES BY DEPARTMENT FOR FOUR GAS TURBINE SHIPS.
FIGURE 4-3 PROPULSION SUBSYSTEM VOLUME REQUIREMENTS FOR FOUR GAS TURBINE SHIPS.

SOURCE: REF [4-16]
requires space which is contiguous and, in most cases, occupies the prime real estate in the ship. Again, the Sea Control Ship, because of its unique mission, does not conform to the relative volume pattern shown for the other three ships.

These figures indicate that the propulsion system has significant cost, space and weight impact on the ship. While the figures all refer to gas turbine propelled ships, similar figures can be prepared for the same ships using other propulsion plant types (steam, nuclear, diesel, and combined power plants). The results in most cases would show increased volume, cost and manning for destroyer applications today, but only narrowly so, especially in a trade-off of steam versus gas turbines. This has resulted in fierce competition among the various types of power plants for new warship designs in this category over the years. Therefore, the best vantage point for observation of the struggle to adopt gas turbines as main propulsion prime movers for naval ships is obtained by reviewing the selection of characteristics and design histories of U.S. destroyers and cruisers since World War II.
4.3 A Competitor Is Born - The 1,200-psi Plant

A significant factor which contributed to the delay in adopting the gas turbine for destroyer propulsion was the existence of the 1,200-psi steam propulsion plant. This competitor was born as a result of the demand for higher speed by the operating forces.

At the start of World War II, the FLETCHER class (DD 445) was the newest class of destroyers. Between 1942 and 1945, the Navy constructed 119 FLETCHER class and 56 "repeat FLETCHER" class destroyers. These ships had a maximum sustained service speed of 31.8 knots and were powered by four 600-psi, 850°F boilers developing 60,000 shp. The operating forces criticized these destroyers for their lack of speed and endurance. They wanted at least three knots more speed. Numerous feasibility studies were conducted incorporating 600-psi power plants and, in all cases, the requirements for speed and endurance could not be met without an unacceptable increase in ship size.

In addition to attempting to correct deficiencies in the DD 445, the Navy attempted to produce a design which would have all the destroyer capabilities needed for modern naval warfare. Since no single ship could incorporate everything desired by all interested parties, secondary task capabilities were curtailed as necessary and primary tasks (speed being most important) were given first consideration. As previously stated, the DD 445 class was considered too slow, especially for effective operations with fast carrier task forces. An increase was necessary but
the question of what speed was acceptable was open to debate. The Navy also had to consider that an increase in speed generally entailed a corresponding increase in the ship's size; however, it was expected that advances in power plant design would effect substantial savings in weight.

By 1941, several studies on new destroyer designs had been completed by the Navy's Preliminary Design Branch (see Table 4-1) [4-17]. In 1942, the design for the SUMNER class (DD 692) destroyers was approved. The first was built in 1943 but it did not attain the desired speed of 36.5 knots. Several other designs were tried; however, no one design appeared to be significantly superior; that is, to gain the desired speed, other military capability had to be sacrificed. Because the steam plants in use at that time did not have the required compactness and efficiency, a serious need to develop more compact, lightweight main propulsion machinery became recognized.

The Navy had long recognized that one of the major factors influencing the efficiency of a steam plant was its initial steam conditions, and, as early as the 1930's, the Navy had endeavored to make improvements in this area. The fight which ensued in the Bureau of Engineering over this effort during the 1930's is well documented in Admiral Bowen's book, "Ships, Machinery and Mossbacks" [4-1], in which he claims that, by 1939, industry was prepared for a steam plant with conditions as high as 1,200-psi, 950°F. He further states:

"Before I left the Bureau, I had proved on a reengined and partly reboilered destroyer, the
<table>
<thead>
<tr>
<th>DD 445 CLASS</th>
<th>SCHEME &quot;B&quot;</th>
<th>SCHEME &quot;B-1&quot;</th>
<th>SCHEME &quot;B-11&quot;</th>
<th>SCHEME &quot;B-III&quot;</th>
<th>SCHEME &quot;B-IV&quot;</th>
<th>SCHEME &quot;B-V&quot;</th>
<th>SCHEME &quot;B-VI&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>I DISPLACEMENT, STD.</td>
<td>2110 T.</td>
<td>2150 T.</td>
<td>2135 T.</td>
<td>2200 T.</td>
<td>2180 T.</td>
<td>2195 T.</td>
<td>2215 T.</td>
</tr>
<tr>
<td>LENGTH, D.W.L.</td>
<td>369'</td>
<td>369'</td>
<td>369'</td>
<td>369'</td>
<td>369'</td>
<td>369'</td>
<td>369'</td>
</tr>
<tr>
<td>BEAM, D.W.L.</td>
<td>38.5'</td>
<td>38.5'</td>
<td>38.5'</td>
<td>39.5'</td>
<td>38.5'</td>
<td>39.5'</td>
<td>39.5'</td>
</tr>
<tr>
<td>DRAFT AT DISPL. II</td>
<td>13.05'</td>
<td>13.2'</td>
<td>13.14'</td>
<td>13.1'</td>
<td>13.20'</td>
<td>13.1'</td>
<td>13.1'</td>
</tr>
<tr>
<td>MAIN BATTERY</td>
<td>5-5'/38</td>
<td>5-5'/38</td>
<td>5-5'/38</td>
<td>6-5'/38</td>
<td>4-5'/38</td>
<td>4-5'/38</td>
<td>5-5'/38</td>
</tr>
<tr>
<td>IN TWIN MTS.</td>
<td>IN TWIN MTS.</td>
<td>IN TWIN MTS.</td>
<td>IN TWIN MTS.</td>
<td>2-TWIN, 1-SGL</td>
<td>1-TWIN, 3 SGL</td>
<td>2-TWIN, 1-SGL</td>
<td>1-TWIN, 3 SGL</td>
</tr>
<tr>
<td>TORPEDO TUBES</td>
<td>2-QUINT.</td>
<td>2-QUINT.</td>
<td>1-QUINT.</td>
<td>1-QUINT.</td>
<td>2-TRIPLE</td>
<td>2-TRIPLE</td>
<td>2-TRIPLE</td>
</tr>
<tr>
<td>HEAVY MACHINE GUNS</td>
<td>1-QUAD.1.1&quot;</td>
<td>2-TWIN</td>
<td>2-TWIN</td>
<td>2-TWIN</td>
<td>4-TWIN</td>
<td>4-TWIN</td>
<td>4-TWIN</td>
</tr>
<tr>
<td>40 M/M</td>
<td>40 M/M</td>
<td>40 M/M</td>
<td>40 M/M</td>
<td>40 M/M</td>
<td>40 M/M</td>
<td>40 M/M</td>
<td>40 M/M</td>
</tr>
<tr>
<td>OTHER</td>
<td>4-0.50 CAL</td>
<td>2-20 M/M</td>
<td>2-20 M/M</td>
<td>2-20 M/M</td>
<td>--</td>
<td>2-20 M/M</td>
<td>2-40 M/M</td>
</tr>
<tr>
<td>DEPTH CHARGE RACKS</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>DEPTH CHARGE THROWERS</td>
<td>4-SINGLE</td>
<td>6-SINGLE</td>
<td>6-SINGLE</td>
<td>6-SINGLE</td>
<td>6-SINGLE</td>
<td>6-SINGLE</td>
<td>6-SINGLE</td>
</tr>
<tr>
<td>DEPTH CHARGES - 600#</td>
<td>10</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>DEPTH CHARGES - 300#</td>
<td>8</td>
<td>32</td>
<td>32</td>
<td>32</td>
<td>32</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>COMPLEMENT - OFFICERS</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>ENLISTED MEN</td>
<td>264</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>S.H.P.</td>
<td>60,000</td>
<td>60,000</td>
<td>60,000</td>
<td>60,000</td>
<td>60,000</td>
<td>60,000</td>
<td>60,000</td>
</tr>
<tr>
<td>SPEED AT DISPL. II (KTS.)</td>
<td>37.8</td>
<td>37.5</td>
<td>37.6</td>
<td>37.1</td>
<td>37.5</td>
<td>37.4</td>
<td>37.1</td>
</tr>
<tr>
<td>ENDURANCE AT 15 KNOTS</td>
<td>6500 MI.</td>
<td>6500 MI.</td>
<td>6500 MI.</td>
<td>6500 MI.</td>
<td>6500 MI.</td>
<td>6500 MI.</td>
<td>6500 MI.</td>
</tr>
</tbody>
</table>
DAHLGREN, that 1,200-psi and 950°F was entirely feasible and urgently required. I do not know why the Bureau of Ships was so slow in following up this additional development, waiting as it did until after the war was over - and then some."

In 1946, it was decided that a DD 692 class destroyer (the TIMMERMANN, DD 828), already partially built at Bath Iron Works, would be used to test the attempted design limits. Different machinery was designed and procured for each of the two shafts of the TIMMERMANN, including boilers with different steam conditions; one was 875-psi, 1,050°F and the other was 2,000-psi, 1,050°F. General Electric built the 2,000-psi equipment and Westinghouse built the 875-psi equipment. Design, building, and manufacturer testing went on for a number of years in the late 1940's. A great deal of planning and testing was required prior to installation on the ship, but a great program for steam propulsion was on its way.

Meanwhile, in the world of destroyer designs, the various participants in the bureaus, as well as CNO and the General Board, were not standing still. The Navy recognized that keeping the Navy up-to-date by making limited expenditures for prototypes rather than large expenditures for step-by-step improvement of all ships, would necessitate determining prototype characteristics on a different basis than that used for new construction. Whereas characteristics for normal new construction provide margins for prospective developments, prototype characteristics should provide much more generous margins, so that experimental improvements to prototypes can guide final characteristics for major new ship construction programs. With this in mind, the characteristics of new ships were to
prescribe generous margins in weight, moment, and accommodations. In addition, they were also to prescribe easy removal of complete units of the armament. This philosophy was bound to cause further increases in the next destroyer design.

A new design decision-making body within the office of the Chief of Naval Operations (OPNAV), the Ship Characteristics Board (SCB), came into existence in 1945. Until that time, the General Board was the responsible body for new ship characteristics. For a few years following the establishment of the SCB, both were in the business of new ship characteristics selection. The General Board, the SCB and the Bureau of Ships each favored a different destroyer design as shown on Table 4-2 [4-18].

The preliminary design for a new destroyer was begun in the latter half of 1947 and completed in January 1948. (The ship's characteristics at the completion of preliminary design are shown on Table 4-3 [4-19].) Even though the TIMMERMAN power plant was still on the drawing boards, the Bureau of Ships selected a 1,200-psi, 950°F propulsion plant design for this new destroyer. This was a crucial decision. Although studies to determine the optimum initial steam pressure indicated 1,200-psi, they were not absolutely conclusive. In 1947, Westinghouse conducted a study to determine the best initial steam pressure. Calculations were based on an initial throttle temperature (TT) of 1,045°F at 50,000 shaft horsepower (shp) and 1,000°F at 4,200 shp (ship speed 20 knots). Several conditions were investigated including the use of cruising feed pumps. Figures 4-4 and 4-5 are based on using the main feed pump at the cruising
<table>
<thead>
<tr>
<th></th>
<th>SCB</th>
<th>Gen. Bd.</th>
<th>Bureau</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length</strong></td>
<td>Ft.</td>
<td>476</td>
<td>450</td>
</tr>
<tr>
<td><strong>Beam</strong></td>
<td>Ft.</td>
<td>47.5</td>
<td>46</td>
</tr>
<tr>
<td><strong>Draft (Trial)</strong></td>
<td>Ft.</td>
<td>13.96</td>
<td>13.4</td>
</tr>
<tr>
<td><strong>Displ. Std.</strong></td>
<td>Tons</td>
<td>3656</td>
<td>3175</td>
</tr>
<tr>
<td><strong>Displ. Trial</strong></td>
<td>Tons</td>
<td>4468</td>
<td>3900</td>
</tr>
<tr>
<td><strong>Displ. Full Load</strong></td>
<td>Tons</td>
<td>4753</td>
<td>4175</td>
</tr>
<tr>
<td><strong>SHP</strong></td>
<td></td>
<td>80,000</td>
<td>70,000</td>
</tr>
<tr>
<td><strong>Speed (Estimated)</strong></td>
<td>Kts.</td>
<td>36</td>
<td>35</td>
</tr>
<tr>
<td><strong>Cruising Radius</strong></td>
<td>Miles</td>
<td>4500</td>
<td>4500</td>
</tr>
<tr>
<td><strong>Armament -</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5&quot;/54 Sgl. Fwd.</td>
<td>1</td>
<td>--</td>
<td>1</td>
</tr>
<tr>
<td>5&quot;/54 Sgl. Aft.</td>
<td>1</td>
<td>--</td>
<td>1</td>
</tr>
<tr>
<td>3&quot;/70 Twin Fwd.</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3&quot;/70 Twin Aft.</td>
<td>1</td>
<td>1 + 1</td>
<td>1</td>
</tr>
<tr>
<td>20mm Twins</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>&quot;A&quot; Launchers Fwd.</td>
<td>1 Sgl.</td>
<td>1 Sgl.</td>
<td>1 Sgl.</td>
</tr>
<tr>
<td>&quot;A&quot; Launchers Aft.</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Torpedo Tubes</td>
<td>2 port</td>
<td>2 port</td>
<td>2 port</td>
</tr>
<tr>
<td>CL I Directors MK67</td>
<td>1 Aft.</td>
<td>1 Fwd.</td>
<td>1 Fwd.</td>
</tr>
<tr>
<td>CL II Directors MK56</td>
<td>1 Fwd.</td>
<td>1 Aft.</td>
<td>1 Aft.</td>
</tr>
<tr>
<td>Characteristic</td>
<td>Value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>---------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length DWL</td>
<td>476' - 0&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam at DWL</td>
<td>47' - 3&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth Main Deck at Side</td>
<td>28' - 2½&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longitudinal coefficient</td>
<td>.691</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Midship section coefficient</td>
<td>.800</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Draft - Trial</td>
<td>15' - 10½&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Displacement - Trial</td>
<td>4472 Tons</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Displacement - Standard</td>
<td>3670 Tons</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHP</td>
<td>80,000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FIGURE 4-4 WESTINGHOUSE ANALYSIS OF OPTIMUM STEAM PRESSURE.

SOURCE: REF [4-30]
FIGURE 4-5 WESTINGHOUSE ANALYSIS OF OPTIMUM STEAM PRESSURE
condition. The steam pressures are slightly higher for the 4,200 shp condition when the main feed pump is used instead of the cruising feed pump. The studies were not absolutely conclusive because the effect of various feed water heating arrangements were not investigated, and weight data was not accurate. The studies did show, however, that the optimum initial steam pressure (based on the above cruising condition) was between 1,000 and 1,500-psi and was probably very close to 1,200-psi.

Taking the plant as a whole (fuel oil plus machinery), it seems that there is no appreciable difference in plant weights between 875-psi and 2,000-psi. Preliminary estimates put both plants at 20 lbs/shp compared with the 35 lbs/shp for the old 600-psi plants. Boilers, turbines, gears and condensers constitute less than one-fourth of this weight. If there is no appreciable difference in plant weights, the optimum steam pressure is the parameter that yields maximum efficiency and maximum cruising radius. Apparently, this optimum figure is closer to 1,200-psi than it is to 875 or 2,000-psi (the TIMMERMAN plants).

The following rough values given by Westinghouse [4-20] show that optimum steam pressure varies with the ship's speed:

<table>
<thead>
<tr>
<th>Power (shp)</th>
<th>Speed (kts)</th>
<th>Optimum Pressure (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4,200</td>
<td>20</td>
<td>1,200</td>
</tr>
<tr>
<td>9,400</td>
<td>25</td>
<td>1,450</td>
</tr>
<tr>
<td>50,000</td>
<td>Full Power (FP)</td>
<td>1,450</td>
</tr>
</tbody>
</table>
The following tabulation of weights and fuel consumptions do not clearly indicate that the 1,200-psi choice appears to be optimum [4-20].

<table>
<thead>
<tr>
<th>Weight</th>
<th>Fuel Consumption</th>
<th>Fuel Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>psi</td>
<td>20 Kts.</td>
</tr>
<tr>
<td></td>
<td>lbs/shp</td>
<td>lbs/shp-hr</td>
</tr>
<tr>
<td>DD 692</td>
<td>600</td>
<td>35.04</td>
</tr>
<tr>
<td>DD 828</td>
<td>875</td>
<td>19.36</td>
</tr>
<tr>
<td>DD 828</td>
<td>2,000</td>
<td>19.62</td>
</tr>
<tr>
<td></td>
<td>0.609</td>
<td>0.604</td>
</tr>
</tbody>
</table>

Everyone at the Bureau of Ships and at Gibbs and Cox who was involved seems to remember that the selection of 950°F was based on the desire to avoid the use of austenitic (stainless) and high-chrome (2-1/4 percent) steels. The selection of 1,200-psi was based on considerations of both efficiency and availability of components (particularly valves and fittings) in industry.

People who were in the Machinery Division of the Bureau at that time indicated (during interviews with the author [4-21] and [4-22]) that although many of them favored 900-psi, 900°F, the 1,200-psi choice was made by naval officers in the Machinery Division at a closed-door meeting. No one can point to a more specific reason for the decision than earlier discussion indicates. It was to be somewhere between the two yet untested TIMMERMAN power plants. The decision to double the plant pressure over that which was accepted as standard at that time was a very bold decision considering the previous struggle in the 1930's to raise the operating pressure from 300-psi to 600-psi, and it created a powerful competitor to
the gas turbine. The existence of the 1,200-psi power plant as a viable power plant in the 1950's was one of the big deterrents to the early introduction of gas turbines. This point was well demonstrated by the fact that all non-nuclear warships in the active fleet today (excluding the new DD 963 delivered in 1975) have 1,200-psi steam power plants.

The specified steam condition for the DD 927 class destroyers (four built in the late 1940's) was 1,200-psi, 950°F compared with 600-psi, 850°F in World War II destroyers. No naval ships were in operation with such steam conditions. The Navy had limited experience with shore installations that reached 950°F. A steam temperature this high necessitates the use of chrome-bearing steels in superheated steam pipes and in those parts of main and auxiliary turbines which are exposed to superheated steam. This material is air hardening. There is no doubt that the use of these steam conditions and the resulting use of chrome-bearing steels definitely increased the industrial effort required to build these ships. Likewise, their repair was more difficult.

On the other hand, these steam conditions resulted in substantially lower fuel rates than those of the 600-psi, 850°F plant. The combined weight of machinery and fuel required for a given operating radius was undoubtedly less for a 950°F installation than for an 850°F plant.

One of the most serious difficulties encountered during the testing of TIMMERMAN boilers at the Naval Boiler and Turbine Laboratory
was the attachment of the superheater tubes to the outlet header. No information was available to indicate what troubles, if any, might be encountered with tube attachments in boilers operating at 950°F instead of at 1,050°F as in TIMMERMAN. Some people felt that this problem would disappear if the steam conditions were changed to use a maximum temperature of 850°F, but no changes were made to the steam conditions.

The decision in 1947 to install the 1,200-psi plant in the DD 927 class destroyers did not mean that it was immediately accepted. Both industry and parts of the Bureau of Ships resisted the change for many years (at least until the late 1950's) [4-23]. In the design of the machinery units for the DD 927 class, the various manufacturers drew heavily on their experience in the design of machinery for TIMMERMAN. In certain cases, the component designs for the DD 927 class were similar to those used in TIMMERMAN. Also, every effort was made to incorporate in these designs the lessons learned during the tests conducted on TIMMERMAN components.

As late as October 1950 when these ships were about to go into construction, many people involved still thought that the Navy should not have chosen the 1,200-psi plant. They were concerned that the machinery plants of the DD 927 class would not be as reliable as those installed in World War II destroyers for the following reasons:

a. The steam conditions specified (1,200-psi, 950°F at superheater outlet) were new to naval ships. These conditions required the use
of materials in steam pipes and turbines which were unfamiliar to the Navy.

b. The stringent weight limitations had required the use of designs very similar to those installed in TIMMERMAN which were untried in service. In addition, high-strength materials were used in novel applications, such as in the main propulsion shafting. This had not been the case in the machinery designs employed in World War II destroyers which had been the result of developments made over a period starting in 1933. These basic designs had ample service experience and the machinery had been proven reliable, as a result of which, it was possible to begin a very large destroyer building program with great confidence at the start of World War II.

It was the opinion of the Design Agent, Gibbs and Cox [4-23] (the same company to which Admiral Bowen attributed the major advance to the 600-psi during the 1930's) that it would be most unwise to embark on a major emergency building program of destroyers of the DD 927 class prior to service experience with these ships. Gibbs and Cox thought that certain changes should have been made in the design of the machinery components, the objective being to produce a more conservative machinery installation. This could have been accomplished only by increasing the weight of the machinery installation.

Gibbs and Cox thought that the design of the following major components should be reconsidered and modified to obtain the increased reliability required in a multiple ship wartime program:
a. Main Propulsion Turbines
b. Main Reduction Gears
c. Main Boilers
d. Ship's Service Turbo-Generators
e. Main Shafting
f. Feed Pumps
g. Auxiliary Turbines.

They estimated that the weight increase required to accomplish this increased reliability would be about 107 tons above the estimated machinery weight of DD 927 as shown in Table 4-4.* The impact for the ship resulting from these 107 tons along with a change to a steel deckhouse in lieu of aluminum and a proposed increase to 100,000 shp to compensate for the accompanying speed loss resulting from these proposed changes is shown in Table 4-5 in comparison with the basic DD 927.

Although the changes were not made, the idea to obtain more speed by going to a 100,000 shp power plant didn’t subside even by 1950; nevertheless, the ship was delivered with 80,000 shp. An eight-year design effort finally resulted in a new operational steam power plant for destroyers. However, the debate over this new power plant design was not over just because it was incorporated into one ship class.

By 1951, the Navy felt that a new prototype destroyer design was needed so that ships could be built in quantity in case of an emergency.

* The reason the DD 929 weights are somewhat different is because of some minor changes in the weapon suite.
TABLE 4-4 ESTIMATED MACHINERY WEIGHT COMPARISON, INCREASED RELIABILITY

<table>
<thead>
<tr>
<th>Group No.</th>
<th>Item</th>
<th>SHP 60,000 Actual Weights</th>
<th>BuShips' Estimate</th>
<th>G&amp;C Est. DD92 Estimate</th>
<th>G&amp;C Est. DD929</th>
<th>G&amp;C Est. 80,000 SHP 8/17/50</th>
<th>G&amp;C Est. 80,000 SHP 8/25/50</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Main Propelling Units</td>
<td>122.33</td>
<td>91.25</td>
<td>91.08</td>
<td>91.56</td>
<td>101.91</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>Main Shafting</td>
<td>56.61</td>
<td>47.06</td>
<td>58.43</td>
<td>58.43</td>
<td>84.97</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>Main Shaft Bearings</td>
<td>9.62</td>
<td>8.68</td>
<td>9.33</td>
<td>9.33</td>
<td>13.53</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>Lube Oil System</td>
<td>14.85</td>
<td>15.16</td>
<td>14.22</td>
<td>14.24</td>
<td>15.27</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>Fuel Oil System</td>
<td>25.27</td>
<td>37.79</td>
<td>39.75</td>
<td>43.49</td>
<td>39.91</td>
<td></td>
</tr>
<tr>
<td>VI</td>
<td>Main Condenser and Air Ejector</td>
<td>50.40</td>
<td>38.21</td>
<td>36.96</td>
<td>39.34</td>
<td>40.19</td>
<td></td>
</tr>
<tr>
<td>VII</td>
<td>Main Circulating and Condensate Pumps</td>
<td>11.31</td>
<td>8.04</td>
<td>9.56</td>
<td>9.14</td>
<td>10.16</td>
<td></td>
</tr>
<tr>
<td>VIII</td>
<td>Propellers</td>
<td>15.38</td>
<td>22.41</td>
<td>22.84</td>
<td>22.84</td>
<td>27.14</td>
<td></td>
</tr>
<tr>
<td>IX-X</td>
<td>Boilers and Boiler Fittings</td>
<td>186.94</td>
<td>211.43</td>
<td>193.27</td>
<td>222.69</td>
<td>226.42</td>
<td></td>
</tr>
<tr>
<td>XI</td>
<td>Smoke Pipes and Uptakes</td>
<td>18.49</td>
<td>23.21</td>
<td>20.84</td>
<td>20.84</td>
<td>20.84</td>
<td></td>
</tr>
<tr>
<td>XII</td>
<td>Steam and Exhaust Piping</td>
<td>58.68</td>
<td>53.35</td>
<td>57.80</td>
<td>57.80</td>
<td>57.80</td>
<td></td>
</tr>
<tr>
<td>XIII</td>
<td>Water and Service Piping</td>
<td>44.05</td>
<td>55.71</td>
<td>56.90</td>
<td>56.90</td>
<td>56.91</td>
<td></td>
</tr>
<tr>
<td>XIV</td>
<td>Insulation and Lagging</td>
<td>25.68</td>
<td>24.46</td>
<td>27.84</td>
<td>27.84</td>
<td>27.84</td>
<td></td>
</tr>
<tr>
<td>XV</td>
<td>Floor, Gratings &amp; Adjuncts</td>
<td>18.35</td>
<td>20.63</td>
<td>23.84</td>
<td>23.84</td>
<td>23.84</td>
<td></td>
</tr>
<tr>
<td>XVI</td>
<td>Auxiliaries</td>
<td>29.88</td>
<td>37.86</td>
<td>38.53</td>
<td>36.52</td>
<td>45.16</td>
<td></td>
</tr>
<tr>
<td>XVII</td>
<td>Fittings and Gear</td>
<td>9.09</td>
<td>16.63</td>
<td>12.65</td>
<td>13.25</td>
<td>13.34</td>
<td></td>
</tr>
<tr>
<td>XVIII</td>
<td>Liquids - Standard</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>XIX</td>
<td>Tools, Equipment &amp; Spares</td>
<td>24.67</td>
<td>41.53</td>
<td>43.50</td>
<td>43.50</td>
<td>43.50</td>
<td></td>
</tr>
<tr>
<td>XX</td>
<td>Independent Engineering Plants and Systems</td>
<td>22.77</td>
<td>63.84</td>
<td>43.94</td>
<td>44.07</td>
<td>48.66</td>
<td></td>
</tr>
<tr>
<td>XXI</td>
<td>Electric Plant</td>
<td>122.04</td>
<td>208.65</td>
<td>198.80</td>
<td>200.20</td>
<td>210.00</td>
<td></td>
</tr>
<tr>
<td>XXII</td>
<td>Liquids - Non-Standard</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL DRY</strong></td>
<td></td>
<td><strong>866.41</strong></td>
<td><strong>1,025.90</strong></td>
<td><strong>1,000.08</strong></td>
<td><strong>1,035.82</strong></td>
<td><strong>1,107.39</strong></td>
<td></td>
</tr>
</tbody>
</table>

SOURCE: REF [4-23]
<table>
<thead>
<tr>
<th>Item</th>
<th>DD 927 as of 8/17/50</th>
<th>Same Hull Steel Deckhouses Heavier &amp; More Reliable Machinery SHP 80,000</th>
<th>Proposed Redesign (Steel Deckhouses) SHP 100,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hull</td>
<td>1507.2</td>
<td>1564.45</td>
<td>1607</td>
</tr>
<tr>
<td>Hull Fittings</td>
<td>288.2</td>
<td>288.2</td>
<td>292</td>
</tr>
<tr>
<td>Equipment &amp; Outfit</td>
<td>110.4</td>
<td>110.4</td>
<td>113</td>
</tr>
<tr>
<td>Armament</td>
<td>322.3</td>
<td>322.3</td>
<td>328</td>
</tr>
<tr>
<td>Margin for Armament</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Machinery (Dry)</td>
<td>1000.1</td>
<td>1107.4</td>
<td>1227</td>
</tr>
<tr>
<td>Margin for Electronics</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Tolerance</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Light Ship Dry</td>
<td>3248.2</td>
<td>3412.8</td>
<td>3587</td>
</tr>
<tr>
<td>Liquids in Machinery</td>
<td>89.5</td>
<td>93.0</td>
<td>99</td>
</tr>
<tr>
<td>Light Ship Wet</td>
<td>3337.7</td>
<td>3505.8</td>
<td>3686</td>
</tr>
<tr>
<td>Ammunition</td>
<td>Same</td>
<td>Same</td>
<td>Same</td>
</tr>
<tr>
<td>Margin for Ammunition</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Stores</td>
<td>90.76</td>
<td>90.76</td>
<td>92</td>
</tr>
<tr>
<td>Potable Water</td>
<td>89.81</td>
<td>89.81</td>
<td>90</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>718.55</td>
<td>718.55</td>
<td>762</td>
</tr>
<tr>
<td>Diesel Oil</td>
<td>64.08</td>
<td>64.08</td>
<td>64</td>
</tr>
<tr>
<td>Fog Oil</td>
<td>16.36</td>
<td>14.36</td>
<td>14</td>
</tr>
<tr>
<td>Reserve Feed Water</td>
<td>71.42</td>
<td>71.42</td>
<td>76</td>
</tr>
<tr>
<td>Complement</td>
<td>42.58</td>
<td>42.58</td>
<td>43</td>
</tr>
<tr>
<td>Full Load</td>
<td>4637.1</td>
<td>4805.2</td>
<td>5035</td>
</tr>
<tr>
<td>Beam</td>
<td>49' 8&quot;</td>
<td>49' 8&quot;</td>
<td>51' 0&quot;</td>
</tr>
<tr>
<td>Mean Draft</td>
<td>14.22'</td>
<td>14.56'</td>
<td>14.75'</td>
</tr>
<tr>
<td>G.M. (Uncorrected)</td>
<td>5.80'</td>
<td>5.46'</td>
<td>6.34'</td>
</tr>
<tr>
<td>G.M. (Corrected)</td>
<td>4.62'</td>
<td>4.32'</td>
<td>5.22'</td>
</tr>
<tr>
<td>Period of Roll (Seconds)</td>
<td>9.8</td>
<td>10.1</td>
<td>9.5</td>
</tr>
<tr>
<td>Trial Displacement</td>
<td>4352</td>
<td>4520</td>
<td>4734</td>
</tr>
<tr>
<td>Mean Draft</td>
<td>13.7'</td>
<td>14.0'</td>
<td>14.4'</td>
</tr>
<tr>
<td>Relative Speed - Trial</td>
<td>100%</td>
<td>99%</td>
<td>103%</td>
</tr>
<tr>
<td>Displacement - Service Factor</td>
<td>1.25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Ref [4-23]
It was felt that the DL-2 (formerly the DD 927) design was not suitable as the prototype because it was too large and intricate. The DD 692 design was obsolescent and rather unsatisfactory with regard to its seaworthiness. Since it was envisioned that large sums of money would be required to build these new destroyers in quantity, design excellence was considered most important.

The Navy felt that knowledge gained from TIMMERMANN should be applied. They also thought that the design should be modern but not experimental. To keep the size of the ship moderate and still meet the characteristics, the preliminary design was made with very little weight margin. With a trend toward high, heavy weights in new ordnance and electronic equipment, great care was required to keep the ship from going overweight and to keep the center of gravity from rising. This design eventually became the DD 931 class, the FORREST SHERMAN.

The first preliminary characteristics [4-24] for this design specified a 380-foot ship with a 2,500-ton standard displacement armed with three 5"/54 single mounts, four 3"/50 twin mounts and sustained speed of over 30 knots.

These were modified in the second preliminary characteristics [4-25] as follows: length 410 feet, standard displacement 2,800 tons, three 5"/54 single mounts, two 3"/50 twin mounts, sustained speed somewhat reduced from the earlier characteristics, but still over 30 knots.
Second preliminary characteristics, revised [4-26], increased the length to 418 feet, 6 inches, and the standard displacement to 2,850 tons.

During the development of the design between first preliminary and the second preliminary (revised) characteristics, Gibbs and Cox reviewed the basic design. Their comments are recorded in their letters to the Bureau of Ships [4-27] and [4-28]. These were presented at a conference in the Bureau of Ships in October 1951. Further comments were presented at a conference on 31 October 1951 [4-29].

After the October conferences, the Gibbs and Cox staff was in general agreement with the details of the design as then developed, but questioned whether the design possessed sufficient speed. This question was referred to the SCB in the comments from the Bureau of Ships on the second preliminary characteristics. In this letter, it was pointed out that one additional knot of sustained speed could be gained at the cost of 100 tons of standard displacement by increasing the shp to 75,000 and the length to 423 feet. The SCB showed no interest in the additional speed, preferring to keep the ship as small as possible.

The design was essentially complete on the basis of a 600-psi, 850°F steam cycle when the decision was made to change to a 1,200-psi, 950°F plant. A 600-psi plant had been originally accepted because, according to the Bureau [4-30]:

76
"All major shipbuilders were experienced in the problems associated with 600-psi, 850°F plants, many designs were available in the 600-psi range and the 600-psi plant required less critical materials than did higher pressure plants."

However, as the design progressed, a growing conviction developed that the 600-psi, 850°F plant was obsolete for destroyer-type ships. Naturally, the calculated fuel rates were no better than those of similar ships designed prior to WW II. The lack of improvement in fuel rates was not from design stagnation, but rather because of a larger hotel load and the fact that poorer efficiency was accepted in some major units in order to save weight. The original reasons for accepting a 600-psi, 850°F cycle were then re-examined. Shipbuilders engaged in production of 1,200-psi, 950°F plants were questioned with regard to production problems. There were no major problems. The higher steam conditions offered an improvement in fuel rate ranging from about 7 percent at cruising speed to 11 percent at full power. This represented a savings of 60 tons in the amount of fuel required to meet the endurance of 4,500 miles at 20 knots. In view of this, a decision was made to change to a 1,200-psi, 950°F plant. The small increase in use of critical materials as a result of this change was considered justified in view of the gains.

With the recommitment to the 1,200-psi plant, a number of power plant components were redesigned to incorporate the latest technologies. These developments strengthened the commitment by both the Navy and industry to the 1,200-psi plant and therefore worked to the detriment of early adoption of gas turbines for destroyer design. Accordingly, the 1,200-psi plant became the "workhorse" for destroyers for the following 20 years.
Even the acceptance of this innovation was not very easy. Industry had vested interest to keep producing the 600-psi power plant components and did not give up easily. In June 1957, five years after the design of the FORREST SHERMAN, on the occasion of the completion of contract design of the DDG 2 class destroyers, the Machinery Design Manager remarked:

"... The design steam conditions of 1,200-psig, 950°F have by now apparently been accepted by the shipbuilding industry as standard for high-powered combatant ships. This is the first such new class of ships on which the Design Branch has not had some recommendation from prospective bidders for more conservative steam conditions; and is probably due to the design and operating experience gained from the DD 931 and the DD 927 class of ships." [4-31]

It is apparent that, by the end of the 1950's when gas turbines were coming of age, as will be seen in future sections of this case study, the climate was most unfavorable for introduction of the gas turbine for destroyer propulsion, since both the Navy and the shipbuilding industry had invested a great deal in this high-pressure, steam power plant development and neither was receptive to the introduction of a new technology which was going to force new training programs for sailors, new risks in maintenance, as well as from industry's point of view, negating the sizable investment made into the 1,200-psi steam plant production.

Let one suppose for a moment, that the DD 931 class had not reintroduced the 1,200-psi plant but had gone into production with the 600-psi plant. In that case, it may appear reasonable to speculate that by the late 1950's the impetus to supersede the old 600-psi plant, which had been developed in the 1930's, with a much more advanced plant would have been substantial enough to push for an early adoption of gas turbines.
4.4 U.S. Naval Gas Turbine Developments Of The 1940's

During the 1940's, the U.S. Navy invested only modest sums in the development of gas turbines. Developments sponsored two principal avenues of investigation:

a. So-called "free piston"* gas generators to be used in connection with a power turbine

b. Gas turbines of the constant pressure type of relatively small power and high weight/horsepower, i.e., industrial vice aircraft type.

Using steam and improving on it was the traditional and natural method of upgrading propulsion systems. Competitive concepts such as gas turbines and nuclear power were either at too early a stage of practical development or were not suited for producing the high powers required for destroyer propulsion (80,000 - 100,000 shp) within reasonable weight and space allocations. These facts did not deter the Bureau of Ships and private companies from investigating and developing, at least on paper, some interesting alternatives to the high temperature/high pressure steam power plant.

Nuclear power was considered by the Navy as early as 1946 as a heat source for the development of power for ship propulsion. Considering

* This concept is explained later in this section.
the scarcity of fissionable material and the demand put on it for weapons, as well as developmental problems associated with such a radically new technology, it appeared that, for some time to come, submarines were going to be the only class of combatant ships which would be considered for nuclear propulsion.

The design and development of high power (30,000 - 50,000 shp per shaft) internal combustion machinery (gas turbines or diesels) suitable for destroyers, cruisers, or other large combatant ships was not actively pursued in the 1940's. During this same period, a number of studies and experiments were initiated by the Navy to develop smaller gas turbines for ship propulsion, but most ended prematurely for lack of funds, success, or enthusiasm. Some gas turbine "firsts" were recorded for the decade by the British. Also, by the early 1950's, the U.S. Navy put to sea two small boats propelled by gas turbines which were not derivatives of its own gas turbine development programs, but small gas turbines developed for aircraft sponsored by Naval Air and the Air Force. Some of the significant naval experience with gas turbines of the period included the following:

14 July 1947 - The British Navy's MGB 2009 (later MTB 5559) put to sea with a gas turbine engine providing part of the propulsion power [4-32]. Actually the British Admiralty actively entered the gas turbine field at a relatively late date. The contract for the development of the Gatric gas turbine engine was not placed until August 1943 [4-33]. This gas turbine engine was the first to be installed and was an adaptation of a simple cycle aircraft turbojet engine to marine service (as opposed to
the industrial units which the U.S. Navy was attempting to develop for marine use).

6 May 1950 - The British commenced trials on a second vessel, the launch TORQUIL, powered by gas turbine engines [4-34].

30 May 1950 - Trials were started by the U.S. Navy on a 24-foot personnel boat using an aircraft engine. This was the first vessel to be propelled solely by a gas turbine with no other engine aboard [4-35].

18 June 1951 - The British Admiralty launch HL 3964, a gas turbine propelled vessel, was put into service. The engine was similar to that in TORQUIL.

15 July 1951 - A U.S. Navy LCVP, powered by the same type engine as that used in the earlier personnel boat, was the fifth waterborne gas turbine installation.

18 Aug 1951 - The British Admiralty launched BOLD PIONEER (MTB 5801), the first vessel ever to be designed and built specifically to exploit the advantages of the gas turbine engine for propulsion. The boat was powered by two gas turbines and two diesel engines, the turbines being similar to those used in the earlier MTB 5559 but having about double the power [4-36].

17 Sept 1951 - The British Admiralty launched BOLD PATHFINDER (MTB 5720), a boat somewhat similar to MTB 5701 [4-36].

The "free piston" gas generator gas turbine development sponsored by the Bureau of Ships starting in late 1943 complemented the constant pressure cycle gas turbine development program proposed by the National Academy of Sciences, such as the Allis/Chalmers and Elliot turbines,
already fairly well advanced by the mid 1940's. This concept became known as the "free piston" gas generator which, when combined with other components of the cycle, became the "free piston" gas turbine. The "free piston" gas turbine incorporated a basically different principle of operation from that of the constant pressure gas turbine type.

Basically, every gas turbine plant requires only three elements: a means for precompressing air, a combustion chamber for burning fuel in that air, and a turbine wheel to expand the resulting gases of combustion and to convert their heat energy into the mechanical energy of a rotating shaft to be absorbed by a suitable load.

The original simplicity of the basic gas turbine plant subsequently has been violated by the addition of improvements in the form of such auxiliaries as heat exchangers or regenerators, intercoolers and two-stage compression, and additional combustors for reheating of gases between two separate turbines. Every new addition or modification has created a new "cycle."

Shortly after World War I, a French engineer, Pescara, applied for a patent for an internal-combustion motor compressor unit "in which the transformation of energy into work is effected without any kinematic connection of the piston intended to transform a reciprocating movement into a rotary movement" (from U.S. Patent No. 1,615,133).
The gas generator portion represented the ultimate goal from the struggle to achieve higher supercharge pressures in internal combustion engines (diesels). It was desirable to go to higher supercharge pressures in order to obtain advantages of greater compactness and lighter weight for given power output and efficiency. Supercharging attained these objectives by providing the cylinders with a denser inlet charge, improved scavenging, and better cooling. The price paid for these gains was the power required to drive the supercharger. In U.S. practice in the 1940's, diesel engines were limited to supercharge pressures of 6-8 psig. This limitation was imposed by:

a. Excessive compressor power requirements
b. Excessive loss of energy in the exhaust gases due to the large unused pressure drop across the cylinder from the inlet manifold pressure to atmospheric exhaust pressure.

The obvious solution to this limitation was to recover the wasted energy in (b) and apply it to the energy demand in (a). An exhaust gas turbine appeared to be the most effective device.

The final stage in the evolution of supercharging was that in which the diesel engine output was totally absorbed by the compressor and all net mechanical work performed by the gas turbine. The diesel compressor system then would become a so-called gas generator serving only as a means of obtaining hot gas under pressure and performing the function that a boiler performs in a steam power plant. This separation of
functions between the power generation in the gas generator and power extraction in the continuous flow gas turbine immediately resulted in three important advantages:

a. Inherent flexibility of plant arrangement due to the possibility of locating the gas generator and the gas turbine independently

b. Isolation of torsional vibrations from the power transmission system of gears, shafting, and propeller

c. Flexibility of operation since the power gas supply would be completely independent of turbine speed.

The gas generator stage of development opened the way for consideration of the balanced work concept in which the work done by the diesel cylinder was completely absorbed by the compressor cylinder. If this were done with a reciprocating engine-compressor set, the rotating mass, provided by fly-wheel and crankshaft, would no longer be necessary for the storing of the inertial energy otherwise required for compression of the charge in the diesel cylinder. This energy could be stored as compressed air trapped in the compressor cylinder clearance volume or in a separate bounce cylinder, and the diesel compression work could be accomplished by expansion of the trapped air during the first portion of the compressor inlet stroke. The compressor piston could then be attached directly to the power piston and, once started, simply bounce back and forth against the compressed air on the one side and the fresh diesel charge on the other.
The "free piston" gas generator was obtained by opposing two power pistons, each with an attached compressor piston, in a common power cylinder suitably connected to the compressor cylinders by manifolds and ports. The sole mechanical linkage between the pistons was a light synchronizing gear to maintain correct relative position regardless of slight variations in piston mass and sliding friction. The synchronizing gear also provided a means of taking off the small amount of mechanical power required to drive auxiliaries, such as fuel and lubricant pumps. The pistons oscillated at a natural frequency determined by the piston mass and the operating pressures of the compressor and diesel cylinders. A maximum frequency variation of approximately 25 percent could be obtained between no load and full load, depending on the variation in operating pressures with varying amounts of fuel injected and on the type of bounce cylinder pressure control.

The "free piston" gas generator appeared to have all of the advantages of the diesel engine-compressor set "gas generator" with the following very important additions:

a. Complete dynamic balance was attained. All motion was rectilinear and all forces were in 180 degree opposition to each other, thus totally eliminating unbalanced couples and torsional vibration within the gas generator itself as well as in the power extraction equipment.

b. Greater compactness and lighter weight were gained through the elimination of all connecting rods, crankshafts, and attendant heavily loaded bearings. Foundation weight was only a fraction of that required for the conventional diesel engine because of the perfect dynamic balance.
c. Higher efficiency was obtained than for any other known form of prime mover. Elimination of the necessity of transferring heavy loads through several bearings made possible the consideration of peak and mean effective pressure which, in a high-speed reciprocating engine, would require crankshaft, rods and bearings of prohibitive size. The first U.S. built experimental units were expected to have a thermal efficiency of 36-38 percent at the turbine shaft with the development ultimately attaining 40-45 percent at the turbine shaft.

d. Improved maintenance and reliability compared with the conventional diesel engine was expected because of fewer moving parts, complete lack of heavily loaded bearings, and absence of piston side thrust.

Studies of the various cycles of the kind described above convinced the Bureau of Ships Research Branch that the possibilities of the "free piston" generator-gas turbine cycle far outweighed those of the various intermediate stages of supercharging. It was decided in 1943 to concentrate on the "free piston" development rather than on highly supercharged diesel engines [4-37]. The "free piston" gas generator was thus incorporated as a second phase of the Bureau of Ships gas turbine development program which previously had included only the constant pressure type of cycles started in 1940.

The "free piston" gas generator the Bureau was developing was fundamentally a single cylinder unit in which two opposed pistons operate as balanced pendulums of infinite radii with fuel burned between them every time they come together (as in an opposed piston diesel engine) for the specific purpose of generating gas at a high temperature and pressure.
suitable for use in a gas turbine. The real heat cycle is not completed until the generated gas is expanded in the gas turbine. In other words, the "free piston" gas generator assumes all the functions of the steam boiler and its multiplicity of auxiliary equipment, but it is by mechanical design very much like a diesel engine.

Figure 4-6 shows schematically a gas generator connected to a gas turbine with the pistons in both of their extreme running positions, while Figure 4-7 gives an enlarged diagrammatic section of the "free piston" unit itself. The power cylinder is very much like that of an opposed piston diesel engine. It has open ends, ports adjacent to its ends, and fuel injection nozzles on its center radial plane.

Technical literature regarding "free piston" machinery was limited largely to a few European publications by the Pescara and Junkers organizations. A captured Junkers 3,000-psi torpedo charging "free piston" compressor was expected to provide a limited knowledge of "free piston" machine operation. However, none of the European "free piston" gas generator work had been directed toward the lightweight high-speed type of machine which the Bureau considered to hold the greatest promise for naval ship propulsion [4-38].

No "free piston" gas generator development of any kind existed in the U.S. Such development required extensive preliminary design studies which could best be accomplished by an engine manufacturer capable of carrying such a study to the practical conclusion of producing an operable
FIGURE 4-6 "FREE PISTON" GAS GENERATOR AND GAS TURBINE.
FIGURE 4-7 SCHEMATIC DIAGRAM OF A "FREE PISTON" GAS GENERATOR.

1 PISTON ASSEMBLY
1a POWER PISTON
1b COMPRESSOR PISTON
1c BOUNCE PISTON
2 BOUNCE CYLINDER
3 SCAVENGE AIR RECEIVER
4 COMPRESSOR CYLINDER
4a REVERSE BOUNCE SPACE
4b COMPRESSOR SPACE
5 POWER CYL., LINER
6 DIRECT BOUNCE HEAD
7 DIRECT BOUNCE SPACE
8 COMPRESSOR INLET VALVES
9 COMRESSOR DISCH. VALVES
10 SYNNCHRONIZING RACK
10a SYNNCHRONIZING PINION
11 STUFFING BOX
12 DUMP VALVE
13 SCAVENGE AIR DUCT
14 INLET PORTS
15 EXHAUST PORTS

SOURCE: REF. [4,37]
unit. A development of this magnitude of necessity required underwriting by the Bureau of Ships in the form of development contracts because of the large expenditures involved in designing, building, and testing experimental gas generators as well as in solving the problems of integrating the gas generator with the gas turbine.

Clark Brothers Company, Inc., the H.O.R. Division of General Machinery Corporation, and Baldwin Locomotive Works (BLW) accepted Bureau of Ships contracts in the 1943-1944 period for the design and construction of a "free piston" gas generator unit. Clark Brothers was awarded a contract for the experimental investigation of combustion condition in a highly supercharged diesel cylinder operating at high exhaust back pressures. The objective was not to develop a highly supercharged diesel engine, per se, but to determine experimentally the limiting pressure levels and maximum amounts of fuel which might be handled by a "free piston" gas generator cylinder. H.O.R. Division contracted for the design and construction of a "free piston" gas generator, exclusive of the turbine, capable of delivering approximately 300 shp. The intent was to develop a final design and specification for a "free piston" gas generator - gas turbine ship propulsion unit of approximately 1,500 shp. Baldwin Locomotive Works was awarded a contract for the construction of a 1,000-hp gas generator - gas turbine propulsion system incorporating reduction gears and a controllable pitch propeller at an estimated cost of $898,000. After a slow start, Baldwin produced excellent analytical work and an experimental crank-connected opposed piston gas generator of approximately 1,000-hp output. Theoretical
investigations had convinced Baldwin that the "free piston" machine was the most promising form of gas generator.

By 1946, the stage of development reached by H.O.R. and by Baldwin in the production of an operable gas generator raised the immediate necessity of wedding the gas turbine to the gas generator. The main problems of operating conditions and controls were those of the gas generator manufacturer since his art had been born but a few months before. The design and control of the gas turbine itself was already a well-advanced art because of the intensive development work accomplished in the previous several years. It was therefore proposed to maintain the gas generator manufacturer as the prime contractor in the Bureau's gas generator propulsion unit program, until such time as the matching of a gas generator with a gas turbine was a thoroughly understood procedure, analogous to the matching of diesel engines with electrical generators and turbines with boilers. The Bureau felt that it did not seem wise to divide the responsibility for producing a complete propulsion plant between the gas generator and the turbine manufacturers. To do so would have required the Bureau to assume the responsibility of specifying gas flows, pressures, and temperatures under all loads for gas generator exhaust and gas turbine inlet, so that the two separately designed components could be united. This the Bureau was not prepared to do, as these flow, pressure, and temperature levels were major variables which had to be investigated in the design of the complete plant.
It further did not appear desirable at that time to consider other manufacturers for completion of any phase of the programs proposed by Baldwin and H.O.R. The Bureau felt that these companies had devoted a great deal of time and effort to attaining a theoretical background as well as a practical "know how" of the gas generator problem. Other companies had been offered equal opportunity but had not accepted. The "education" of Baldwin and H.O.R., which was paid for by the Bureau of Ships, would have had to been needlessly repeated with other manufacturers while knowledge already existent would not have been used to maximum advantage and at minimum cost to the Navy. This logic "married" the Bureau eventually to BLW for as long as another decade without the production of a single practical engine of the "free piston" type. It is interesting to note that about 13 years after the initial, Bureau sponsored work on the "free piston" engine by BLW and a few million dollars later, a branch of the machinery division recommended that no funds be budgeted for any further development effort with BLW. The reasons for this recommendation were [4-39]:

"a. A new development effort would cost about $1,000,000 and take several years.

b. The new engine would not be competitive in cost for cheap landing craft boats and inshore minesweepers.

c. General Motors and Ford were developing automotive free piston gas turbine engines which, if successful, would be available - probably at a
lower cost. It was more likely that these companies would go into production.

d. The BLW Corp. was slow to complete work on three previous free piston development projects and over $4 million and 13 years had already been committed to BLW.

e. DL2, the latest engine developed by BLW was too large and heavy. Also, BLW had not developed any commercial interest in the DL2.

f. Because of higher priority developments (e.g., nuclear), funds were not available."

Thus, the BLW work did not result in a single workable engine. All this led to the demise of any interest in this type of gas turbine by the mid-1950's.

As a result of the BLW "free piston" experience and the general lack of funds for gas turbine development, there was luke-warm response by the Bureau, to a 1948 Gibbs and Cox proposal of a yet different approach to combining diesels and gas turbines.

Gibbs and Cox recommended in January 1948 that the solution to the problem of the propulsion plant for high-power combatant naval vessels using the internal combustion principle could be found by using a combination of cruising units consisting of diesel electric drive or gas turbine electric drive with diesel-type compressors [4-40]. Either type was to be supplemented by gas turbines and turbine compressors for full-power operation. Gibbs and Cox and the General Electric Company worked together on this project and assumed the cost in the interest of developing an innovative solution to the problem of lightweight power for combatants.
A comparative study of destroyer power plants was made between the DD 692 long-hull steam plant of 60,000 shp, the then projected 100,000 shp steam plant for DD 828, and four types of internal combustion power plants of 100,000 shp. Four combinations of internal combustion propulsion machinery units, each containing some significant gas turbine units, were compared with the two types of steam plants: Type I (used in DD 692) and Type II (used in DD 828). The four types of internal combustion machinery units required for the propulsion of one shaft of 50,000 shp are shown in Table 4-6.

Table 4-7 presents the salient features of the DD 692 long-hull steam plant (Type I) which represented the best operational destroyer plant in the 1940's. Also shown are comparable data for the 2,000-psi General Electric steam plant with Combustion Engineering boilers contemplated at that time for DD 828 (Type II), and the two most attractive of the four internal combustion plants considered. The two plants recommended were Type V, the direct reversible geared gas turbine plant with independent gas turbine reversing unit and Type VI which provided electric drive for cruising and maneuvering. All types had the same full load displacement of 3,479 tons, the same combined weight of machinery and fuel of 1,707 tons, the same cruising speed of 26 knots and occupied the same over-all machinery space. The estimates of cruising radii were on a directly comparable basis for all of the types as well.

From Table 4-7, it is evident that in a destroyer having the same full load displacement, cruising speed, combined weight of machinery
| TYPE III: | A combination of electric drive gas turbines and diesel engines. There are four gas turbine driven a.c. generators, four gas turbine driven axial flow air compressor units, four main propulsion synchronous motors of 12,500-hp each driving the main shaft through a reduction gear. For cruising and maneuvering only, there are eight reciprocating diesel engines of the General Motor's Model 12-278A type mounted in pairs, each pair driving a 2,500-hp a.c. generator placed between. The cruising engines are not used above cruising speed. |
| TYPE IV: | This type is also a combination of electric drive, gas turbines, and diesel engines. It is a modification of Type III in which the diesel driven generators supply propulsion power for cruising and maneuvering and also as much of the propulsion power as practicable at speeds above cruising. This alternative to Type III requires more complicated electrical equipment since the rpm difference of the propellers at cruising speeds and full power will necessitate the use of pole-changing apparatus. |
| TYPE V: | A straight geared gas turbine plant consisting of four 12,500-hp gas turbines driving the main shaft through a reduction gear with three gas turbine driven axial flow air compressors, three special type reciprocating controlled piston internal combustion compressors, three cruising gas turbines driving the main reduction gear, and one gas turbine for astern operation. |
| TYPE VI: | A combination of four 12,500-hp main propulsion gas turbines, three gas turbine driven axial flow compressors, three special type reciprocating controlled piston internal combustion compressors, and one 12,500-hp gas turbine driven generator for cruising and maneuvering. The maneuvering and cruising generator drives two 6,250-hp synchronous motors connected to the main reduction gear. |

SOURCE: REF 14-40
<table>
<thead>
<tr>
<th>TYPE</th>
<th>I</th>
<th>II</th>
<th>V</th>
<th>VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destroyer Number</td>
<td>DD 692</td>
<td>DD 828</td>
<td>DD 828</td>
<td>DD 828</td>
</tr>
<tr>
<td>Type of Machinery</td>
<td>600 psi</td>
<td>2,000 psi</td>
<td>Gas Turbine</td>
<td>Gas Turbine</td>
</tr>
<tr>
<td></td>
<td>850°F</td>
<td>1,050°F</td>
<td>Geared</td>
<td>Geared and Electric</td>
</tr>
<tr>
<td>Shaft Horsepower (shp)</td>
<td>60,000</td>
<td>100,000</td>
<td>100,000</td>
<td>100,000</td>
</tr>
<tr>
<td>Total Net Weight of Machinery (Tons)</td>
<td>968.70</td>
<td>860.11</td>
<td>925.59</td>
<td>1,049.58</td>
</tr>
<tr>
<td>Weight Net (Lbs) per shp Full Power</td>
<td>35.04</td>
<td>19.267</td>
<td>20.73</td>
<td>23.51</td>
</tr>
<tr>
<td>Weight per shp Full Power as Percent of DD 692</td>
<td>100.00</td>
<td>55.00</td>
<td>59.17</td>
<td>67.10</td>
</tr>
<tr>
<td>Weight of Fuel in Tons (2,240 Lbs)</td>
<td>768.76</td>
<td>847.35</td>
<td>781.87</td>
<td>657.88</td>
</tr>
<tr>
<td>Fuel Rate at 25 Knots Cruising Speed in Lbs/shp/hr.</td>
<td>0.61</td>
<td>0.58</td>
<td>0.35</td>
<td>0.39</td>
</tr>
<tr>
<td>Endurance at 25 Knots (Nautical Miles)</td>
<td>3,621</td>
<td>4,253</td>
<td>6,433</td>
<td>4,762</td>
</tr>
<tr>
<td>Endurance at 25 Knots as Percent of DD 692</td>
<td>100.0</td>
<td>117.5</td>
<td>177.7</td>
<td>131.5</td>
</tr>
<tr>
<td>Fuel Rate at 100,000 shp in Lbs/shp/hr.</td>
<td>-</td>
<td>0.562</td>
<td>0.825</td>
<td>0.76</td>
</tr>
<tr>
<td>Endurance at 100,000 shp (Nautical Miles)</td>
<td>-</td>
<td>1,325</td>
<td>830</td>
<td>752</td>
</tr>
<tr>
<td>Endurance at 100,000 shp as Percent of DD 828</td>
<td>-</td>
<td>100.0</td>
<td>62.5</td>
<td>56.6</td>
</tr>
</tbody>
</table>

SOURCE: REF [4-40]
and fuel, and machinery space as the DD 692 long-hull (Type I), it was possible to install in place of the 60,000 shp plant a 100,000 shp plant (or 66 percent more power than DD 692) using either high-pressure and high-temperature steam (Type II) or internal combustion plants (Types V and VI).

Figure 4-8 shows the fuel rates at the 25-knot condition and at 100,000 shp for DD 692 and the 2,000-psi plant for DD 828 and for Type VI plants. Since DD 692 had a maximum 60,000 shp, it was omitted from the full-power chart. Both gas turbine plants appear to be markedly superior to the steam plants at 25 knots, with the Type V plant somewhat better than the Type VI. At 100,000 shp, the fuel rate of the 2,000-psi steam plant which was installed in DD 828 is superior to both types of gas turbine plants. Gibbs and Cox and G.E. believed that further investigation and development would improve the full-power fuel rates of the gas turbine plants while no substantial improvements were expected for the steam plant.

Figure 4-9 compares the weight and endurance at 25 knots and at full power for these existing and projected steam plants with the proposed gas turbine plants. The weight per ship of the 2,000-psi steam plant which was installed in DD 828 and the two proposed types of gas turbine plants were comparable, and all were markedly superior to the steam plant installed in DD 692. Gibbs and Cox and G.E. believed that further investigation and development would result in a substantial reduction in the weight of the gas turbine plants. No great reduction in the weight of the type of steam plant installed in DD 828 was foreseen.
DD692
DD828 - 2000 PSI PLANT
TYPE V - GAS TURBINE DIESEL GEARED PLANT
TYPE VI - GAS TURBINE DIESEL GEARED & ELECTRIC PLANT

25 KNOTS

FULL POWER - 100,000 SHP

SOURCE: REF [4-40]

FIGURE 4-8 COMPARISON OF FUEL RATES.
DD692
DD828 - 2000 PSI PLANT
TYPE V GAS TURBINE DIESEL GEARED PLANT
TYPE VI GAS TURBINE DIESEL GEARED & ELECTRIC PLANT

WEIGHT OF MACHINERY

TOTAL WET WEIGHT IN TONS

<table>
<thead>
<tr>
<th></th>
<th>TONS</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>DD 692</td>
<td>939</td>
<td>DD 828</td>
<td>860</td>
<td>TYPE V</td>
</tr>
<tr>
<td>TYPE VI</td>
<td>988</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

WEIGHT WET LBS PER SHP

<table>
<thead>
<tr>
<th></th>
<th>SHP PER</th>
<th>DD 692</th>
<th>35</th>
<th>DD 828</th>
<th>19</th>
<th>TYPE V</th>
<th>19</th>
<th>TYPE VI</th>
<th>22</th>
</tr>
</thead>
</table>

ENDURANCE

BASED ON SAME TOTAL WEIGHT OF MACHINERY AND FUEL

25 KNOTS IN PERCENT OF DD692

<table>
<thead>
<tr>
<th></th>
<th>PERCENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>DD 692</td>
<td>118%</td>
</tr>
<tr>
<td>DD 828</td>
<td>194%</td>
</tr>
<tr>
<td>TYPE V</td>
<td>145%</td>
</tr>
<tr>
<td>TYPE VI</td>
<td></td>
</tr>
</tbody>
</table>

FULL POWER - 100,000 SHP IN PERCENT OF DD828

<table>
<thead>
<tr>
<th></th>
<th>PERCENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>DD 828</td>
<td>68%</td>
</tr>
<tr>
<td>TYPE V</td>
<td>62%</td>
</tr>
<tr>
<td>TYPE VI</td>
<td></td>
</tr>
</tbody>
</table>

SOURCE: REF (4-40)

FIGURE 4-9 COMPARISON OF WEIGHT OF MACHINERY AND ENDURANCE.
Both gas turbine installations showed a superiority in endurance over the steam plants at 25 knots. The superiority of the Type V gas turbine plant appeared particularly outstanding. At 100,000 shp, the 2,000-psi steam plant which was installed in DD 828 was superior to both gas turbine installations. However, as pointed out earlier, the margin possessed by the steam plant might diminish or disappear if further development proceeded with the gas turbine plants.

The success of the two gas turbine installations which had been presented was entirely dependent on the successful development of a diesel-type reciprocating compressor and its associated gas turbine. It was the opinion of Gibbs and Cox that the G.E. studies indicated that such a compressor could be successfully developed within a short period of time.

The diesel/gas turbine plant developed by G.E. was very interesting. What was being proposed was a compound engine cycle embodying a stepped piston with a highly supercharged (6 atmospheres) diesel cylinder driving a reciprocating supercharging compressor which then was to exhaust at 1,200°F and 6 atmospheres into a gas turbine which was to produce all of the useful power. G.E. designed this cycle based on materials available in 1948. Turbine and compressor efficiencies of 82 percent and 84 percent were attainable with a 1,400°F inlet turbine temperature. The fuel rate expected of such a typical unit (Figure 4-10a) was to be 0.72 lb/bhp-hr. G.E. pointed out that although turbine inlet temperatures of the order of 3,200°F were out of the question, the diesel "expander" (as shown on
FIGURE 4-10  FUEL RATES FOR VARIOUS TURBINE AND COMPRESSOR EFFICIENCIES.
Figure 4-10c) did use this high a gas temperature for very short time periods and G.E. felt that it was possible by proper cooling around the "expander" to keep metal temperatures to within that which was possible with materials available in the late 1940's. Therefore, the proposed scheme (shown on Figure 4-10c) would have come close to that obtainable theoretically with a gas turbine cycle operating at 3,200°F turbine inlet temperature (shown on Figure 4-10b) using temperatures and efficiencies unattainable at that time.

It was the combined opinion of G.E. and Gibbs and Cox that the results of these studies fully warranted the Bureau of Ship's support of a program aimed at development of a gas turbine plant of 50,000-hp per shaft. They were convinced that such a plant could be successfully developed, provided a satisfactory diesel-type reciprocating compressor could be built. Therefore, they recommended that the Bureau support the development of the type of diesel compressor described earlier together with a gas turbine capable of fully testing the compressor. Both were to be designed to take full account of the conditions to be encountered in a marine environment. This program called for a full-scale development of one shaft's worth of machinery. Its shore-based testing was calculated to require 4 years, and estimated cost was somewhat over $4,000,000. This program was received by the Bureau in 1948, but no action was taken to develop it further. By that time, the Bureau had participated in a series of gas turbine programs (products of the early 1940's) starting with the one recommended by the National Academy of Sciences as well as the BLW effort in the "free piston" area.
What G.E. proposed was different from that which the Navy was engaged in, but because of lack of R&D funds and lack of enthusiasm on the part of the Bureau to take on yet another development effort in this area, the G.E. and Gibbs & Cox proposal was not pursued.

The constant pressure cycle gas turbine recommended by the Academy in 1940 was pursued during this same period. In 1940, after two years of study, the National Academy of Science committee recommended the establishment of a naval gas turbine program including the construction and exhaustive laboratory testing of a gas turbine engine capable of sustained operation at 1,500°F [4-15]. This resulted in a contract being awarded the Allis-Chalmers Company for the design and construction of a 3,500-hp unit suitable for laboratory testing [4-41]. This unit incorporated an axial flow compressor and turbines, and in 1942 two other laboratory units were ordered. A 2,500-hp engine using Lysholm compressors was ordered from the Elliott Company and a 750-hp unit utilizing Birmann mixed-flow compressors and turbines was ordered from the DeLaval Steam Turbine Company [4-42]. As a result of the test experience gained from these laboratory units, a number of gas turbine engines were ordered by 1951 from the Boeing Airplane Company, the Solar Aircraft Company, and Allison Division of General Motors for installation aboard naval vessels. Most of these engines were highly experimental and either did not meet predicted performance or fell apart during testing, and they were altogether too small as prime movers for anything larger than PT-boat-size vessels.
The power requirements of large combatant ships necessitated
the substitution of the steam plant in place of the diesel engine as the
cruising plant. A study [4-43] made in 1950 indicated that a combination
steam-gas turbine plant would reduce the weight of a destroyer's propul-
sion equipment by 28 percent and reduce the length of the machinery space
required by the plant by more than 10 feet. A steam plant would provide
sufficient power for a ship's speed of 20 knots after which the gas turbine
engines would be cut in. Conversely, it would be possible to concentrate
higher powers in the same space and weight as the existing steam plant by
the substitution of a combination steam-gas turbine plant. However, this
concept was also not pursued in the 1940's.

In the 1940's, the U.S. Navy started another special gas turbine
development. In this case, the gas turbine was not to be connected directly
to the propulsion of the ship, rather it was to be used as the prime mover
of fans located on top of steam boilers for the purpose of compressing air
on the combustion side of the boiler. This was to lead to a more light-
weight and compact boiler and was part of a development program dealing
with a special steam power plant which interestingly enough found itself
in the early 1960's to be a competitor of the gas turbine as a propulsion
prime mover. The program was called "closed-cycle" or "special submarine
cycle." This closed-cycle submarine program was begun in June 1946 and
had the purpose of developing machinery plants which would result in radical
improvements in submarine performance over that possessed by our WW II sub-
marines. Like many other developments initiated in the 1940's which were
discussed earlier, this program was bogged down as well. By 1952 the status
of this program was as follows [4-44]:

104
"a. A total of $24,000,000 had been spent.

b. No one of three manufactured closed-cycle propulsion plants had been fully evaluated.

c. A fourth plant being developed by G.E. was cancelled in January 1950 owing to lack of funds, after a $2,000,000 expenditure.

d. After six years, the program still had no plant for submarine installation.

e. The Navy lost interest in this program, engineers left, and so did the contractors' engineers."

Being a waiving program by the early 1950's and being overtaken by successful results of nuclear propulsion for submarines, the gas turbine efforts throughout the 1940's did not provide a viable prime mover alternative for warship propulsion. In retrospect, the decade was noted for complex, problem-solving research which, even if successful, would have resulted only in large heavy industrial type gas turbine plants.

It is important to note that the Navy spent practically no effort in attempting to adapt the aircraft derivative, lightweight, gas turbine for marine use, even though by this time, the engine had a decade of intensive successful development behind it.

Thus, by the early 1950's, the gas turbine development sponsored by the Bureau for a decade and a half appeared to be getting bogged down. There was no in-service gas turbine exhibiting sufficient reliability and of large enough size to be considered a serious competitor to the 1,200-psi steam plant. The Navy was switching to nuclear power for submarines and
to the closed-cycle power plant which, started for conventionally powered submarines, was developing a boiler which was to add one more competitor to gas turbines. Nuclear power, successfully developed for submarines by the early 1950's, also presented a potential competitor to surface warship propulsion. This was a fairly grim picture for gas turbines in the role of a contender as prime mover for surface warship propulsion.
4.5 The Early 1950's - The Work Of The Ship Design Coordinating Committee And Its Propulsion Panel

The problems of advancing an innovation in a large bureaucracy are well illustrated by the history of the Ship Design Coordinating Committee (SDCC). This Committee was established in early 1952 by the Chief of the Bureau of Ships. Its membership consisted of high ranking and very competent military officers and the civilian technical director of the Ship Design Code of the Bureau of Ships. This Committee was chartered with the broad task of studying significant issues related to ship design.

It is significant that many members of this Ship Design Coordinating Committee were senior officers from outside the Washington area. This was done to ensure an objective committee whose results would not be biased by the policies and the politics of the Bureau.

In addition to its broad charter, the Committee was directed to form panels to study specific ship design areas and to make specific recommendations for improvement. Four panels were established:

a. Main Propulsion Panel
b. Noise and Shock Panel
c. Electronics System Panel
d. Hull and Hydrodynamics Panel.

Through an examination of the SDCC's efforts to foster the adoption of gas turbines for naval ship propulsion, one can recognize several
of the political and organizational problems in large organizations which
directly bear on innovation adoption.

a. The power of consensus in obtaining support for recommenda-
tions

b. The effectiveness of committees in influencing innovation
   adoption

c. The effectiveness of organizational rivalries in thwarting
   innovation adoption

d. The difficulties in overcoming the conservatism inherent in
   large bureaucracies

e. The need for a strong influential champion to garner the
   political support required to see an innovation through to implementation.

The first meeting of the full Ship Design Coordinating Committee
yielded some general guidelines formulated from policy level recommenda-
tions by the Main Propulsion Panel. The subjects which were considered important
enough to be discussed indicate an extremely good understanding of the R&D
process in general and especially in the very large organization of the
U.S. Navy [4-45]. Some of these guidelines are summarized as follows:

a. Bureau codes were to work more closely with personnel from
   laboratories and civilian agencies in planning and developing main-propul-
sion projects and designs. It was felt that this would bring more expertise
to bear on the Bureau's work and would prepare laboratories to handle the
testing and evaluation of associated machinery and equipment.
b. Bureau codes were to make greater use of the Office of Naval Research outlets in research phases of problems in propulsion.

c. Existing designs were to be reviewed periodically to assume that they are not frozen for inordinate periods by the necessary demand of standardization for mobilization planning.

d. The Bureau was to capitalize on new ideas for both equipment and arrangements in each new design and was to consider the human factors involved.

e. The Bureau was to reemphasize and follow the policy requiring that major new developments in main propulsion should be subject to prototype evaluation, encompassing first laboratory and then shipboard evaluation. Shipboard evaluation was to be accomplished in a vessel designated as experimental during the evaluation.

f. Laboratory and Bureau officials were to visit appropriate foreign institutions for the purpose of studying those foreign research and development programs which have merit.

g. The Bureau was to follow a realistically austere policy of conserving critical materials by limiting their use in propulsion plants. The Bureau was also to make firm and consistent demands for the application of alloys to permit use of high-temperature cycles and improved components. This policy was to be implemented by close and early collaboration between machinery and materials development personnel in both the Bureau and the laboratories. Greater relative development effort was estimated to be required in blade-cooling schemes, use of ceramics, and improved metallurgical processes to meet the requirements of high-temperature cycles.
h. Criteria were to be established which could be used to evaluate alternative power plants for decisions affecting further development.

The results of the evaluation was going to determine what would be developed further. They considered two general groups of influencing factors:

a. Performance factors such as weight, space, and fuel rate.
b. Other influencing factors such as cost, critical materials requirements, procurability, and mobilization.

In spite of the positive action of establishing the guidelines, the committee failed to recognize many other factors which should have been influential in evaluating competing power plants; for example, in the case of gas turbines versus steam these could have been:

a. Improved potential for power plant automation
b. More flexibility in ship arrangements
c. Reduced space and weight devoted to ship propulsion
d. Improved power plant growth potential
e. Central stocking and rapid worldwide delivery by aircraft of complete engines or parts
f. Projection of a progressive image of the Navy as a service
g. Shift in dependency from a very small to a very large industrial base for support and further development of the power plant.
A meticulous process for disseminating information was to be followed to keep the various Assistant Bureau Chiefs informed so that they could comment on the work of the Committee and Panel.

The procedure for handling reports from the Ship Design Coordinating Committee and associated panels was as follows [4-46]:

"a. Interim reports are required for matters for which the chief might want to initiate some action by the Bureau

b. Information reports are required for subjects requiring a Bureau record but not involving further implementing action."

Each type of report was to be numbered serially by the Ship Design Coordinating Committee or the originating panel, then recorded and distributed in the official mail system. When panel reports were forwarded to the Chief (via the Ship Design Coordinating Committee) for endorsement, it was to state specifically the concurrence or nonconcurrence of the Ship Design Coordinating Committee.

Originals of interim reports were to be identified separately as "ACTION COPY" and were to be forwarded to the Assistant Chief concerned for comment and endorsement, who then sent it to the Chief (with copies to Ship Design Coordinating Committee and originating panel). The Assistant Chief of the Bureau concerned was then to initiate necessary actions based on the Chief's approval or disapproval, in whole or in part, of the report and the comments in the endorsement.
It is quite evident that the Chief understood well the politics of a large bureaucracy like the Bureau of Ships and was hoping that these explicit procedures would ensure an orderly process toward decisions.

The comments from the design and R&D organizations of the Bureau on the first report by the Main Propulsion Panel were indeed slow, though not unusually so in a bureaucratic setting (a factor in retarding innovation). In fact, the comments came a full, half year later.

In general, the design organization endorsed the report but pointed out very clearly the danger associated with an overly concerned attitude toward conservation of materials at the time of technology development [4-47].

The R&D organization considered it highly desirable that personnel from laboratories participate in meetings concerning future prospective main propulsion plants. It was pointed out that the Bureau had been criticized in the past by laboratory personnel for proceeding on a project without laboratory consultation and then calling upon the laboratory to "bail them out" by developing design changes during the test period. These calls for help usually occurred after a great deal of money had already been unwisely invested in the project and could have been avoided by having a laboratory evaluation made during the early design stages.

In July 1952, the SDCC met, at which time, then Captain Rickover made a presentation on the status of nuclear power for naval ships. He
discussed four programs [4-48]. Captain Rickover pointed out that nuclear plants had been considered for destroyers and destroyer escorts but that such plants would have greater advantages for carriers and submarines. He did not feel that other closed-cycle power plant developments should cease in view of the potential success of the nuclear program. He indicated that the AEC looked to the Navy to develop atomic power for the United States. Therefore, the plants were of dual interest: for naval power plants and prototypes for commercial power plants.

As a result of the July 30th meeting [4-49], the Main Propulsion Panel reached the following conclusions:

a. The number of nuclear power installations which would be authorized in the following 10 years would probably be limited.

b. Internal combustion installations would dominate the lower horsepower/ shaft field and would increase at a reasonable pace because of:
   1. Their inherent advantages
   2. Possibilities of CODAG and COGAG
   3. Inability of industry under mobilization conditions to produce steam plants at the required rate in the zone of medium horsepower/ shaft where steam might still be desired.

c. The Bureau was to initiate a comprehensive systems investigation to determine the ability of industry to produce, under mobilization conditions and in the times required, the propulsion systems required by the Navy integrated with the parallel requirements of MARAD, AEC, and industry. This investigation was to include major components peculiar to
modern steam propulsion systems such as boilers, valves and piping, turbines, reduction gears, and auxiliary machinery.

d. The Bureau was to initiate a survey into the allocation of fuels after mobilization.

e. The Bureau was to initiate a study of the feasibility of the segregation of low-vanadium fuels with the object of being ready to answer this question when a gas turbine was ready for operation on a selected residual fuel.

f. The Bureau was to continue to exert every effort to procure and to operate new propulsion plants at sea.

g. Shipbuilding was to be authorized to utilize the conversion of a satisfactory hull for the installation of newly designed propulsion plants in order to get rapid operating experience with these plants.

The Main Propulsion Panel studied [4-50] the status and the future possibilities of the following various power plant systems:

a. Steam Propulsion Systems - The primary short-term recommendation for steam propulsion was that the Bureau devote its major effort to the refinement of the main plant and the improvement of the auxiliaries of the 1,200-psi 950°F installations. It was agreed that steam would dominate the higher-powered field for at least 10 years. In support of the high-pressure system and for the long-range planning to benefit from industrial programs dealing with higher steam temperatures, it was recommended that a comprehensive R&D program be established at Naval Boiler Turbine Laboratory (NBTL) in Philadelphia primarily on boilers and associated
combustion problems, and secondarily on turbines. This recommendation was based on the lack of adequate incentive in industry to develop better steam generators or turbines for marine use.

b. Internal Combustion Systems — It was recommended that the then ongoing projects for development of a 3,000-hp or higher-powered diesel unit be pursued with vigor.

Evaluation of the "free piston" gas generator-gas turbine cycle was to be expedited to the point where, if warranted, the Bureau could be ready to design either a generator drive or a propulsion plant of this type for an auxiliary vessel.

The plan to convert aircraft jet engines to marine gas turbines was to be actively pursued. This was considered an excellent capitalization of NACA, BUAIR, Air Force and industrial progress for the Navy's purposes. Such gas turbines were urgently required to increase the available power range per unit from 4,000-hp, in steps up to possibly 15,000-hp, particularly for installation as booster units in combined power plant systems. In the interest of economy, it was recommended that major emphasis be placed on a unit in the 8,000-10,000-hp range. Selection in any case was to be based on a system which could serve as a propulsion unit for a small craft and as a booster unit for combined plants. A close liaison was considered important with those agencies engaged in blade materials, cooling, etc. to permit the Bureau to adapt their results to its gas turbine program at the earliest possible date.

It was recommended that one prototype closed-cycle gas turbine plant, utilizing residual fuel, be developed to serve as a prototype plant. It was further recommended that one prototype complex open-cycle gas turbine plant be developed for the same uses.
c. Combined Systems - Combined systems appeared to offer the greatest short-range promise of increasing speed within the existing limitations of weight and space. It was recommended that COSAG, CODAG, and COGAG be developed and that single vessel installations be accomplished. Specifically, the following was recommended [4-50]:

"COSAG. Adapt the Bethlehem Steel Company design, which the Navy funded, to a suitable vessel and install as soon as satisfactory laboratory evaluation of the booster unit was completed.

"CODAG. Design an installation and put it in a destroyer escort or other suitable vessel as soon as satisfactory laboratory evaluations of the base-load plant and booster unit were completed.

"COGAG. Design an installation and put it in a suitable vessel after satisfactory test of the base-load and booster units. Evaluate a closed-cycle and an open-cycle plant and make a comparison to determine the base-load plant in this combined installation in case authorization for both types could not be obtained."

d. Special Submarine Cycles - It was recommended that a single designation be adopted for the special submarine propulsion plants designated: Kreislauf, Alton, Wolverine, Ellis. The term "closed-cycle" was too frequently used with these plants which bore little, if any, relation to the orthodox closed-cycle gas turbine. It was doubted that any term was more descriptive than "special submarine cycles" and it was recommended for use in all Bureau correspondence relating to these plants.
Initiation of steps to develop the engineering necessary to use hydrogen peroxide as an oxidant in Ellis and Wolverine was recommended. These contracts were to cover prosecuting the design of these plants toward an actual submarine design for installation and to permit shifting to a shipbuilding contract when an appropriation became available.

The Panel recommended that evaluation of Ellis operating on oxygen be aggressively pursued. This plant, the Panel felt, could be of valuable assistance in the development of future, pressure-fired surface steam propulsion plants. After evaluation of operation on oxygen and satisfactory progress of the engineering study, it was concluded that a decision should be made for converting to operation on hydrogen peroxide.

It was also recommended that evaluation of Wolverine operation on oxygen be pursued with similar vigor. This plant was expected to be valuable in the development of future surface gas turbine propulsion plants. After evaluation of operation on oxygen and satisfactory progress of the engineering study, a decision was to be made for converting to operation on hydrogen peroxide.

Finally, it was recommended that evaluation of Alton be continued with equal energy to insure that one hydrogen peroxide plant would be in a satisfactory state of development when it was finally decided which plant would be installed in the submarine included in the FY 1954 tentative shipbuilding program.

e. Nuclear Propulsion - The Panel felt it inconceivable that all of the country's war requirements for high-speed submarines could be met by those having nuclear-power plants because of their high initial cost. It was unreasonable to assume that the inherently large
nuclear-powered submarine was necessary for all of the tactical uses envisioned at that time.

To reassure the Navy of the availability of high submerged speed, it was considered essential that some other new power plant be proven in a submarine. The importance of early evaluation of such a submarine made it desirable for the Bureau to support the authorization of one submarine in FY 1954 as planned.

To prepare for building a submarine (if authorized in the FY 1954 program) and to insure that a contract could be awarded by mid-FY 1954, the Bureau had several problems to resolve in quick succession: No nuclear power plant designed for ship use had been put into operation, and all authorized nuclear power submarines were considered experimental even by the nuclear-power project officers. Although an exceptional effort to achieve success on the first try was in progress, prudence and experience indicated otherwise. The Navy had often met with serious reverses when jumping from laboratory proof to service application even in relatively simple matters. The nuclear power plant was untried, completely new, very expensive and extremely complex. The Panel felt that authorization of a large, fast vessel to be driven by nuclear power, before ship operating experience had been gained even on a small one, involved grave risk.

The tremendous war and fleet potential committed in a large aircraft carrier made the assurance of the main propulsion power plant's complete success a matter of paramount importance. The Panel felt that minimum evaluation preceding the Bureau's commitment to build a nuclear-powered aircraft carrier should be required, including seagoing operation
on the submarine and shore operating experience with the single shaft plant already ordered.

The completion of the first nuclear submarine was scheduled for mid-FY 1955 and the operation of the single aircraft carrier shaft on shore was tentatively scheduled to commence in 1957. The Panel felt that the Navy should not commit to nuclear power in an aircraft carrier prior to successful evaluation of that shaft's worth of equipments ashore.

No significant action was taken on the Panel's recommendations until mid-December 1952, when the senior member requested that the overdue comments be submitted.

The organization responsible for the management of naval shipyards at the Bureau responded [4-51]:

"The type of studies recommended are comprehensive and time-consuming. With the limited personnel that is available in the Bureau of Ships for this work, as well as in the other agencies with similar component requirements who must participate in such studies, it is estimated that a minimum of one year would be required to complete the basic investigations. This minimum estimate of time is based on the optimum participation of Bureau of Ships and other agency personnel and would require full support and assistance from Bureau of Ships personnel, other than those in the Field Activity Divisions. However, it is concurred that such studies are essential and should be made."

Another concern of the headquarters organization for naval shipyards was the industry's capacity to manufacture propulsion plant components. Specifically, they felt that the Bureau should initiate joint investigations
and surveys with representatives of MARAD, AEC, industry, and other Department of Defense mobilization planning agencies for those major components which had a known or apparent production capacity deficiency. At the time, such a project would have involved investigations into turbine and gear production capacity, since a similar boiler survey was already underway. They also felt that the Bureau should develop "dollar feasible" program requirements for the other principal steam main propulsion components. Previous Production Allocation Planning had indicated a questionable adequacy of mobilization production capacity. If production deficiencies did exist in these items, corrective action consistent with the funds allocated was to be taken.

Simultaneous with the steam component investigation, it was recommended that similar investigations of the major components for diesel plants be conducted. The components to be investigated included diesel engines, main switch gear, main motors and generators, and gears.

The proposed effort left out consideration for gas turbines, nuclear or combined plants [4-51]. Their exclusion may be taken as indicative of the lack of confidence in the eventual development of these power plant types. Lack of confidence was definitely a factor in retarding the development and adoption of these innovations. (Save nuclear power which had its successful champion, Admiral Rickover.)

Both R&D Planning and the design organizations commented on the Propulsion Panel's second report [4-52], [4-53]. The R&D Planning Division
suggested the development of heavy distillate fuel from shale oil deposits in Colorado as a possibility for use in gas turbines, as well as steam plants. Also pointed out was the potential problem of vanadium and sulfur in fuel for high-temperature gas turbine operations.

It was also correctly observed that when propulsion system tests are funded from shipbuilding appropriations, there is a tendency to make unrealistic commitments resulting in embarrassing shipbuilding delays. Therefore, it was questioned whether to fund from R&D or to arrange administratively for the shipbuilding schedule to be made contingent upon successful development of prototype components. The answer, it was felt, depended upon the urgency for completion of the ships.

The Bureau's design organization endorsed the continued development of the closed-cycle submarine power plants, one of the Wolverine type and one of the Ellis type. They expected the manufacturing and operational experience gained in building the 1,200-psi machinery plants for the CVA 59 and the DD 931 class destroyer to provide the manufacturing "know-how" for constructing a high pressure-temperature steam plant and thereby guide future developments. It was anticipated that the results of tests already scheduled at NBTL for the CVA 59 boilers would furnish information as to the logic and wisdom of going to higher steam temperatures for future designs. It was also pointed out that:

a. In the past, the Machinery Design Branch and the Diesel Branch had indicated the feasibility of constructing high speed
lightweight diesels in the 8,000-10,000-hp range but this effort was not
funded.

b. The development of a "free piston" gas generator had been
underway as a Machinery Design R&D project for some time. A unit developed
by Baldwin-Lima-Hamilton under that project was undergoing a five hundred
hour endurance test, and the results of that test were expected to be
available shortly.

c. The Bureau had a contract with Westinghouse Electric Corp.
to convert the J40 jet aircraft engine into a 7,500-hp marine gas turbine
for installation in a COSAG plant. It was felt that a successful marine
booster type gas turbine would be obtained only by a specific development.
Conversions and modifications always impose compromises. For example, the
J40 had a very high relative air rate which was undesirable in a marine
unit.

d. It was recommended that a project be initiated to design a
closed-cycle gas turbine of about 8,500-hp for installation in an auxiliary
vessel and to develop an air heater for use with this turbine.

e. The Bureau had requested preliminary proposals from inter-
ested manufacturers for the development of a 10,000 shp complex, open-cycle
gas turbine.

f. A contract had been signed with Bethlehem Steel Company to
design and prepare specifications for a COSAG installation in a DD 931
class ship. It was planned to install and test one shaft's worth of this
installation at NBTL.

g. The Bureau had planned to install the converted J40 booster
gas turbine in a CODAG installation; however, since the prospects for
COSAG appeared better at that time, CODAG had been limited to a design
study. Preliminary study indicated that the division of power for a DE 1006 class ship was not proper because the diesel engines under development were rated at 3,200 bhp and the gas turbine was of 7,500-hp size.

h. The development of COGAG had been expected to follow the successful application of a booster type gas turbine in COSAG and the development of a base-load gas turbine plant, either open- or closed-cycle.

On March 20, 1952 (about one year after the establishment of the SDCC and its panels), the anticipated bureaucratic action of lessening the disturbance of ongoing efforts and the surfacing of potentially embarrassing issues to high levels in the organization, resulted in a request by the design organization for a change in the procedure of report submissions by the panels of the SDCC. The change requested was [4-54]:

"That Panel reports to the Assistant Chiefs involved contain advance information only and official reports to the Chief of the Bureau, on which the Assistant Chiefs must comment, be forwarded to the Assistant Chiefs via the Ship Coordinating Committee itself. The purpose of this is to obtain the coordination of the Ship Design Coordinating Committee of recommendations of Panels and screening of Panel recommendations by the Committee as a whole. The Ship Design Coordinating Committee should sit over all of the panels exactly as the Ship Structure Committee sits over its subcommittees, and final official reports to higher authority should be screened by and bear the approval of the Committee, itself. This would have another advantage in that the volume of paper that has to be passed to the Chief with comments on every item may be reduced, such reports being restricted to those items of the panel reports which carry the approval of the Ship Design Coordinating Committee itself. The panels work for the Committee as a whole. The Committee may not and, in many cases, will not, concur with the panel report."

123
In 1972, the Technical Director of the Machinery Division told the author that the best tactic to have a problem disappear is to cause delays in response, thus preventing a decision; and by the time the subject eventually surfaces, the need may vanish. The previous quotation resembles that tactic.

At times, the Panel was used independently to evaluate a design decision. The Panel's seventh report dealt with a design decision regarding the steam turbine configuration to be selected for the upcoming first introduction of the 1,200-psig/950°F steam conditions into a destroyer (DD 931 class) and a future carrier (CVA 59). The case in point was the two-casing series-parallel turbine design as opposed to the conventional system with a cruise turbine.

Turbines built to that basic design had been in operation in the German Navy for over 10 years in sizes up to 50,000 shp/shaft and with comparable steam conditions. Available records indicated no appreciable difficulties except with the middle and end packing glands because of rigid mounting, and too-close clearances caused by an attempt to obtain maximum efficiency. This was verified by an employee of the Naval Boiler and Turbine Laboratory who had shipyard experience with these installations in Germany during the war. The Panel studied the problem and concluded that the packing gland difficulties experienced by the Germans with turbines to this basic design had already been corrected by features incorporated in both the General Electric Company and Westinghouse Electric Corporation designs. They recommended going ahead with the DD 931 and CVA 59 designs, testing both at NBTL. In a memorandum for file, the Chief
of the Bureau recorded his decision to go ahead with the two-casing series-parallel turbines. His memorandum is revealing as to the required ingredients for the success of a significant innovation within a large government organization [4-55]:

"I have reviewed the correspondence pertaining to the new design of propulsion turbines for the CVA 59 and the new destroyer, and I have gone over the minutes of our conference on this subject held in the Bureau on 30 January 1953. I find such preponderance of opinion in favor of proceeding as we are that I can find no adequate justification whatever to discontinue the proposed new design and revert to the old design. It is therefore my decision that we shall proceed."

The chances of an innovation that does not have "a preponderance of opinion in its favor" would appear slim. The Chief felt compelled to back up this decision in spite of the "preponderance of opinion" with further elaborate justification [4-55]:

"a. While we must assuredly have reliability of performance in our new ships, especially the CVA 60, naturally we must not sacrifice important steps of progress because we cannot be certain of 100 percent reliability, else, there would be no progress.

b. Sufficient evidence has not been presented to indicate that the new design of turbine will be lacking in reliability. On the other hand, it is anticipated that in some respects reliability will be enhanced, - at least inherent difficulties hitherto encountered in old design are expected to be alleviated.

c. This step forward in progress promises much to the Navy although we cannot guarantee that the new design will be free of all difficulty. Similar steps forward in the past have been fraught with some difficulty. It is anticipated that these difficulties will be removed and that we shall end up
with a superior installation, - superior in performance, in simplification of arrangement, in weight and space, etc.

d. Mobilization requirements are of course important. The new design will reduce considerably the number of units required to meet mobilization needs. That is significant because of the great shortage of turbine capacity in the country in comparison with mobilization requirements.

e. The representative of General Electric Corporation expresses reasonable confidence that the new design will be successful and he bases his confidence upon successful operation of similar shore based installations. The representative of Westinghouse likewise also expresses reasonable confidence although he has not had similar operating experience."

The further emphasis by the Chief pertaining to unanimity of opinion from the broad community involved certainly raises concern in the mind of a potential innovator [4-55]:

"Into this problem has been brought the best thinking of many turbine-experienced officers and civilians within the Bureau of Ships organization. In addition to the Engineering Experiment Station, Annapolis, the Boiler and Turbine Laboratory, Philadelphia, the David Taylor Model Basin, and the Main Propulsion Panel of the Ship Design Coordinating Committee have considered this problem very carefully. The unanimous agreement of all these persons who are experienced in machinery design and operation is that the Bureau should proceed with the new design.

"To hold up this forward step would mean the loss of several years. Certainly before the design can be produced and service-tested four or five years will probably have gone by. This is too great a loss in time in view of the unanimous opinion of BUSHIPS experts that the new design has every promise of being successful. We simply must accept some risk in order to take this important step of progress."
Main Propulsion Report No. 4 was published in 1952. It addressed the development of high horsepower range medium speed diesels [4-56]:

"It is recommended that the Bureau reassess its requirements for diesel engines in the approximate range of 8,000-10,000-hp/engine both as a primary choice of prime mover and as a mobilization alternate for steam turbines. If the need for such a diesel engine is verified, it is then further recommended that development and design of a diesel engine be conducted in the subject hp range and in the medium speed-medium weight class to meet naval requirements."

The design division concurred with the Panel's recommendation and supported it [4-47].

The bulk of American diesel engine production capacity at that time was limited to the production of high-speed lightweight engines of not more than 2,500 bhp. For main propulsion plants requiring more than 2,500-hp per shaft, the following alternatives were available to meet prospective requirements:

a. Two or more engines connected through a reduction gear to the shaft

b. Diesel electric drive using multiple diesel engines as required to supply needed power

c. Installation of low-speed, heavy, direct-drive diesels of the power required.

None of these solutions was ideal because of their space and weight requirements, and cost. A review of foreign and domestic engines
in the 8,000-10,000-hp range showed that all those available were of the low-speed lightweight type. They were too big for any destroyer type of ship.

In the event of mobilization, it was anticipated that the production capacity of American turbine and gear manufacturers would be entirely absorbed in producing main propulsion plants for combatant ships and possibly for merchant ships. If this assumption was correct, it appeared necessary to develop propulsion systems that did not use these production facilities for the many auxiliary ships required. In 1952, the actual and potential production facilities of diesel engine manufacturers offered the best solution to the problem of supplying the required alternate propulsion units.

The closed-cycle gas turbine plant offered another solution to the problem but had certain disadvantages which made its choice undesirable. First, such a plant required turbines and compressors which would cut into turbine manufacturing capacity. Second, it was highly probable that all available gas turbine capacity would be absorbed by mobilization requirements for aircraft engines.

In late 1952, the Ship Design Coordinating Committee issued a report in reference to PT boats and their future development. Although PT boat operations during World War II were largely confined to temperate and tropical zones, the board felt that future PT boats should be designed for all ice-free coastal waters. The Panel also recognized that more electronic
equipment was being put on them and that, even in World War II, they were used mostly as gunboats and not torpedo boats. The PT boat was being replaced by the gunboat, which is now the missile-gunboat.

From a propulsion viewpoint, it is important that the Committee recognized hydrofoils as a potential hull form for the missile-gunboat in the future. By necessity, such a craft is much more sensitive to weight, thus, they would create a "requirement pull" for development of gas turbines. The closing paragraph of the report stated [4-58]:

"Propulsion by gas turbines should be fully considered on the basis of the direct advantages that may be obtained, on the basis of reduction of danger of fires resulting from elimination of gasoline as a fuel and the reduction in over-all requirements for critical high-octane gasoline on mobilization. If this decision is made, the boats should be designed from the beginning for gas turbines in order to make maximum use of their characteristics and avoid resorting to unnecessary compromises that ordinarily follow conversion restrictions."

The comment from the design organization was brief [4-59]:

"Concur that gas turbine propulsion should be fully considered; however, the disadvantages associated with high fuel rates at cruising speeds, the weight penalties of cruising engine installations, and the necessity for operation at idling speeds will require solution or a compromise in the characteristics."

The crux of a new design PT, either for a future naval ship-building program or for mobilization, appeared to be the choice of power plant. Even though gas turbines appeared to be the answer, the selection
was not that simple. The V16 cylinder gasoline engines were used in PT 809 through PT 812, a postwar development by Packard; 40 engines were built. Of these, 16 were installed in PT 809 through PT 812; 11 were in overhaul or spare status for these PT boats, and the remaining 13 in Scotia. The production line for these engines had been dismantled. It could only be reestablished for quantity production at a cost between $12 million and $14 million. The Metro Vick G2/2 gas turbine was in the process of being procured for experimental installation in PT 812. This was another power plant possibility for a new PT design, but until the engine had been evaluated, it did not seem prudent to plan a ship design around this type of installation. Delivery of these gas turbines was scheduled for mid-1954. It would have been the middle of 1955 before preliminary evaluation was available.

It was not until 1965 that the gas turbine was adopted for a non-experimental conventional hull gunboat, but it was this type of craft which became the first U.S. naval vessel, the PG 84 class, to have operational experience with gas turbines as main propulsion prime movers. The British by that time (1953) had had a motor gunboat using gas turbines for 5 years and less than four years later committed a whole new class of 6,000-ton destroyers to a combined steam-gas turbine (COSAG) power plant.

By the latter part of 1953, two American "free piston" gas generators had reached the stage of development where they appeared to be ready to be considered practical for installation. They were the Baldwin-Lima-Hamilton (BLH) 400-hp to 500-hp Model DL gas generator and
the Cooper Bessemer (CB) 1,500-hp Model R gas generator turbine plant. These units were to be used as follows:

a. Installation of one BLH Model DL unit in a PCS 1376 class vessel

b. Installation of a CB Model R into an ATA 174 class B rescue tug

c. Design and construction of a plant suitable for installation in an AM 421 class vessel. This plant was to be based on the Model DL.

The Main Propulsion Panel dealt with the "free piston" gas turbine in its ninth report and recommended that more detailed studies be made on the subject with respect to installations into AD's, AR's, and AS's. The Panel concluded that the "free piston" gas turbine had the potential of savings in machinery space, weight, and operating personnel. Since the three aforementioned types consume more fuel while in port than while underway, it was felt that a "free piston" gas generator-turbine installation could improve the situation by providing a machinery plant with high efficiency both underway and in port. The machinery plants installed at that time in these vessels were primarily designed for good underway efficiency. Because of their inherent characteristics, the efficiency of the plant in port was poor. The "free piston" gas generator-turbine installation for both main propulsion and auxiliary power was to be coupled with a waste-heat boiler for auxiliary steam and evaporator requirements. The specific advantages as seen by the Panel were [4-60]:

131
"a. Fuel economy in port approximating that of underway, yielding maximum annual fuel economy.

b. Resultant economy better than the cost differential between diesel fuel and Navy special fuel.

c. Better lubricating oil economy than diesels.

d. Rugged and simple installation.

e. Release of space and weight due to fuel economy (for same endurance) for other purposes."

The Bureau compared steam, diesel, and the "free piston" gas turbine in an 8,500-hp application [4–61]. The diesel installation had an approximate weight per shaft horsepower of 273 pounds, the steam plant an approximate weight per shaft horsepower of 210.5 pounds, and the "free piston" had an approximate weight per shaft horsepower of 175 pounds. Since the "free piston" was a relatively new prime mover at the time, this initial decrease in overall weight was considerable, especially considering many possibilities to improve the overall characteristics of the "free piston" engine.

The design organization's reaction was positive and demonstrated that it had given the concept of "free piston" gas turbines considerable thought [4–62]. However, nothing practical developed.

The Main Propulsion Panel's 11th report addressed the evaluation of new developments and the dissemination of information, a very important aspect of the innovation process. The Panel complained that formal evaluations, final reports, or comprehensive statements of objectives did not
appear to exist for many of the propulsion development projects. It was feared that the TIMMERMAN Project could suffer the same fate, although a private firm had been awarded a contract to oversee the conduct of all analyses and the preparation of reports.

The Panel attributed the problems to: the changing personnel in both the Bureau and OSPANV who injected different requirements and views into unfinished projects without thorough analysis of causes and effects; to a lack of a formal well-circulated statement of each project's objectives; to the failure to become "operational" at the earliest possible date; and to the over-classification and failure to remove or lower the security classification at the appropriate time.

Therefore, the Panel recommended [4-62]:

"a. That the major main propulsion and associated developments be assessed, and periodically reassessed as to security classification and as to additional information which may be given increased circulation.

b. That comprehensive statements of objectives of these developments be prepared in specific terms understandable in nonscientific quarters.

c. That approximately annual meetings be held in the Bureau to acquaint appropriate personnel of OSPANV and the Secretary's Office with the objective and status of such projects without security restriction. Such meetings will stimulate preparation of interim evaluation reports. Interim evaluation reports should be prepared approximately annually regardless of meetings."

The design organization concurred with the recommendation of the Panel but in connection with TIMMERMAN, the major experimental ship project
at that time, the trial agenda had already been prepared and promulgated to the activities concerned. These trials were to be carried out under the operation control of the Commander, Operational Test and Evaluation Force (COMOPTEVFOR). Results of specific trials and tests were to be reported on a continuing basis over a period of approximately three years. At the completion of these trials, a summary report was to be prepared.

In preparing its twelfth report on 24 September 1953, the Panel considered the history of the Bureau's gas turbine projects along with units available and further developments which appeared feasible at that time. The multiplicity of possible developments and applications was so great that a firm, comprehensive gas turbine program appeared essential to promote economy. Such a program, the Panel felt, would also afford information to assist the management at the gas turbine testing facilities at the Engineering Experiment Station (EES) and at NBTL.

The Panel thought that gas turbines had great promise as prime movers. They also believed that gas turbines should not be adopted solely for a change nor denied for any single characteristic. Gas turbines were to compete with other prime movers based on complete evaluation of their relative advantages and disadvantages. The Panel felt that neither gas turbines nor nuclear propulsion would supplant all other prime movers in all ranges in the near future. On this basis, they felt that (except for small craft) the use of gas turbines for boosters, either COSAG or CODAG, promised to be the most valuable application for naval main propulsion for a short range (five years) program. The Panel thought that
gas turbines could also be expected to have healthy growth in the area between large diesels and small steam turbines, in small craft, and for generator drive. The Panel urged that a number of gas turbine installations of different types and applications be produced. Their production would develop operating experience with naval personnel and develop confidence in this type of prime mover. The Panel's proposed gas turbine program is shown on Table 4-8. It was submitted to the SDCC for consideration, along with their other recommendations.

At the SDCC's meeting in September 1953, issues regarding all of its panels were discussed [4-64]. While this study is concentrating on the Main Propulsion Panel's work, it is important to consider several interesting points made during the Committee's general discussions by other sources.

One member suggested that it appeared appropriate to review the accomplishments of the Committee to date, specifically whether concrete results stemming from Committee reports and recommendations were proportional to the time and effort devoted to their preparation. The chairman pointed out that, of the recommendations put forward by the Main Propulsion Panel, only the series-parallel turbine appeared to have been acted upon by the Bureau. The chairman stated that possibly other reports had been acted upon without the Committee's knowledge, but since there was no established procedure to inform the Committee of action, either initiated or intended, he did not know that the Committee's recommendations were not always received with favor in the Bureau. Considerable care was to be
TABLE 4-8 PROPOSED GAS TURBINE PROGRAM

I. OPEN CYCLES
   a. COSAG
      (1) It is recommended that this current development and installation proceed with all practicable speed using the booster unit now selected. It is further recommended that this type of propulsion be installed in a DD in the FY 1954 building program. If this should not be approved, it should be planned for a DD in the FY 1955 building program.
      (2) In connection with further development for additional installations it is recommended that:
         (a) Alternate improved booster units be investigated.
         (b) A feasibility study confirms the requirement, a booster unit in the 12-15,000 H.P. range should be selected for installation in vessels with larger H.P./shaft than DD's as soon as a satisfactory jet engine is available.
         (c) New booster units will require laboratory evaluation but no further complete COSAG laboratory evaluation should be necessary pending results of presently planned tests at NREL.
   b. COSAG. This type of plant offers many of the advantages of COSAG with, however, a probably more limited field of application. Provided a thorough feasibility and application study including careful evaluation of tactical use, speeds, etc., support COSAG, its early development and installation is recommended. The PT 812 will furnish considerable information and experience.
   c. "Free Piston" Gas Generator-Turbine. The following applications of this type should proceed with all practicable speed when authorization can be obtained supported by feasibility and application studies.
      (1) Presently studied installation on one shaft of a PCS.
      (2) Repair ship or tender installation.
      (3) Mine sweeper prototype.
      (4) Small landing craft prototype.
      (5) Tug.
   d. Small Craft Propulsion. Small craft present a broad field for the application of gas turbines to prove the units as such and to enhance the operating characteristics of the craft. Several possibilities exist for the Allison 510-B-1 2,000 HP unit and the Solar T-522 HP unit now available. These possibilities and others are outlined in Code 541 memo Serial 541-094 dated 4 September 1952 which may serve as a basis for more thorough feasibility and application studies which are recommended for early accomplishment.
   e. Generator Drive
      (1) This application should be available for early operating experience. Code 541 memo Serial 541-0102 dated 28 October 1952 outlines many possibilities as a basis for more thorough feasibility and application studies which are also recommended for early accomplishment.
      (2) It is recommended that a feasibility study be made based on driving half the generators on a major vessel with steam turbines and half by gas turbines. Provided such study is favorable development of a suitable gas turbine for generator drive is recommended in the indicated power range, probably between 1,000 and 1,500 shp.
   f. Complex Open-Cycle Gas Turbine. Development of this unit for approximately 10,000 hp/shaft should proceed for future application as the sole propulsion unit and as a COGAG base load unit as soon as supported by a feasibility and application study.

SOURCE: REF [4-64]
II. PRESSURIZED CYCLES

a. Semi-Closed Cycle. Project WOLVERINE is of this type and was originally visualized for modification to surface ship propulsion. It is recommended that such study be instituted and development of feasibility studies progressed for application to:

(1) Escort vessels.
(2) Auxiliary vessels.
(3) Base load unit for COGAG.

b. Closed Cycle. The development and installation of a closed cycle gas turbine in a suitable vessel is recommended to take advantage of its part load characteristics provided feasibility and application studies are favorable. This type of propulsion should be considered for the following possible applications:

(1) Auxiliary vessel.
(2) With nuclear heat source.

The early initiation of a development project for a suitable air heater is recommended.

III. COROLLARY DEVELOPMENTS

The development of the following corollary projects supporting the foregoing gas turbine projects should proceed in so far as they directly support the primary projects.

a. Blade cooling
b. Improved materials
c. Components
d. Fuels.
taken to insure that the Committee's judgments would be based on full information, carefully weighed, and that the reports and recommendations should be put forward tactfully and in a constructive vein. It was generally agreed that, while evidence of concrete action in the Bureau was not plentiful, the Committee did have indirect influence merely by a general awareness of its presence and function, and direct influence through its reports and the discussion they aroused. Therefore, the time and effort devoted by the Committee and its panels to various problems was amply justified.

The Committee next discussed a suggestion by one of the Bureau's organizations which recommended that they be permitted to attend Committee meetings as observers. The Committee felt that the presence of such observers would inhibit free discussion. Accordingly, it was decided that Bureau personnel would attend Committee meetings only when specifically invited.

The issue of bureaucratic delay tactics was also raised at the meeting. Interim Reports No. 6 (Special Submarine Cycles) dated June 5, 1953 and No. 7 (Single Versus Twin Screw Propulsion for Submarines) dated June 5, 1953, still had not been endorsed by the Ship Design Organization of the Bureau by that time, more than three months after their distribution. The Committee felt such long delay was most undesirable and was not consistent with the purpose for which the Committee was formed. If the Committee's recommendations were to have timely influence, they should receive prompt attention in the Bureau.
In addition, Interim Report No. 12 (Gas Turbine Program) dated September 14 was ready for Committee action. Copies were distributed to all members.

In the same meeting, it was also decided that the Committee should hear the Machinery Design Branch presentation on propulsion projects before discussing the endorsements. The Committee asked for information regarding the curtailment of Project Ellis which was of particular interest since the Committee had recommended that Ellis be continued. One of the members said that the curtailment resulted from the unwillingness of CNO to provide sufficient funds to continue Ellis at that time. He explained that CNO seemed to feel that there was no operational requirement for this type of propulsion plant.

The head of the Machinery Division of the Bureau briefly outlined the Bureau's approach to the problem of advancing the design of new propulsion plants. The discussion which followed centered around three topics:

a. The COSAG power plant development for destroyers
b. The "free piston" gas turbine development program
c. Status and proposed steps for the development of gas turbines suited for naval ships.

COSAG was being studied for two applications, both the DL 4 destroyer (80,000 shp) and the DD 931 class destroyers. Results of this
study showed that there was a weight saving of 186 tons and a 26 percent reduction in space requirement. An increased cruising radius was effected because of the increased fuel capacity. By dividing the power equally between the steam and gas turbine boost engines, 80 percent of maximum speed was achieved with conventional steam machinery alone. It also had the gas turbine's rapid start feature in case of emergency. The only disadvantages seen were the need for two kinds of fuel and the increased boiler loading.

In the DD 931, the power was to be increased from 70,000 to 80,000 with a resulting increase of speed of as much as 1.5 knots. The cruising radius would also increase 15 percent for the same reasons as in the DL 4.

The schedule at that time was envisioned as:

a. Final DD 931 Design Study – 1 November 1953
b. Complete delivery of all hardware – September 1955
c. Commence tests at NBTL – February 1956
d. Completion of tests at NBTL – February 1957.

As for the Bureau's program on the "free piston" gas turbine, the installation of one BLH Model DL gas generator-turbine plant in a PCS 1376 class vessel was in the planning stage. Funds for the equipment had been allocated and construction of the gas generator and turbine was expected to commence about November, 1953. Actual installation in the vessel was
tentatively scheduled for March, 1955; however, CNO authorization and shipbuilding conversion funds had not yet been made available.

At the Engineering Experiment Station, the BLH Model B gas generator with a supercharging unit was in the testing phase.

A feasibility study was in the process of outlining a complete "free piston" installation, including both propulsion and electrical generator, in an AM 421 class vessel.

The machinery division suggested extending the work on this area substantially by a long list of additional tasks [4-65]. Table 4-9 lists the various gas turbines which were under consideration by the Bureau, together with the proposed and possible installations.

An equally important area of discussion led by the Machinery Division was organizational in nature. This pertained to the establishment of a separate gas turbine organization in the so-called Ship Technical Division (versus Ship Design Division). At that time, the responsibility for the gas turbine program was divided between the Ship Design Division and the Ship Technical Division. The Bureau of Ship's Administrative Manual listed several Ship Design Division objectives which pertained to gas turbines. Those objectives included the responsibility for initiating research and development projects relating to ship design, construction and propulsion, and for developing basically new propulsion systems for application to surface and submarine vessels. The objectives further
<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Cog. Buships Code</th>
<th>Mfg's Model No.</th>
<th>Rated Horse Power</th>
<th>Application</th>
<th>Proposed Installation</th>
<th>Existing Engine</th>
<th>Existing Installation</th>
<th>Date When Available For Shipboard Installation</th>
<th>Possible Future Installations (Subject to Design Study)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Aircraft Co.</td>
<td>541</td>
<td>T-45</td>
<td>45</td>
<td>Fire Pump Drive</td>
<td>All Ships</td>
<td>Yes</td>
<td>No</td>
<td>Nov</td>
<td>PT Small Craft</td>
</tr>
<tr>
<td>Solar Aircraft Co.</td>
<td>541</td>
<td>T-45</td>
<td>45</td>
<td>Generator Drive</td>
<td>(1)</td>
<td>Yes</td>
<td>Yes</td>
<td>Nov</td>
<td>LFT</td>
</tr>
<tr>
<td>Boeing Aircraft Co.</td>
<td>541</td>
<td>502-2.3</td>
<td>160</td>
<td>Propeller Drive</td>
<td>LCVP, MSL</td>
<td>Yes</td>
<td>Yes</td>
<td>Nov</td>
<td>Emerg. Gen. Drive, 50' MSL</td>
</tr>
<tr>
<td>Solar Aircraft Co.</td>
<td>541</td>
<td>502-6</td>
<td>160</td>
<td>Generator Drive</td>
<td>MSL</td>
<td>Yes</td>
<td>Yes</td>
<td>Nov</td>
<td>Emerg. Gen. Drive</td>
</tr>
<tr>
<td>Solar Aircraft Co.</td>
<td>541</td>
<td>T-600</td>
<td>300</td>
<td>Generator Drive</td>
<td>DD 828</td>
<td>Yes</td>
<td>Yes</td>
<td>Nov</td>
<td>Enum. Gen. Drive</td>
</tr>
<tr>
<td>Solar Aircraft Co.</td>
<td>541</td>
<td>T-520</td>
<td>500</td>
<td>Generator Drive</td>
<td>MSL</td>
<td>Yes</td>
<td>No</td>
<td>Dec 1953</td>
<td>Emerg. Gen. Drive, 50' MSL</td>
</tr>
<tr>
<td>Solar Aircraft Co.</td>
<td>541</td>
<td>T-522</td>
<td>500</td>
<td>Propeller Drive</td>
<td>40' AVR</td>
<td>Yes</td>
<td>No</td>
<td>June 1954</td>
<td>MSL</td>
</tr>
<tr>
<td>Solar Aircraft Co.</td>
<td>541</td>
<td>T-500</td>
<td>500</td>
<td>Experimental</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(Water cooled turbine blade design)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(Not for installation)</td>
</tr>
</tbody>
</table>

II. GAS TURBINES UNDER DETAIL DESIGN CONSTRUCTION OR TEST FOR SHIP PROPULSION

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Cog. Buships Code</th>
<th>Mfg's Model No.</th>
<th>Rated Horse Power</th>
<th>Application</th>
<th>Proposed Installation</th>
<th>Existing Engine</th>
<th>Existing Installation</th>
<th>Date When Available For Shipboard Installation</th>
<th>Possible Future Installations (Subject to Design Study)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metropolitan</td>
<td>541</td>
<td>G.2/2</td>
<td>4,000</td>
<td>Propeller Drive</td>
<td>PT 832</td>
<td>Yes</td>
<td>No</td>
<td>Sept 1954</td>
<td>(5)</td>
</tr>
<tr>
<td>Rolls Royce Ltd.</td>
<td>541</td>
<td>RM 60</td>
<td>6,000</td>
<td>Propeller Drive</td>
<td>DT (PMR)</td>
<td>Yes</td>
<td>No</td>
<td>Dec 1954</td>
<td>(5)</td>
</tr>
<tr>
<td>Baldwin-Lima Div. G.M. Corp.</td>
<td>430</td>
<td>DL</td>
<td>405</td>
<td>Propeller Dr.(6)</td>
<td>PC 81376 class</td>
<td>Yes</td>
<td>No</td>
<td>(7)</td>
<td>APA, AM, 250kW Ship Serv. Gen. Drive</td>
</tr>
<tr>
<td>Allison Div. G.M. Corp.</td>
<td>541</td>
<td>510-B-1</td>
<td>2,000</td>
<td>Propeller Drive</td>
<td>None Selected</td>
<td>No</td>
<td>No</td>
<td>Dec 1954</td>
<td>PCB, 62' AVR (8), Hydrofoil Boat</td>
</tr>
<tr>
<td>Westinghouse</td>
<td>436</td>
<td>Wolver-</td>
<td>7,500</td>
<td>Prop./Gen. Drive</td>
<td>SSK (10)</td>
<td>Yes</td>
<td>No</td>
<td>(11)</td>
<td></td>
</tr>
<tr>
<td>Westinghouse</td>
<td>541</td>
<td>J-40-8E-2</td>
<td>7,500</td>
<td>Propeller Drive</td>
<td>DD &quot;COSAG&quot; (9)</td>
<td>No</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Westinghouse</td>
<td>436</td>
<td>Wolver-</td>
<td>10,000</td>
<td>Propeller Drive</td>
<td>SSK (12)</td>
<td>No</td>
<td>No</td>
<td>(13)</td>
<td>DE 1006</td>
</tr>
<tr>
<td>(14)</td>
<td>541</td>
<td>10,000</td>
<td>Main Prop. Plant</td>
<td>DE 1006</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td></td>
<td>Booster Unit</td>
</tr>
<tr>
<td>(15)</td>
<td>541</td>
<td>7,000-10,000</td>
<td>Propeller Drive</td>
<td></td>
<td>No</td>
<td>No</td>
<td>No</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

III. GAS TURBINES UNDER CONSIDERATION OR PRELIMINARY DEVELOPMENT

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Cog. Buships Code</th>
<th>Mfg's Model No.</th>
<th>Rated Horse Power</th>
<th>Application</th>
<th>Proposed Installation</th>
<th>Existing Engine</th>
<th>Existing Installation</th>
<th>Date When Available For Shipboard Installation</th>
<th>Possible Future Installations (Subject to Design Study)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Westinghouse</td>
<td>436</td>
<td>Wolver-</td>
<td>10,000</td>
<td>Main Prop. Plant</td>
<td>DE 1006</td>
<td>No</td>
<td>No</td>
<td></td>
<td>Booster Unit</td>
</tr>
<tr>
<td>(14)</td>
<td>541</td>
<td>10,000</td>
<td></td>
<td>Propeller Drive</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(15)</td>
<td>541</td>
<td>7,000-10,000</td>
<td></td>
<td></td>
<td>No</td>
<td>No</td>
<td>No</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NOTES:
(1) Generator not selected  
(2) Dependent on selection of generator (9% kW)  
(3) Superseded by Model T-520  
(4) Engine being built for Buships by Rolls Royce  
(5) Continued production not planned  
(6) "Free Piston" Gasifier Plant  
(7) Experimental Unit being tested at Lima-Hamilton  
(8) 40' AVR - Air Sea Rescue Boat  
(9) Machinery Design Study for DD 931 Class Completed by Bethlehem Steel Co. Contract No. 3445  
(10) "Closed Cycle" Submarine Plant  
(11) Experimental unit to begin test at HUBERS, March 1953  
(12) For surface and snorkel operation only  
(13) Present status: design studies in preparation by Code 430 and Westinghouse  
(14) & (15) Not selected.

This list does not include component development projects such as elimination of critical materials, residual fuels, aerothermopressor, etc.
stated that the essential component units for the new propulsion systems were to be developed in collaboration with the appropriate technical branches. The Administrative Manual then listed the following objective for the Ship Technical Division: design and develop ship components which were under the Ship Technical Division's cognizance. The main point of distinction between the objectives of the ship design and technical design seemed to be whether the development was for a component unit or a system.

In the case of the gas turbine, there was no clear division of authority. The component units of the gas turbine could not be considered individually because each one was dependent on the other. This relationship of component units necessitated that the gas turbine be considered a complete power unit. Therefore, its development and production had to be directed and guided by one group. This need was further exemplified by private industry manufacturing processes. Steam turbine manufacturers did not ordinarily design and build boilers, but the gas turbine was usually built or assembled by one firm. At that time, both the Ship Design Division and the Ship Technical Division were handling projects which, according to the Administrative Manual, belonged to the other division. To avoid confusion, the following recommendation was made [4-65]:

"1. Transfer all gas turbine research and development projects, including present and future funds, to the gas turbine code.

2. Obtain more well-qualified personnel for the new gas turbine code."

The Committee reconvened in executive session to discuss the apparent conservatism of the Bureau's policy regarding the installation
of new designs of propulsion machinery in new construction vessels. It was felt that the then existing policy so delayed service evaluation that it inhibited progress. The Committee agreed that progress could only be maintained by vigorous pursuit of reasonably specific goals and that awaiting full and satisfactory completion of laboratory tests tended to bog down promising developments with undue emphasis on detail. The Committee felt so strongly on the subject that its views were embodied in a report to the Chief of the Bureau [4-64].

"During the Committee's discussions it was apparent that the general atmosphere extant in the Bureau is one of undue conservatism. The Committee understands that it is the current practice to avoid the incorporation of developmental installations in new construction ships. This attitude may well result from the policy of CNO's directive (OPNAV INSTRUCTION 4470.1 of 28 May 1953), but it is the Committee's belief that this directive is intended only for production items and that the ship is the laboratory for the service "evaluation" of hull designs and new propulsion plants. It is believed that the time is now ripe to reconsider this practice. In order to obtain maximum engineering progress while the current opportunity exists, the Committee feels that shipboard installations of new developments should be made as early as possible. This is the period when engineering judgment indicates a promise of improved performance coupled with reliability.

"An example in point is the COSAG development. Here one finds a composite plant of developed units. The steam plant is of conventional design. An acceptable basic jet engine for the gas turbine portion has been extensively tested. Coupling of these two plants is certainly feasible within the time required for application to an early shipbuilding program. The Committee has been advised that the Bureau plans to install COSAG in a FY 1957 DD if at that time complete laboratory evaluation has been successfully accomplished. Unless more zeal for the worthy COSAG development is exhibited it may well wither on the vine like Kreislauf and Ellis power plants."
"It is recognized that a change in the current practice mentioned above may result in some delay in the completion of the individual ships concerned but it is strongly believed that the accelerated engineering progress more than justifies this risk. The Committee urges the adoption of this as a policy in order to consolidate to the maximum extent engineering gains."

The long-delayed first endorsement of the Main Propulsion Panel's twelfth report dealing with the Navy's gas turbine program by the R&D Planning Division came at the end of September. It generally agreed with the findings, but it stated that the R&D Planning Division was already doing what had been suggested in the report but that a semi-annual development and approval of a formally stated program such as the one described by the Panel would be of great benefit to the Bureau.

It wasn't until February 1954, that the Machinery Design Division responded to the same Panel report. The letter brought up the issue of lack of people, priorities, and money which is always true in a large bureaucratic organization.

The Machinery Design Division also disagreed with the Panel about the installation of a COSAG plant into a destroyer as early as the FY 1954 destroyer program, which actually would have been delivered to the fleet at the earliest in 1957. They wanted to continue toward a FY 1956 destroyer. Two Rolls Royce RM60 gas turbines were being purchased from the Admiralty for installation in a DE(FMR) type vessel. The units were scheduled for delivery in December 1954 and the Boston Naval Shipyard was preparing working plans for their installation. That conversion had been recommended for the FY 1955 shipbuilding program.
They also disagreed with the Panel's suggestion that a number of gas turbine installations be made to develop operating experience with naval personnel and to develop confidence in this type of prime mover. They recommended that the Navy wait until results were obtained from phases that were already planned. In short, they wanted to proceed without any disturbance to the present program and the tone of the letter left no doubt that the Machinery Design Division did not take kindly to outside suggestions.

Back in October 1953, the Chief of Naval Operations wrote to the Chief of the Bureau of Ships [4-66] stating that there was no longer an operational requirement for closed-cycle power plants of the Wolverine, Ellis, and Alton types for submarine propulsion. Therefore, the Bureau of Ships was requested to review their budgetary estimates for research in FY 1955 and to recommend to the Chief of Naval Operations diversion of research funds from submarine closed-cycle projects to the support of submarine nuclear propulsion or to other important projects.

The Chief of the Bureau did not give up easily and wrote back stating [4-67]:

"a. The Bureau of Ships was one of the original supporters of the idea of atomic power. Its belief in the feasibility of this type of power and the need for its successful development has never waivered.

b. The Bureau feels that while progress to date has been most encouraging, the history of all power plant developments has been that there is a considerable period of elapsed time in the developed phase before such plants should be considered for general
adoption. In spite of the remarkable success which has attended the development of the atomic power plant up to this point, it is believed only prudent to assume that it will be some time before the technical difficulties which must be anticipated have been sufficiently countered to make the general adoption of atomic power for submarine propulsion advisable."

Furthermore, he asked to be allowed to continue to pursue all three plants: Alton, Wolverine and Ellis.

In January 1954, the Chief of Naval Operations wrote to the Chief of the Bureau of Ships and rejected the Bureau's proposal on the closed-cycle submarine projects [4-68]:

"The Chief of Naval Operations does not desire application of gas turbine propulsion to submarines as proposed. Application of nuclear propulsion to submarines offers many more advantages than does closed-cycle......every effort must be made to expedite nuclear propulsion research and development."

However, the subject of closed-cycle plants was not over, yet. More than a year later, it was to be the subject of the 17th report of the Main Propulsion Panel.

In December 1953, the Main Propulsion Panel's report on future applications of nuclear power was issued [4-69]. The Panel reiterated the conclusion stated in an earlier report that it did not believe that gas turbines or nuclear propulsion would supplant all other prime movers in all ranges of power in the then foreseeable future. It recommended the
application of nuclear power to additional types of vessels and in additional numbers within the following ten years. Furthermore, the Panel felt that the program should be flexible enough to be accelerated or revised based on actual operating experience aboard the submarines, NAUTILUS and SEAWOLF.

In March 1954, the SDCC strongly endorsed the concept promulgated by the Panel, that is, an orderly phased program for further application of nuclear power. Since the Committee questioned the ability of the then existing facilities in the United States to produce nuclear propulsion plants in quantity in case of an emergency, it suggested that the following aspects be considered [4-70]:

"a. Those special facilities to manufacture reactors and associated components.

b. The increased demand for turbines and reduction gears for installation in submarines in lieu of diesel engines in view of surveys indicating that mobilization shipbuilding requirements based on current prototypes are in excess of the capacity of the turbines and gear facilities in the country.

c. The availability of critical materials required."

In a report of its own on 12 March, the SDCC stated [4-71]:

"The Committee has considered the current development and the trends of development and thinking regarding nuclear and other advanced types of power plants. It is recognized that nuclear power offers great promise for the future but it is considered that at this time the development has not progressed sufficiently far to warrant total reliance on this type of power for ships of the future."
"It is also observed that while two entirely different types of nuclear reactors are being installed in submarines and a third type is being developed for shore power, which developments involve tremendous financial expenditures, other types of advanced power plants lack the funds necessary for minimum progress. The Committee strongly recommends that the imaginative appeal enjoyed by nuclear power not exclude the continuance of other power plant developments.

"There are indications that the operational advantages of nuclear power plants are being taken for granted.... While there are undoubtedly justifiable applications of nuclear power, these applications may not extend to all types of ships or to all ships of any type."

In March 1954, the SDCC held its eighth meeting. Upon completion of the Main Propulsion Panel's reports, the chairman of the SDCC questioned whether it was appropriate for the committee to express an opinion on the necessity of "debunking" the earlier statements which had appeared in the public press relative to the design of future naval vessels. He felt that the opinions being expressed regarding nuclear propulsion and its reliability were inconsistent with past engineering experience. New plants had always developed deficiencies after being installed afloat and the Bureau of Ships had always had to contend with a considerable degree of impatience with those deficiencies on the part of operating personnel. It appeared prudent not to allow the opinion to grow that the state of development of nuclear propulsion was comparable with the contemporary gas turbine, steam, or diesel plants. Further, it appeared advisable for the Bureau to complete the development of at least one special submarine cycle plant as a stand-by. The Committee generally agreed that it would be appropriate for the Committee to express itself along the lines outlined by the chairman.
A member of the Committee pointed out that, during the preceding five years, by far the largest proportion of the money devoted to development of propulsion machinery had gone into nuclear propulsion projects. This member felt that the enforced termination of the special submarine cycle development placed the Bureau in a position where serious deficiencies in the nuclear plant in SSN571 would be very embarrassing because there was no stand-by plant. Further, the termination of these projects would inevitably lead to the dispersal of men and equipment assembled at considerable cost and devoted during the preceding ten years to the development of those cycles.

The following recommendations were clearly anti-nuclear arising in large part from the success of Admiral Rickover to garner most of the naval propulsion dollars [4-72]:

"a. That extensions of the nuclear power program to increased numbers of submarines or to other types of ships be undertaken only after full consideration of both operational value and mobilization needs and demands.

b. That other advanced types of power plants be progressed with reasonable financial support.

c. That the hydrogen peroxide developments for special submarine cycle power plants be continued."

However, on 5 May 1954, the Chief of the Bureau sent a letter to the CNO recommending an elaborate five-year program for nuclear power in the Navy.
The program was aimed at providing five nuclear power plants, which could be adapted to any class of vessel for which nuclear power was or could have become technically feasible and operationally desirable.

The Chief of the Bureau, in defending high costs, stated in part [4-73]:

"Nuclear power plants are potentially similar to other types with respect to fabrication techniques, complexity, operating conditions, and, with some exceptions, materials. Ultimately nuclear plant costs, pound for pound, should not differ materially from conventional plants. No new propulsion system has ever been, in the first experimental model, economically competitive with established conventional systems. If this had been made a requirement of our present propulsion systems, they would never have been developed."

This last statement is very interesting, lending credence to the idea that innovation is a political process, since such a statement of unqualified support has never been made with respect to gas turbines.

In retrospect it appears that the emergence of nuclear power in the Navy was a definite factor which contributed through the siphoning of funds to the lack of a well planned, broad-front, non-nuclear naval propulsion program, which could have evolved from the efforts during World War II and the immediate postwar years.

It is true that developmental systems should not be handicapped by being compared with existing ones. But most often they are, and
specifically, gas turbines always were compared with operational plants until they were eventually adopted in the 1970's.

A very important factor influencing the adoption of gas turbines was the issue of fuel. The Panel had considered the question of fuel for gas turbine power plants and combination steam and gas turbine power plants, including application problems, quality, availability and handling of such "special fuels" compared with the current Navy special fuel oil and diesel fuel.

Some of the problems considered were:

a. Gas turbines required distillate fuel to avoid ash deposition and serious corrosion. There was little hope of solving the problem of operating gas turbines and COSAG boosters under Navy operating conditions on Navy special fuel oil.

b. A COSAG installation required two fuels in considerable quantities, namely, Navy special fuel oil and a gas turbine fuel.

c. The Bureau did not have at that time a purchase specification for any fuel between diesel fuel and Navy special fuel oil.

The Panel considered the possibility of adopting a new fuel for gas turbine and COSAG applications which would have eliminated the deficiencies of Navy special fuel oil. That fuel was to be designated "COSAG fuel" and would have had low carbon residue and ash content. The only advantage of using Navy special fuel oil in conjunction with a distillate fuel in
combined power plants such as COSAG was the possible savings in fuel cost. The alternative of using an appropriate single fuel for all COSAG operations had great merit due to lower handling and maintenance costs and more effective operating practices.

The Panel submitted the following recommendations [4-73]:

"a. That detailed requirements for a COSAG fuel be studied and a pilot specification be prepared by the Bureau with the view of using this fuel in gas turbine and COSAG power plants.

b. That experimental lots of COSAG fuel be procured and evaluated in the Bureau's laboratories.

c. That equipment codes conduct a study to determine how new ship design can benefit from the potential advantages inherent in COSAG fuel. Where practicable, specifications for new equipment should include the requirement that the equipment be able to operate satisfactorily on such fuel.

d. That all future gas turbines should be designed to use COSAG fuel and such fuel should be used in presently planned gas turbine installations. Future COSAG power plants should similarly be designed to use COSAG fuel. Components for the present COSAG test plant should be modified as necessary to handle this fuel.

e. That necessary experimental data be obtained and studied to determine what machinery changes, if any, would be required on existing vessels in the event COSAG fuel were adopted either for emergency or standard use.

f. That no sweeping substitution of COSAG fuel for Navy special fuel oil in existing vessels be made in the immediate future, but that periodic availability studies be made to determine the feasibility of ultimately accomplishing such full-scale substitution.

g. That a comparative test be arranged using two destroyers operating together in the same division, one vessel using Navy special fuel oil and one vessel using COSAG fuel."
The policy of which fuel to use in evaluating competing power plant types during any particular new ship design as well as the price of the different fuels had a significant part to play in the eventual adoption of gas turbines as discussed in Section 4.11 of this chapter.

The Machinery Design Division sounded a note of caution in response to the Panel's recommendation [4-75]:

"Studies to determine the feasibility of adopting COSAG fuel for standard use should be undertaken. However, it is noted that present indications are that fuels suitable for COSAG power plants and gas turbines require a greater volume of carrying space for equivalent thermal energy than does Navy special fuel oil. Further, existing pumping and burning facilities will probably require modifications to accommodate a COSAG fuel. Therefore, the recommendation that no sweeping substitutions of COSAG fuel for Navy fuel oil in existing vessels be made is concurred in."

It looked like the introduction of a COSAG power plant was seriously being planned in 1954, and further evidence was supplied by a letter from the Chief of the Bureau to CNO on 25 June 1954. Resting his argument on a comment made by an OPNAV letter to the Ship Characteristics Board on 7 December 1951, the Chief of the Bureau pointed to the need which was expressed at that time to increase substantially the endurance of the DD 931 class destroyers [4-76]:

"Means of increasing the endurance of ships having steam-powered propulsion plants include; (a) improving the thermal efficiency of steam cycles, and (b) reducing the machinery weight while keeping the combined machinery and fuel weight constant. Therefore, one of the most promising methods of increasing the endurance of a
destroyer is to reduce the weight and space requirements of installed machinery, and utilize this space and weight for fuel.

"While destroyers operate over a wide range of power, studies of World War II operations indicate that less than 1 percent of the total underway operating life of typical destroyers was spent in the upper half of the power range. It therefore appears profitable to replace that portion of the steam plant used only infrequently for high power with lightweight, relatively short life, gas turbine engines in order to effect a net saving in machinery weight. Such a combined steam and gas turbine main propulsion machinery installation has been termed COSAG."

Design studies for the installation of a COSAG plant in a DD 931 hull indicated that the characteristics shown in Table 4-10 could be achieved. DD 931 characteristics are included for comparison.

The Chief of the Bureau noted that COSAG would provide power from a conventional steam plant up to 80 percent of full speed ahead and for all backing power. Quick starting of a cold ship by use of the gas turbines alone was also possible but under this condition no astern power was available (no controllable reversible pitch propellers).

However he was also quick to point out some of the disadvantages [4-76]:

"a. Presently available gas turbines have a relatively high fuel rate and this will reduce the DD's endurance at speeds of 29 knots and above. Expected improvements in gas turbines will overcome this at a later date.

b. Since gas turbines cannot successfully burn boiler fuel, it is necessary to use diesel distillate fuel altogether or to bunker two grades of fuel. Efforts
<table>
<thead>
<tr>
<th></th>
<th>Existing Design DD 931</th>
<th>COSAG Design DD 931</th>
<th>NET Change from Existing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total installed power</td>
<td>shp 70,000</td>
<td>78,000</td>
<td>+ 8,000</td>
</tr>
<tr>
<td>Total steam power</td>
<td>shp 70,000</td>
<td>35,000</td>
<td>- 35,000</td>
</tr>
<tr>
<td>Total Gas turbine power</td>
<td>shp None</td>
<td>44,000</td>
<td>+ 44,000</td>
</tr>
<tr>
<td>Full Power trial speed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Steam plant only)</td>
<td>knots -</td>
<td>-</td>
<td>- 5.2</td>
</tr>
<tr>
<td>(Gas turbine plant only)</td>
<td>knots -</td>
<td>29.2</td>
<td>-</td>
</tr>
<tr>
<td>(Steam plant plus gas</td>
<td>knots -</td>
<td>-</td>
<td>+ 1.6</td>
</tr>
<tr>
<td>turbine plant)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net saving in weight</td>
<td>tons -</td>
<td>-</td>
<td>129</td>
</tr>
<tr>
<td>due to machinery changes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net increase in bunker</td>
<td>tons -</td>
<td>-</td>
<td>129</td>
</tr>
<tr>
<td>capacity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endurance at 17 knots</td>
<td>miles -</td>
<td>-</td>
<td>+ 1,100</td>
</tr>
<tr>
<td>Endurance at 20 knots</td>
<td>miles -</td>
<td>-</td>
<td>+ 810</td>
</tr>
<tr>
<td>Endurance at 27 knots</td>
<td>miles -</td>
<td>-</td>
<td>+ 450</td>
</tr>
<tr>
<td>Endurance at 29 knots</td>
<td>miles -</td>
<td>-</td>
<td>- 30</td>
</tr>
<tr>
<td>Endurance at 33 knots</td>
<td>miles -</td>
<td>-</td>
<td>- 190</td>
</tr>
<tr>
<td>Overall length of machinery box</td>
<td>feet 140</td>
<td>118</td>
<td>- 22</td>
</tr>
</tbody>
</table>
are being made to develop a lower grade distillate fuel suitable for use in both boilers and gas turbines."

In conclusion, he asked for a destroyer in the 1956 program:

"Design studies indicate that for a destroyer type vessel, the installation of a combined steam and gas turbine main propulsion plant will permit, by reducing machinery weight and space requirements, an increase in endurance at normal cruising speeds. This can be accomplished in a DD 931 hull without sacrificing any of the military characteristics of the DD 931 class. It is therefore recommended that the 1956 shipbuilding program include one destroyer utilizing combined steam and gas turbine main propulsion machinery."

The destroyer was never approved and experimentation on full-scale at NBTL went on for several years. The British observed these tests, thought it was a good idea and built a class of eight ships using this type of power plant.

The Main Propulsion Panel's last major study influencing the adoption of the gas turbine for naval ship propulsion concerned Supercharged Steam Propulsion, i.e., the issue of pressure-fired boilers. The Panel surveyed the status and results of the engineering study sponsored by the Bureau to determine the applicability of the Elliott Supercharged Steam Propulsion Plant. The study conducted was based on the DD 931 class. Two factors gave the study major support, the Ellis developments and tests and commercial gas turbine developments contributing to a practicable supercharger. The Panel considered that the supercharged boilers offered several major advantages:
a. Reduction of machinery weight by over 30 percent (over 300 tons for DD 931)

b. Reduction of machinery space requirements by half

c. Reduction of operating crew and maintenance work. Greatly simplified cycle giving approximately the same designed fuel rates

d. More feasible remote control which was amenable to operation from a control cubicle properly protected against ABC contamination.

One disadvantage was that the boiler design had been predicated on using distillate fuel. The study added emphasis to the Bureau's project to develop a heavy distillate COSAG fuel.

The Panel recommended to the Chief of the Bureau [4-77]:

"a. That arrangements be made to furnish a complete shaft's worth of the subject propulsion system, suitable for a FY 1956 design DD, to NBTL for pre-shipboard installation test at the earliest possible date.

b. That one DD in the FY 1957 building program be reserved for the installation of the subject type propulsion system in a FY 1956 designed hull suitably modified. Further, that the ship design modifications be accomplished by the same design agency in parallel with the development of the FY 1956 design.

c. That firm austerity be enforced in this design to prevent the addition of complications tending to improve the fuel rate over the integrated rate obtainable with the orthodox installation.

d. That design studies be initiated to adapt the subject plant to vessels requiring either greater or lesser SHP per shaft."
The R&D planning organization concurred with the recommendation that one complete shaft's worth of the subject plant be procured and tested at NBTL at an early date. They further stated that if $250,000 was made available for the design phase in FY 1955 and $2 million were made available for hardware in FY 1956, the components could be delivered to NBTL for test around January 1957. It was recommended that $250,000 of FY 1955 funds be made available so the design phase of the contract could be initiated. They felt that there were several types of ships planned at that time with powers ranging from 70,000 to 85,000 shp on two shafts. Therefore, a prototype design for 35,000 shp would provide the information necessary to evaluate the suitability of the Elliott plant in that power range.

There was some disagreement with the Panel's recommended schedule [4-78]:

"The recommendation to reserve a Fiscal Year 1957 DD for installation of the subject propulsion plant is not concurred in. Inasmuch as the testing of the land based plant should be initiated in the latter half of Fiscal Year 1957, the same year in which the contract design of a ship in the 1958 building program would be underway, it is recommended that the subject plant be applied to a destroyer type in the Fiscal Year 1958 program rather than any earlier building program."

It was agreed that a shaft's worth of machinery be procured, including a turbine, gear, condenser, one pressure-fired boiler, one supercharger with drive and all auxiliaries necessary for plant operation. An additional pressure-fired boiler and supercharger (duplicate of those
to be ordered), necessary for full plant operation were by then on order; however, it was recommended that a supercharger as a "back-up" for the Elliott design for the above shaft be designed.

They also did not agree that application should be made to a destroyer in the FY 1958 program. Although it was considered possible to complete testing in NBTL by April 1958 (based upon contract date of 1 May 1955 and hardware delivery by April 1957), the Machinery Division did not consider it advisable to associate this plant with a specific hull until components were successfully tested at NBTL, because of the tendency to compromise testing to avoid a delay in a specific building program. Also, once a plant is associated with a specific hull, outside activities, such as CNO, were expected to associate normal delays and developments in testing as proof of unreliability in the ship installation.

The Machinery Division felt that the dollar amounts suggested be increased from $250,000 and $2 million to $325,000 and $2,425,000 respectively to take care of the cost of the new supercharger which they proposed.

As a result of these differences of opinion within the Bureau, a DD was not asked for in the FY 1957 shipbuilding program. Consequently, the pace of development slowed down and the pressure-fired boiler was not fully ready for adoption into a whole class of new ships when the decision to proceed was made a few years later.
By 1955, the Bureau's Gas Turbine Program was quite extensive (Table 4-11) yet, its adoption for anything other than as a prime mover for fairly small power generation did not appear to be near.

On February 28, 1955, the Chief of the Bureau dissolved the SDCC and all of its panels [4-79]. Thus, ended a three-year period during which most of the pertinent issues concerning the development of naval ship propulsion had been critically examined by technically competent people who also had the appropriate overview and experience required to do a good job. No such group in the Bureau of Ships was again assembled for this purpose. Their deliberations as summarized in this section provide a tremendous insight into the mechanism and obstacles in the process of the innovation adoption in a large bureaucracy like the Navy.
TABLE 4-11 BUREAU OF SHIPS GAS TURBINE PROGRAM (1955)

I. OPEN CYCLES
   a. COSAG
      (1) A preliminary design of a COSAG plant in a DD 931 hull was completed during December 1953. Procurement of components for one shaft's worth of COSAG machinery for test at NBL is underway. We presently contemplate recommending this vessel for the FY 1956 shipbuilding program.
      (2) The J-40 Westinghouse gas turbine engine currently being built for the laboratory test will be used for the first shipboard installation.
      (3) Development of a new booster unit will be initiated when studies to determine desired characteristics are completed.
   b. CODAG
      (1) A study of a CODAG plant in the DE 1006 hull will be completed about 1 March 1954. Other applications of this principle will be studied.
      (2) Two Metrovick G-2 gas turbine engines are being purchased from the Admiralty for installation in the PT 812. CNO approval for this project has been obtained. The engines will be delivered by December 1954. Philadelphia Naval Shipyard is preparing working plans for this installation.
   c. "Free Piston" Gas Generator-Turbine
      (1) The Baldwin-Lima-Hamilton Corporation Model DL "free piston" gasifier has been successfully developed and tested. One of these units is now being built for installation in a FCS class vessel. The turbine and gear will be provided by Cleaver-Brooks Company (Eacher Wyss).
      (2) Technical review of a proposal by Cooper-Bessemer Corporation for installation of their 1,300 shp "free piston" engine in an ATA 174 class tug is being made.
      (3) Application of "free piston" engines to an AN 421 vessel has been investigated. This application was found to be undesirable because of excessive machinery weight and because of the effort which would be required to produce these equipments of non-magnetic material.
      (4) Further studies are now underway to determine optimum application and size of "free piston" gasifiers of the Baldwin-Lima-Hamilton Corporation design.
      (5) EES is now investigating supercharging of the "free piston" engine.
   d. Small Craft Propulsion

Numerous studies of the application of gas turbines to small craft propulsion have been made. In general it may be said that results are at best only marginal with the exception of a few short range - high-speed craft. The weight advantage of the gas turbine is lost in most cases due to the high fuel consumption. Exhaust ducting has also posed a problem.

Because of the ultimate potential of the gas turbine propulsion for a large variety of small craft applications (when the now high fuel rates can be brought to a reasonable level) it is our policy to develop a limited number of engines (three), install these in selected vessels, make improvements where possible, gain operating experience, and as a result of the foregoing, come to a conclusion as to our future course of action.
The following steps have been taken to carry out this part of the program:

(1) Boeing Model 502-2 gas turbine engines rated at 160 bhp have been installed in two LCSV's. Four of these engines are being procured for installation in four 36-foot MLS's. Two additional engines are being purchased as spares. Application studies have been made for installation of this engine in the LCSM, 50-foot Utility boat, 40-foot Utility boat, 40-foot Personnel boat, 40-foot Motorboat, 57-foot MGB, and 28-foot Personnel boat. The performance characteristics of the existing propulsion engines could only be improved in the case of the 28-foot Personnel boat. Here the disadvantage of initial cost, configuration of exhaust arrangement and cost of operation have not warranted the adoption of gas turbine propulsion.

(2) The Solar T-522, 500 hp gas turbine engine is now under development and one engine will be delivered in June 1954. Application studies have been made for installation in the 57-foot MGB and 40-foot Rescue Boat. Studies are now under way for application to 40-foot and 52-foot Rescue Boats using the hydrofoil principle. The rescue boat applications have shown some promise thus far.

(3) One Allison 510-B-1, 2,000 hp gas turbine is scheduled for delivery by June 1955. Application studies have been made for installation in the 52-foot and 94-foot Rescue Boats. Neither of these applications show overall advantages with the Allison engine and other applications are being investigated.

   a. Generator Drive

   (1) Boeing Model 502-6 engines are being installed as prime movers for minesweep generators in the current shipbuilding programs. 250 engines have been purchased. 200 have been or are being installed in fifty MGB-5 class vessels, two will be installed in 36-foot MLS's and the balance are spares.

   (2) The Solar T-510 was developed for the MB-5 class as an improved drive over the Boeing 502-6. Six engines have been purchased. Four engines will be installed for minesweep generators in the last two MGB's in the current program. Two are spares.

   (3) Studies have been completed on gas turbine drive (Boeing, Solar and Allison) for generators for AN 421 class. No advantage in ship's performance or arrangement can be gained.

   (4) Application of gas turbines for 1,000 kW emergency generators suitable for CVA's is being investigated.

   (5) Application of gas turbine emergency generator drive for DD's will be studied. A Solar T 400 rated at 290 hp is installed in DD 828.

   f. Pump Drive

   (1) Seven Solar T 45 gas turbines have been purchased with 500 gpm pumps. One will be tested at EES by March 1954. Six will be delivered to the operating forces for evaluation after the EES tests. (137 Solar T 45 engines have been purchased by the U.S. Air Force for generator drive.)

   g. Complex Open-Cycle Gas Turbine

   (1) A procurement request has been initiated for the design of a complex 10,000-shp open-cycle gas turbine plant suitable for the main propulsion plant of a DE. Detailed application design studies will be conducted concurrent with the gas turbine design.

II. PRESSURIZED CYCLES

a. Semi-Closed Cycles

   (1) The ex-WOLVERINE plant is being tested at EES to determine feasibility of the semi-closed cycle and to obtain engineering data to advance design knowledge of gas turbines for surface-type vessels. Existing plant is not suitable for surface application in its present configuration. Application studies will be made upon satisfactory completion of tests and final design of component.

b. Closed Cycles

   (1) The Bureau is now negotiating for a preliminary design of an 8,500-shp closed cycle gas turbine plant in an auxiliary vessel. The ultimate target will be an AP 58 type. Negotiations for design of an air heater suitable for this plant are also underway.
TABLE 4-11 BUREAU OF SHIPS GAS TURBINE PROGRAM (1955) (Continued)

III. COROLLARY DEVELOPMENT

a. Blade Cooling
   (1) Solar Aircraft Company is developing a blade cooling system suitable for marine gas turbines under a Bureau of Ships contract. Satisfactory performance of this system will result in improved efficiency, increased output and a reduction in critical materials.

b. Improved Materials
   (1) High temperature metals and metal coatings development is being continued at Boeing Airplane Company, International Nickel Company and Haynes Stellite Company under contracts administered by Code 300.

c. Components
   (1) A number of component developments are now underway such as the rotary regenerator, aerothermopressor, and the closed cycle air heater. However, there continues to be a need for basic design data for compressors, turbines, and combustion chambers, and the Bureau will undertake work in this direction as funds become available.

d. Fuels
   (1) Residual fuel combustion for gas turbines is being studied at the Engineering Experiment Station and by Gulf Oil Company under a contract administered by Code 300.

e. CRP Propellers, Reverse Gears, and Clutches
   (1) The need for such corollary developments is well recognized. The RM-60 installation in a DE(FMR) will employ CRP's and designs of the 10,000-shp open cycle complex gas turbine and the 8,500 closed cycle gas turbine is proceeding on the basis of using this type propeller.
   (2) Negotiations are underway for the design of a suitable 10,000-shp CRP.
   (3) Clutches for the COSAG plant will be developed and tested in advance of the MBTL installation.
   (4) A 2,000-shp reverse gear will be used for the Allison 510-B-1 gas turbine.
4.6 The Adoption of Medium Speed Diesels for Destroyers:

The DE 1033 Class

The DE 1033 design relates to the gas turbine case study in several ways:

a. The DE 1033 class is the U.S. Navy's only post-World War II diesel destroyer design, of which only four were constructed. (During the war, 559 diesel-powered destroyers had been built.)

b. Its developmental process illustrates the strength of the steam lobby in the Bureau of Ships.

c. DE 1033 design decisions point to various factors which influence selection of naval ship propulsion plants, though they have nothing to do with classical economic-type trade-offs among propulsion plant options (e.g., envisioned mobilization needs and industrial capacity).

d. The gas turbine propulsion alternative was not considered in the DE 1033 trade-offs despite its availability as an alternative to the steam option.

To understand the origin of the DE 1033, we need to examine the evolution of the requirement for the ship itself. In 1948, the General Board held extensive hearings on a proposed ten year building program to begin in FY 1950. The Soviet submarine development program required a substantial anti-submarine warfare (ASW) force in the U.S. fleet. Because of higher submarine speeds, the former 24-knot DE had to be upgraded to 30 knots, and the former 20-knot coastal escort (PC) to 25 knots.
The latter was reassigned as a mass production merchant convoy escort. DE's on hand were designated "ocean escorts" or "escort vessels" and only the new DDE's were called "destroyer escorts."

In response to the new requirements, in October 1950, the Ship's Characteristic Board (SCB) initiated an ocean escort design which became the USS DEALEY (DE 1006) class. Practicality dictated the selection of a 600 psi steam power plant, expected to produce 25 knots at trial speed with an endurance of 6,000 miles at 12 knots. The DE 1006 turned out to be more expensive than initially envisioned and, in 1954, a high level Navy committee recommended that a more austere escort be designed.

In a letter to the Chief of the Bureau of Ships on June 7, 1954, the Chief of Naval Operations (CNO) requested feasibility studies on this escort [4-80]:

"A review of recent shipbuilding and conversion programs indicates that the Ocean Escort (DE) Project No. 72 (DE 1006) may be too costly and too complex to lend itself to rapid and economical construction of large numbers in an emergency. It is desired to investigate the possibility of designing a simpler, cheaper ASW ship suitable for the escort of convoys. Such a ship would lack the versatility required to perform other tasks; however, a large number of ships may be required for this purpose in wartime, and considerable savings to the national economy could be expected to result from the construction of ships of the most austere capabilities consistent with the specific mission."

This letter specified a twin-screw, 21-knot, sustained speed, and an endurance of 8,000 miles at 12 knots.
The SCB/Bureau of Ships study became SCB #131, which eventually became the DE 1033 (CLAUD JONES) class. In contrast to DE 1006 development, during which a COSAG plant option was studied, a diesel propulsion system was quickly chosen for the DE 1033.

The only propulsion plant options considered were steam and diesel. In the event of mobilization, large numbers of DE-type escort vessels were envisioned to be required. The CNO favored a diesel design because of its mobilization potential compared with steam. From the standpoint of critical materials, neither plant offered compelling reasons for selection over the other. In terms of manufacturing capability, the diesel plant had the advantage.

Since the CNO favored a diesel design, the Machinery Branch limited its study to evaluating alternative engines for twin and single screw options. The single screw option was chosen for the following reasons:

a. A twin screw steam plant would have taken up an excessive amount of space compared with a diesel plant in the required hp range.

b. A long cruising radius was required and the single screw plant allowed a better fuel rate. Cruising range would decrease with the twin screw design.

c. The single screw plant was better suited for mobilization production as it required one-half the total number of propulsion units.
Studies showed that either a geared turbine or geared diesel would most nearly meet the requirements. Both plants could have been accommodated within the space limitations imposed.

The first preliminary characteristics issued by the SCB specified the following [4-81]:

"a. Speed: 23 knots under trial conditions
   12 knots cruising speed

b. Endurance: At least 8,500 miles at 12 knots

c. Power Plant: Twin screw, steam or diesel powered. Insofar as practicable, the power plant shall be designed so as to determine the requirement for critical materials or the employment of critical manufacturing processes."

There was no mention of gas turbines. The SCB's second preliminary characteristics eliminated all options and called for single screw diesel power.

Thus, the emphasis on mobilization capability prevailed in the final propulsion characteristics for the DE 1033 [4-82]:

"a. Speed: 22 knots under trial conditions
   12 knots cruising speed

b. Endurance: At least 7,000 miles at 12 knots

c. Power Plant: Single screw, diesel powered. Insofar as practicable, the power plant shall be designed so as to minimize the requirement for critical materials or the employment of critical manufacturing processes."
Bureau personnel, both in the Preliminary Design Branch and the Machinery Branch, considered the selection of the single screw diesel too hasty and prepared further studies on steam alternatives, comparing them with the diesel option. The wide divergence in required operating conditions, 22 knots trial speed and 12 knots cruising speed, created a problem for diesel propulsion. Steam turbine propulsion, on the other hand, did not suffer from this difficulty. For plants of comparable power, the diesel machinery weighed about 23 percent more than the steam, required about 39 percent more machinery space length and a corresponding increase in ship length of about 10 feet. Diesel plants are inherently more noisy and require more maintenance than steam plants; however, the diesel plant used about 22 percent less fuel at cruising speed.

However the overriding consideration in the selection of the power plant was the issue of adequate manufacturing in case of World War II-type mobilization [4-83]:

"Since this design is envisioned as a mobilization prototype and, for this power range, it is expected that at mobilization there will be more manufacturing capacity for diesel than for steam, it is recommended that a diesel drive be required."

On December 8, 1954, the approved characteristics were issued with the following statement [4-84]:
"With the advent of war, ships capable of performing trans-oceanic escort of convoy duty will be required in large numbers. Such ships should have excellent ASW detection capability, good ASW kill capability, and an adequate speed margin to screen merchant convoys. These ships should be of minimum size, complexity, and cost, consistent with the mission and tasks. The design should be such as to facilitate rapid and economical construction of large numbers in an emergency. The design will be such that a steam turbine main propulsion plant may be substituted for the specified diesel main propulsion plant with a minimum of redesign work. Such reduction in cruising radius as may result with the steam plant is acceptable."

The final characteristics for DE 1033 propulsion and engineering features were approved without change.

Although the contract design was completed in September 1955, using diesel engines, the dissatisfaction with the diesel design soon surfaced. The Preliminary Design Branch wrote to the head of the Ship Design Division [4-85]:

"Code 420 believes that a review of Project 131 should examine the requirement for Diesel engines very thoroughly. This design is penalized quite severely by having to use the multiple diesel arrangement on a single screw. If a steam plant can be used, we feel the design could be smaller and probably less expensive. The steam plant takes less hull length and would thus permit shifting activities now on the main deck to spaces below. Instead of an upper deck arrangement we could probably use a flush deck or forecastle deck arrangement which appears to be a more reasonable ship to us.

"One of the requirements for this ship is quiet operation. Here again, we feel that the steam plant would have a slight advantage.

"We feel that for ships which are repeat designs as the DE's in the FY 1957 shipbuilding program will be, the Navy would get a better ship by constructing these to the SCB #72 (DE 1006)
"design with a reduced power plant if the 22 knot speed is all that is desired. A reduced power plant in DE 1006 would permit a stern redesigned to favor quiet operation, another advantage to be realized if quiet operation is of significant importance.

"If it turns out that a diesel power plant must be used, we feel that we could design a much better ship if we were not required to provide for the alternate installation of a steam plant. We could then use compensated diesel oil tanks which would give better stability characteristics, better subdivision, and possibly reduced beam."

The strong pro-steam feeling in the Bureau was again evident almost a year later in a 1956 memorandum from the Machinery Design Branch [4-86]:

"Our original feeling about this design was ably expressed by the Preliminary Design Branch on a route sheet comment to the Head of the Design Division. In brief he stated that we considered the DE 1006 a better design than the DE 1033 and that after the DE 1033 FY 1957 ships, the Bureau should recommend the DE 1006 for future building programs.

"However, it should be recognized that the endurance of the DE 1006 is one of the major deficiencies of that design. To improve this we should recommend pressure-fired boilers coupled with increased oil capacity to improve endurance.

"In the same memo, reference is made to the low speed of the DE 1033 and trend toward increased convoy speed. In this regard DE 1006 is not much better in lieu of the low endurance at 12 knots. The 1033 is only slightly better and could maintain a convoy speed of 13-1/2 knots for the same endurance as the 1006; namely 5,800 miles.

"It may be a better plan to redesign 1033 to fit a 10,000 shp steam plant, carry the same armament as 1006, and increase endurance by increasing fuel capacity as much as possible."

Also in 1956, the Preliminary Design Branch again voiced its opposition to diesel propulsion of the DE 1033 [4-87]:

"Code 420 again wishes to emphasize the position with respect to the Project 131 design which it presented before the review of the characteristics for the FY 1957 Shipbuilding Program."
"The design is penalized severely by having to use the multiple diesel arrangement on a single screw. It is true that some of the objections to the diesel power plant can be eliminated by re-engineering as proposed by Code 430 memo Serial 436-070 dated 11 January 1956. However, the steam turbine drive can produce a faster, quieter ship without an appreciable difference in cost. In addition, obtaining approval for a steam powered ship similar to SCB #72 (DE 1006) would permit installation of the pressure-fired boiler if and when it is accepted. Note that Gibbs and Cox is now preparing studies for this plant in a DE 1006 hull under a Code 430 contract.

"Four of the DE 1033 class (SCB #131) are now authorized in FY 1956 and 1957 shipbuilding programs. This should be a sufficient number to allow complete service evaluation of the diesel type ship (a principal argument advanced to justify the two ships in the FY 1957 program). Thus, since the Bureau of Ships was the prime mover in forcing a change from the good DE 1006 type to the marginal DE 1033, we believe that the Bureau should take the lead in trying to make the switch back to steam in the FY 1958 and subsequent programs."

Another year passed and, in view of a pending new escort design, the head of the Ship Design Division selected a group consisting of senior officers and civilians in the design division to study the worth of the DE 1033 as an ocean escort. Again, the ship was compared with the DE 1006 class. The results are shown in Table 4-12.

Though the ships were of comparable size, the DE 1033 was slower and more lightly armed. It had a larger cruising radius and was more adaptable to a marine environment. Cost of one DE 1033 class ship was about 10 percent less than a 1006 class ship. The DE 1033 carried about one-half the weight of armament and ammunition carried by ships of the 1006 class. Its center of gravity was about one foot higher in all conditions of loading. (This was primarily due to the upper deck construction made necessary by the 30 foot longer machinery box required for the diesel propulsion plant.)
<table>
<thead>
<tr>
<th></th>
<th>DE 1033 Class</th>
<th>DE 1006 Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>312 feet</td>
<td>314 feet</td>
</tr>
<tr>
<td>Beam</td>
<td>38 feet</td>
<td>37 feet</td>
</tr>
<tr>
<td>Displacement (light)</td>
<td>1,368 tons</td>
<td>1,268 tons</td>
</tr>
<tr>
<td>Displacement (full load)</td>
<td>1,851 tons</td>
<td>1,904 tons</td>
</tr>
<tr>
<td>Cruising radius @ 12 knots</td>
<td>8,600 miles</td>
<td>5,800 miles</td>
</tr>
<tr>
<td>Propulsion machinery</td>
<td>Single screw, geared</td>
<td>Single screw, geared</td>
</tr>
<tr>
<td></td>
<td>Diesel (4 engines) SHP 9,200</td>
<td>Steam turbine SHP 20,000</td>
</tr>
<tr>
<td>Trial Speed</td>
<td>22 knots</td>
<td>26 knots</td>
</tr>
<tr>
<td>Armament</td>
<td>2-3&quot;/50 single</td>
<td>2-3&quot;/50 twin</td>
</tr>
<tr>
<td></td>
<td>2-MK 4 A/S torpedo launchers</td>
<td>2-MK 4 A/S torpedo launchers</td>
</tr>
<tr>
<td></td>
<td>1-DC track</td>
<td>1-DC track</td>
</tr>
<tr>
<td>Cost (follow ship)</td>
<td>$9 million</td>
<td>$10 million</td>
</tr>
<tr>
<td>1-MK 108 A/S rocket launcher</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The committee unanimously concluded that the DE 1033 would be relatively ineffective as a convoy escort and ASW ship because of its low speed and lack of long-range A/S weapons, particularly in view of the trend toward increased convoy speed and the speeds attainable by modern submarines.

A number of studies were conducted in an attempt to improve this design. These involved lengthening the ship, increasing the installed horsepower, removing the variable depth sonar (which had not been produced by that time), substituting aluminum for steel in the upper deck and in the shell above the main deck, eliminating one motor whale-boat, and installing a positive water displacement system in the diesel oil tanks. While the incorporation of these features would have effected some improvements in speed and stability, the committee felt they would not materially affect the capabilities of the ship while increasing ship cost. In the interest of providing maximum ship capability with the funds on hand at that time, the committee recommended halting construction of the DE 1033 class and using the funds to procure additional DE 1006 class ships [4-88].

By September 1958, the DE 1033 trials showed a number of deficiencies such as too much noise in habitable spaces above the diesel generators as well as a problem of propeller pitch/engine horsepower output/fuel rack setting, which limited the utilization of the installed horsepower to somewhat less than that installed. However, those engineering
problems did not seem to have deterred the Commanding Officer of the DE 1033 (CLAUD JONES) from being quite pleased with the ship on one of its first fleet exercises in the Atlantic in November 1960 [4-89]:

"a. CLAUD JONES class destroyer escorts are capable of operating with DEALEY class destroyer escorts in convoy operations.

"b. CLAUD JONES class destroyer escorts can be operated at sea for extended periods of time with a minimum amount of logistic support.

"c. The engineering plant is much more economical than the steam plants in DEALEY destroyer escorts.

"d. Further flexibility is offered in JONES through the capability of employing diesel oil and JP5 fuel interchangeably.

"e. JONES is limited in speed to 5 knots less when compared with speed available in DEALEY class destroyer escorts. However, this limitation has not yet handicapped the ship in convoy escort operations. Furthermore, judicious use of speed can make diesel destroyer escorts available for many collateral tasks because of the greater economy of operations in such ships and their tremendous on-station endurance.

"f. The arrangement of spaces and the room available in JONES superior to that of DEALEY destroyer escorts. Consequently, utilization of equipment is more efficient, and habitability is excellent."

Even when it came to the issue of the slow speed relative to DEALEY, the Commanding Officer of the DE 1033 praised his ship.

In spite of all this, discussion in the Bureau made it quite clear that future diesel destroyer designs would not come easily. The
number of ships of the DE 1033 class was curtailed to four, all of which have been sold to other nations by now. The U.S. Navy does not have even one of them, after some 8 years of design and development work and about 15 years after the commissioning of this class. It seems doubtful if, in the near future, one will see a renewed interest in the diesel power plant for destroyers. One of the primary reasons against it, apart from the negatives discussed earlier, is its poor structureborne noise characteristics.

Although diesel propulsion in U.S. destroyers was a short-lived experience, its introduction at the time once more eliminated the opportunity for the adoption of gas turbines.
The Adoption of Pressure-Fired Boilers (the DE 1040 Class)

The abandonment of the CLAUD JONES class (DE 1033), which was pressed by the Bureau of Ships, succeeded. Instead an attempt was made to produce a quality Ocean Escort in the form of a modernized DEALEY (DE 1006). Of course, matters could not be that simple. A great deal had happened to Anti-Submarine Warfare (ASW) technology between 1951 and 1958. When the Ship Characteristics Board (SCB) requested a study of an improved DE in March 1958 for the FY 1960 program, it desired the incorporation of the new bottom-bounce sonar (SQS-26), ASROC, and a helicopter facility for extending ASW capability beyond ASROC range. These capabilities could no longer be incorporated in a design based on the DE 1006. The first ships which resulted were the BRONSTEIN class (DE 1037) with a total of two ships in the class followed by 10 ships of the GARCIA class (DE 1040), one AGDE, and 6 DEG 1 class. These ships, with the exception of the DE 1037 and DE 1038, were the first to incorporate pressure-fired boilers.

In March 1958, the SCB [4-90] requested that the Bureau make a cost and feasibility study regarding the incorporation of advanced ASW features for a FY 1960 Destroyer Escort. The requirements for this study were outlined by a set of tentative characteristics [4-91]. Briefly, these characteristics were patterned after the DEALEY class (DE 1006) but included requirements for a new long-range, bottom-bounce sonar (AN/SQS-26), an ASROC launcher, and a helicopter facility for extending the ASW capability beyond the ASROC range. A quick study of the requirements indicated
a ship of 325 feet overall length, 2,000 tons full-load displacement, and 25 knots trial speed. The results of this study were reported by the Bureau of Ships in reference [4-92]. Subsequent discussions by the SCB working level group resulted in a number of changes in the characteristics, notably the addition of dynamic roll stabilization, a 3"/50 twin-mount, a Class 4 gunfire control system, as well as an increase in helicopter facilities, countermeasure, aircraft control functions, and complement. Additional studies by the Bureau incorporating these features were conducted and reported to the SCB. Approved characteristics [4-93] were issued with the following principal features:

- Displacement Light ----------------- 1,640 tons
- Length Between Perpendiculars (LBP) ------ 325 feet
- Beam ---------------------------------- 38 feet
- Draft, maximum ------------------------ 24 feet
- Special features ---------------------- dynamic roll stabilization
- Power plant --------------------------- steam turbine,
  2 boilers,
  single-screw

While the characteristics indicated that a fairly moderate sustained speed was acceptable, some concern was felt in the Bureau and by CNO about developing a new escort ship with a speed 1-knot below the ASW task force speed even though the helicopter attack capability relieved the ship of high-speed runs on the target. A study was made to increase speed
without changing the power plant. This was done by a redistribution of volume in the ship resulting in a ship of relatively slimmer shape (350 feet LBP). It was felt that this could be done at no significant increase in cost. The changes resulted in a speed gain of about 0.7-knot and the Bureau's decision was to incorporate these changes in the design.

During the feasibility stage, additional studies were made attempting to introduce more power without increasing ship size. One notable example was the incorporation of a pressure-fired boiler with one-half of a DD 931 machinery plant, giving a total of 34,000 shp. It should be noted here that "pressure" does not refer to the 1,200 psi steam pressure by then adopted in some U.S. destroyers, but to the fire-side pressure of the boiler. The pressure-fired boiler had the same steam pressure, temperature, and equivalent horsepower as conventional boilers, but required approximately one-half the weight and space. This reduction in weight and space resulted from use of high-gas-side furnace pressure (4-1/2 atmospheres). This pressure was obtained from a supercharger driven by boiler exhaust gas, eliminating all forced-draft blowers. The water-steam cycle was based on conventional natural circulation. Distillate (diesel) fuel was burned to minimize gas-side deposits and pressure drop. A schematic arrangement of the pressure-fired boiler cycle is shown on Figure 4-11. The preliminary design, as finally developed from SCB 199, did not incorporate the pressure-fired boiler. Rather, it was based on the DE 1006 (600 pound, 20,000 shp) plant.
Soon thereafter the issue of the incorporation of pressure-fired boilers surfaced again. It was concluded that a satisfactory design could be produced incorporating pressure-fired boilers for a FY 1961 program.

The Chairman of the SCB requested [4-94] that the Bureau study the feasibility of increasing the maximum speed of the DE to a substantially higher value without increasing the existing hull dimensions. The resulting study indicated that a maximum sustained speed significantly higher, but not as high as that requested by the SCB, could be obtained within the existing hull dimensions by use of a power plant of improved capabilities. The Bureau had also completed a second study of a DE which met the sustained speed requirements, permitting the hull dimensions to increase as necessary.

The pressure-fired boiler used in the new design had by that time undergone an extensive laboratory development and test program during the previous 10 years but had not been tested at sea. For comparable horsepowers, this boiler was approximately one-half the weight and size of a conventional boiler. In 1952, a 7,500-hp pressure-fired boiler was successfully tested at the Naval Boiler and Turbine Laboratory. During the five years preceding 1959, a destroyer-size, pressure-fired boiler (17,500 equivalent shp) had been developed and tested. Over 1,000 hours of testing and correction of design deficiencies had been conducted at the U.S. Naval Boiler and Turbine Laboratory. Based on this experience, the Bureau of Ships was prepared to procure pressure-fired boilers for application and evaluation afloat.
The pressure-fired boiler offered many advantages over destroyer boilers of equal capacity at that time, such as \[4-95\]:

a. Major reduction in machinery plant weight and space which can be utilized for increased endurance, armament or speed.

b. Increased ruggedness and decreased maintenance by elimination of all brick-work and fire-side corrosion.

c. Simplified operation due to elimination of fuel oil heaters, forced-draft blowers, burner cut in and cut, and reduced light-off time.

Because of the advantages of the pressure-fired boiler for destroyer and escort types, the Bureau recommended its early application at sea. The power of the boiler in the medium speed design for Project No. 199 coincided with that of the NBTL installation; thus, no further laboratory trials would have been necessary before installing it in a ship. However, no pressure-fired boiler in the power range required for the high-speed ship design had been built. A boiler with that power would have required shore-based testing before its shipboard installation. Since it was too late to change the two FY 1960 authorized designs (DE 1037 and DE 1038), one of the FY 1961 ocean escorts with speed increased to the medium range was recommended for the first application of the prototype pressure-fired boiler. The ship was to be designated an EDE (E for experimental).

The Bureau had the following rationale for proceeding with this development \[4-95\]:

182
"a. The proposed EDE would utilize the already tested pressure-fired boiler design and proven DDG turbines, gears and auxiliary machinery.

b. A single hull design would accommodate either a DEALEY-type power plant or the proposed single-shaft DDG machinery plant with pressure-fired boilers. This was because of the weight and space saving with the pressure-fired boilers.

c. Studies made of various ships suitable for service evaluation of pressure-fired boilers indicated substantial characteristics improvement for the DE-type, at the least additional cost.

d. Service experience in this pressure-fired boiler DE would be directly applicable to subsequent DE and DD types."

The Bureau recommended revising the approved characteristics of the ocean escort to achieve a reasonably high sustained speed. FY 1961 DE characteristics were changed accordingly to incorporate pressure-fired boilers. The change was to be accomplished by "line-in/line-out" of the DE 1037 specification.

The major changes were as follows:

a. Completely new machinery arrangements and system plans within the presently defined machinery boundaries.

b. Redesigned uptake areas to permit approximately 70 percent greater volume rate of flow of inlet combustion air and exhaust gases, as well as increased ventilation air for both machinery spaces.

c. Redesigned fuel system to permit continuous compensation to attain required stability characteristics.
d. Redesigned propellers, shafting and shaft lines to deliver higher horsepower and attain satisfactory tip clearances.

However, instead of accepting the EDE designation recommended by the Bureau, OPNAV decided to make the first pressure-fired boiler ship, the lead ship of a class. Thus, a new class was born, the DE 1040 (SCB 199A). Contract design revisions to the DE 1037, though accompanied by some changes in hull characteristics, reduced sustained speed by about 1/2-knot. This reduction in speed could be avoided only by a major change in hull characteristics, particularly length. The introduction of the pressure-fired boiler plant with more power than the conventional plant further emphasized the need to redesign the hull for the DE 1040. As a result, the final hull characteristics selected for the DE 1040 accommodated the additional weight and increased power of the machinery plant for the pressure-fired boilers by increasing length from 371 feet on the DE 1037 to 414 feet for the DE 1040; beam was increased by 4 feet.

DE 1040 preliminary design was complete and entered the contract design phase in June 1960. There was considerable disagreement over power plant component choices within the Machinery Design Branch. By October 1960, a number of major deviations from conventional design practices had been incorporated in the DE 1040 machinery on a piecemeal basis.

The Machinery Design Branch was concerned about the effect that these features could have on plant design and operation and sought to halt any additional changes to the power plant [4-96]:

184
"The purpose of this memorandum is to restate the Machinery Design Branch's understanding of the policy behind the decision to include pressure-fired boilers in the DE 1040 and to point out the development status to date.

"Subject propulsion plant is the first to include pressure-fired boilers heretofore never installed in U.S. naval ships. The decision to incorporate pressure-fired boilers in a combatant design was primarily based upon the apparent advantage of reduced size and weight as compared to conventional boilers of equal steam generating capacity.

"From the onset of the design development, the Propulsion System Design Branch was of the understanding that the rest of the plant would remain as conventional as possible being sure not to incorporate new features yet unproven either by laboratory test or previous ship installation.

"As it now stands, the Branch believes that we may have arrived at that point in the design development which, if any new features are added, can only lead to installation of equipment (such as gas turbine generator sets with or without a waste-heat boiler) yet unproven either by laboratory or in service tests.

"Notwithstanding the fact that testing at NBTL has uncovered some of the bugs, we should not be led into believing that additional bugs will not develop even if only as a result of shipboard operation.

"Since the use of pressure-fired boilers in a naval ship embraces an entirely new concept, we should make every effort to keep the remainder of the plant on a conventional basis. Other new items, should they prove troublesome in service, will only reflect on the initial decision to install pressure-fired boilers on this and all other subsequent designs."

The specific objections were directed to a scheme defined by the Machinery Design Division Coordinating Branch for the DE 1040. The major deviations proposed by that organization are identified on Figure 4-12 as Scheme I and are as follows [4-97]:
FIGURE 4-12 DESIGN SCHEMES FOR DE 1040.
"a. Exhausting ship's service (S.S.) turbo-generators (T-G sets) into the main condenser.


c. Elimination of non-condensing sonar turbo-generators in favor of gas turbine drive."

The net result was two 750-kW T-G sets in the engine room and two 750-kW gas turbine generators with a common waste-heat boiler in the auxiliary machinery room aft. One gas turbine generator was for S.S. use and the other for sonar.

The Machinery Design Branch proposal is identified as Scheme II on Figure 4-12 and included the following [4-97]:

"a. S.S. turbo-generators exhausting to their own condensers.

b. Non-condensing, turbo-generators for SQS-26 sonar.

c. Medium speed, diesel-driven generators in the machinery space aft, and a package unit auxiliary boiler in fireroom."

The net result was two 500-kW or 750-kW S.S. T-G sets and one single-stage 500-kW sonar T-G in the engine room, two 500-kW S.S. diesel generators in auxiliary machinery aft with the auxiliary boiler located in the fireroom.

Advantages and disadvantages of Scheme I as compared with Scheme II are listed in Tables 4-13 and 4-14.
TABLE 4-13 EXHAUSTING S.S. T-G SETS INTO MAIN CONDENSER

ADVANTAGES:

(1) Eliminates some piping, two auxiliary condensate pumps, two auxiliary condensers, salt water circulating pumps and air ejectors.

(2) Takes up less space and offers some weight savings.

(3) Less steps involved in starting up T-G sets providing vacuum is already up on main engine.

DISADVANTAGES:

(1) Any casualty (or normal repair or maintenance function) requiring (or causing) securing of main engine will compound corrective action to be taken since S.S. turbo-generators will trip out due to loss of vacuum on main condenser. Whenever this happens, all propulsion auxiliaries will be affected and will require restarting after emergency electric power is made available or normal source of power is restored.

(2) On top of all the possible ways of normally losing vacuum on main plant, we are generating several more by this arrangement.

(3) Whenever operating personnel consider it more desirable to keep main boiler and S.S. T-G set lit off in port (whether at dockside, anchorage or mooring) it will be necessary to keep vacuum up on main engine with jacking gear engaged.

(4) Continual slow turning of rotor, gears and shafting will lead to an increased bearing wear rate.

(5) Loss of main engine vacuum during battle or any other underway periods causes loss of large portion of electrical generating capacity.

(6) Any operational testing to be performed on either S.S. T-G set necessitates lighting off main engine and associated systems.
TABLE 4-14 GAS TURBINE-WASTE HEAT BOILER COMBINATIONS

ADVANTAGES:

(1) Gas turbine-waste heat boiler installation estimated to be lighter than (Packard) diesel-auxiliary boiler combination by 8,000 pounds or 14,000-20,000 pounds compared to "standard" 1,200 rpm models.

DISADVANTAGES:

(1) No production models available. Units must be developed - no service experience.

(2) Fleet personnel not familiar with gas turbine operation with or without waste heat boiler.

(3) Cost of 750 kW gas turbine unit about $140,000. Cost of waste heat boiler estimated at $30,000 - $35,000 plus cost of development and test ($27,000).

(4) During low kW load, supplemental oil firing may be required which further complicates in-port steam generating system.

(5) If trouble experienced in service, main boilers, engines, etc., will be used during in-port operation.

(6) Fuel consumption worse than diesel-generator-auxiliary boiler by 7 percent at only 10 inches water back pressure and 10 percent worse at 20 inches water back pressure.

(7) Gas by-pass control will be needed since hotel load essentially "on-off" in nature.
The Propulsion Systems Design Branch issued the following statement regarding Scheme II [4-98]:

"It is our belief that introduction of the pressure-fired boiler represents a major design innovation, and as such should not be overshadowed by other plant complexities or any other changes which fall into the category of requiring service testing. It is not our intention to suppress new ideas nor is it our intention to remain conservative just for its own sake. In this regard, we should be guided by the experience gained with the DL 2 class, where forced circulation boilers, combined feed and booster pumps and high-speed turbo-generator sets, all new to U.S. Navy, were all introduced together. Even though these items were previously laboratory tested, their operation aboard ship was not without mishaps of major proportions resulting in ultimate removal of all three items with replacements drawn from conventional equipment. It is interesting to note, that forced circulation boilers and combined feed and booster pumps are tried and proven equipment in installations outside of the U.S. Navy.

"We should not assume that the pressure-fired boiler will not pose new or repeat trouble spots as a result of shipboard operation just because they were previously laboratory tested. Even so, any other new ideas whether laboratory tested or not, if worked into the DE 1040 design at this time would offer the same possibilities detracting from the overall plant design.

"Therefore, in the light of experience gained in other installations having an excess of unproven ideas, and in keeping with the conservatism expressed in the original decision to install pressure-fired boilers, this Code recommends adoption of Scheme II for subject ship plant design."

Scheme II was subsequently adopted.
A number of other design changes occurred as the design progressed. In October 1960, a SCB meeting was held regarding the design progress of the FY 1961 DE.

The Chairman opened the meeting by discussing the FY 1961 DE in general terms. He briefly discussed the pressure-fired boiler and its associated increased horsepower and indicated that naval architects stated that the ship should be increased in length to take advantage of the increased horsepower and thus provide additional speed. He further stated that he had asked the Bureau to look at the possibility of including a surface-to-air missile capability with weight which would be equivalent to 80 tons at the main deck level. The purpose was to provide the same hull for the FY 1961 gun ship and the FY 1962 DE missile ship.

The approved characteristics of the DE 1040 were issued shortly thereafter. The propulsion section read as follows [4-99]:

"Power plant: A single-screw DDG-type power plant with two distillate fuel pressure-fired boilers."

The FY 1962 Shipbuilding Program included three DEG's. It was desired that these DEG's be as similar to the DE's in the FY 1961 Program as possible. To realize this design goal necessitated designing the FY 1962 DEG first, since it was controlling in regard to space, arrangements, and accommodations to be provided.
New characteristics were agreed to in January 1961 and the DE 1040 and DEG 1 classes were on their way and with minor changes survived, any further departure from the characteristics listed in Table 4-15 including the pressure-fired boilers.

In the early 1960's, further modification to the DE 1040 class was desired. This new class was a further evolution of the SCB 199 study and was designated as SCB 199C. This class became the DE 1052. The DE 1052, the last of the DE 1037 evolutions, started with the pressure-fired boiler concept and completed its contract design phase as such.

The contract for the detail design of the DE 1052 was awarded to Gibbs and Cox, who had done the detail design of all U.S. destroyers since World War II with the exception of the DE 1040 which had been completed by Bethlehem. Fairly soon after the award of the detail design of the DE 1052, the power plant was abruptly changed back to a non-pressure-fired boiler plant, i.e., to the DE 1037 class power plant. This abrupt change away from a power plant type to which nearly two decades of development and testing had been devoted and to which 17 ships were committed (none of which were completed and in the fleet at the time of the decision) certainly appears to have been politically motivated. Interviews with the Bureau of Ships and Gibbs and Cox personnel have verified this assumption.
<table>
<thead>
<tr>
<th></th>
<th>Original Preliminary Design</th>
<th>Final Accepted Preliminary Design</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gun</td>
<td>TARTAR</td>
</tr>
<tr>
<td>LOA (feet)</td>
<td>398.4</td>
<td>398.4</td>
</tr>
<tr>
<td>LBP (feet)</td>
<td>375</td>
<td>375</td>
</tr>
<tr>
<td>Beam &amp; DKL (feet)</td>
<td>39.5</td>
<td>39.5</td>
</tr>
<tr>
<td>Depth to Main Deck Amidship—</td>
<td>22.25</td>
<td>22.25</td>
</tr>
<tr>
<td>no camber (feet)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth at side to upper deck</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>amidships (feet)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Navigational draft to Bottom</td>
<td>23.7</td>
<td>23.7</td>
</tr>
<tr>
<td>of Dome—full load (feet)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sustained speed (knots)</td>
<td>same</td>
<td>same</td>
</tr>
<tr>
<td>Shaft Horsepower</td>
<td>34,000</td>
<td></td>
</tr>
<tr>
<td>Endurance at 20 knots</td>
<td>same</td>
<td>same</td>
</tr>
<tr>
<td>Configuration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complement</td>
<td>16 Off.</td>
<td>16 Off.</td>
</tr>
<tr>
<td></td>
<td>179 Enl.</td>
<td>179 Enl.</td>
</tr>
<tr>
<td></td>
<td>1-3&quot;/50 RFTM</td>
<td>1-MK 13 TARTAR</td>
</tr>
<tr>
<td>Armament</td>
<td>1-3&quot;/50 RFSM</td>
<td>1-3&quot;/50 RFSM</td>
</tr>
<tr>
<td></td>
<td>2 MK 32 Torpedo Tube Installations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No Torp.</td>
<td>6 MK 25 Torp.</td>
</tr>
<tr>
<td></td>
<td>Tubes</td>
<td>Tubes</td>
</tr>
<tr>
<td>DASH-3 Helicopter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radars</td>
<td>ASROC</td>
<td>ASROC</td>
</tr>
<tr>
<td>Surface Search</td>
<td>SPS-5</td>
<td>SPS-5</td>
</tr>
<tr>
<td>Air Search</td>
<td>SPS-40</td>
<td>SPS-39440</td>
</tr>
<tr>
<td>Sonar</td>
<td>SQS-26</td>
<td>SQS-26</td>
</tr>
<tr>
<td>Light Ship displ.</td>
<td>2167T</td>
<td>2200T</td>
</tr>
<tr>
<td>Full load displ.</td>
<td>2886T</td>
<td>2950T</td>
</tr>
</tbody>
</table>
How did this abrupt change come about? A very interesting story appears to lie behind this change which lends strong support to the hypothesis that innovation adoption is a political process.

The request for proposals (RFP) for DE 1052 detail design was issued on October 15, 1963. Gibbs and Cox prepared a proposal presenting their views as synthesized from discussions with various boiler manufacturers and first-hand experience with pressure-fired boilers.

On December 9, 1963, Gibbs and Cox was awarded the contract for detail design of the DE 1052. Later that month, Mr. Francis W. Gibbs, the President of the company, a highly influential and respected ship designer in Navy circles for almost 30 years, advised the Chief of the Bureau against using the pressure-fired boiler design and suggested redesigning the DE 1052 with conventional boilers.

The Bureau and Gibbs and Cox held a major conference in early January 1964, concerning ramifications of changing from pressure-fired boilers to conventional 1,200-psi boilers.

Bidding on the ships was suspended the following day and the Bureau advised its contractor that the boilers would be changed from pressure-fired to conventional.

According to Gibbs and Cox personnel, the major reason for the change in boiler type was that, although 17 ships were committed to pressure-fired boilers, none were in operation and would not be until some time
after the DE 1052 class construction program was underway. It seemed imprudent to them to commit a 50-ship class to a type of boiler which had not been proven in service and which did not permit fallback to a conventional-type boiler because of space considerations.

Given these misgivings concerning the pressure-fired boiler, the question arises regarding the rationale for committing the 17-ship class to the concept in the first place a few years earlier. A "not invented here" attitude by Gibbs and Cox certainly appears to have been an influencing factor. After all, if one had had a monopoly on the detail design of U.S. destroyers up to the time of the DE 1040 design, it certainly was very convenient to be able to prove that the Navy had failed to get a good design when, for a single time it broke with tradition and had Bethlehem Steel, not Gibbs and Cox, do the detail design of a warship - the DE 1040.

The Chief of the Bureau at that time, in a 1976 interview with the author of this study, recalled that he had received a call from the Secretary of the Navy after his decision, asking him by what authority he had made such a significant change and so abruptly. To this, the Chief cited the authority vested in him as Chief of the Bureau of Ships and the issue was laid to rest.

Though there were some valid technical reasons for not committing more ships to the pressure-fired boiler, the decision appears to have been strongly influenced by politically-motivated advice.
In spite of some unsolved engineering problems regarding the pressure-fired boilers at that time, the abrupt change at that late stage of design development provides an interesting and unusual insight into the way in which innovations get adopted or rejected.

Thus a competitor to the gas turbine was eliminated by the DE 1052 class but the fact is that gas turbines were losers as well, since they were not even considered as an option even though by that time both the British and Soviets had operational gas turbine warships in their fleets.
During the 1950's, the Ship Characteristics Board (SCB) continuously attempted to get a small inexpensive Destroyer Escort (DE) which could be mass produced. This goal was reflected in the preliminary characteristics for the DE 1006, DE 1033, DE 1037, DE 1040, DEG 1 and DE 1052 classes, but, as the evidence shown on Table 4-16 bears out, the ultimate trend was one leaning to increasing size. In addition, costs kept increasing at an even more rapid rate than ship size because of the increased use of high-priced electronic and aviation components.

In March 1959, the Chief, Bureau of Ships was requested by the Chairman of the SCB [4-100] to make a limited cost and feasibility study of a Convoy Escort Vessel. This ship was to be a manned platform for the high performance active sonar (SQS-26) and was to be used for screening merchant convoys and for protecting assembled shipping. Procurement and operating costs had to be kept to a minimum since large numbers of these ships would be required. To minimize cost and manning for this new ship, the SCB did not require speed in excess of that necessary to keep station with and provide sonar coverage around, the majority of merchant convoys. Self-defense armament was to be minimal and the ship was to rely on Anti-Submarine Warfare (ASW) aircraft from other ships or shore bases to localize and kill the submarines it detected.

This exploratory study was intended to provide long range assistance in determining whether adequate escort ship protection for
<table>
<thead>
<tr>
<th></th>
<th>Length (O.A.) Ft.</th>
<th>Beam Ft.</th>
<th>Displacement (F.L.) Tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE 1006</td>
<td>314</td>
<td>37</td>
<td>1,904</td>
</tr>
<tr>
<td>DE 1033</td>
<td>312</td>
<td>38</td>
<td>1,851</td>
</tr>
<tr>
<td>DE 1037</td>
<td>371.5</td>
<td>40.5</td>
<td>2,650</td>
</tr>
<tr>
<td>DE 1040</td>
<td>414.5</td>
<td>44.2</td>
<td>3,245</td>
</tr>
<tr>
<td>DE 1052</td>
<td>438</td>
<td>46.75</td>
<td>4,100</td>
</tr>
</tbody>
</table>
merchant convoys could be planned for the 1969-1974 period within the anticipated available shipbuilding funds. It was requested that the subject study be completed prior to 1 September 1959.

A sustained speed of 15 knots was required and propulsion noise interference with sonar performance was to be minimized. Simplicity and minimum cost were important criteria in this ship, and it was hoped that the substantially reduced power and speed requirements would make it feasible to hold noise to acceptable limits while still utilizing a conventional plant with limited noise reduction features.

The Preliminary Design Branch's interpretation of these instructions was that OPNAV was willing to sacrifice operational performance in many areas in an effort to obtain a ship with good submarine detection capabilities at low cost. There were soon indications that where machinery was concerned, "optimum noise-free operation" and "minimum cost" were conflicting requirements. Since this design study was to be used for planning purposes for the late 1960's, the design organization presented two different studies for SCB review:

**Scheme A** - A design which could be built right away or in the immediate future.

**Scheme B** - A design which could be built ten years from then; i.e., 1969, incorporating the best foreseeable technological advances in hull, machinery, electronic, and acoustical design.
The Minimum Ocean Escort took advantage of the slow speed requirement to provide a good quiet platform for an AN/SQS-26 sonar without going to unconventional propulsion plants. Since the requirements for the Escort Ship did not include any capability which could not be provided in the hull of a merchant ship, an alternative study was prepared which would utilize a mobilization type cargo ship hull, such as a C3, as a platform for the SQS-26 sonar. In this ship, the propulsion machinery was to be located aft in order to provide the greatest separation of machinery noise from the sonar. With the ship fully loaded, the transducer would have been submerged about 36 feet. This location of the transducer plus the inherent stability of a big, heavily loaded merchant ship could have provided the sonar with an excellent operating environment.

A nuclear submarine alternative was also studied. Although the cost of this small submarine was considerably greater than the cost of any of the conventionally powered surface ship alternatives, the detection capability of the integrated sonar system on a submarine was expected to be greater than that of the SQS-26 surface ship sonar. This submarine would have the further advantages of a significant attack capability, security from air attack, and, compared with the convoy escort type, economy of personnel.

In view of the increasing numbers of 15 to 20 knot merchant ships, the Bureau felt that it would be appropriate to consider the effect of requiring the Minimum Escort of 1969-1974 era to have a sustained speed of 20 knots. Detailed studies were not made of a 20 knot
Minimum Escort Ship but extrapolation of 15 knot designs gave a close approximation of the size and cost which would be expected in such a ship. Twenty knot versions of three ship alternatives were proposed.

The characteristics and prices of the various alternatives studied are shown in Table 4-17.

In late 1959, this data was provided to the SCB but was put aside without further action. By 1961, development of aircraft derivative gas turbines with the performance and fuel economy characteristics required for naval service as well as successful developments in the diesel engine industry, prompted the Bureau to study the possibility of Combined Diesel and Gas Turbine (CODAG) power plants as propulsion systems for combatant ships. Since Controllable Reversible Pitch Propellers (CRP) in the larger horsepower ranges had been shown to be feasible, their marriage with the CODAG plant promised a degree of flexibility in performance and improved fuel economy never before realized in major naval ships. Developments made in gearing and coupling enhanced the possibility of relatively simple, efficient, quiet propulsion systems. The anticipated reduction in manning based on experience with successfully automated industrial power plants further enhanced the potential of CODAG, so that, when in September 1961, the Chief of Naval Operations (CNO) kicked off the SEAHAWK program, a machinery study was already underway.

The SEAHAWK studies were to determine the feasibility of designing destroyer escorts with optimum ASW capability, minimum Anti-Aircraft Warfare (AAW), reduced complement, lowered operating costs, with
<table>
<thead>
<tr>
<th></th>
<th>15 Knots</th>
<th></th>
<th>20 Knots</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum Ocean Escort</td>
<td>Merchant Ship with Sonar</td>
<td>Submarine Escort</td>
</tr>
<tr>
<td>Speed (Kts.)</td>
<td>15 Sustained SQS-26</td>
<td>15 Sustained SQS-26</td>
<td>15 Submerged SQS-26 BQQ-2</td>
</tr>
<tr>
<td>Sonar</td>
<td>4-21&quot; tpdo tube mt.</td>
<td>None (DASH could be provided)</td>
<td>1-Mk 32 tpdo tube mt.</td>
</tr>
<tr>
<td>Armament</td>
<td>6-Mk 44 tpdos 1-40 mm twin</td>
<td>(Naval Unit)</td>
<td>6-Mk 44 tpdos 1-40 mm twin</td>
</tr>
<tr>
<td>Accommodations:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Officers</td>
<td>10</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Enlisted</td>
<td>80</td>
<td>50</td>
<td>80</td>
</tr>
<tr>
<td>Endurance</td>
<td>4500 miles @ 15 Kts.</td>
<td>25,000 miles @ 15 Kts.</td>
<td>3,000 miles @ 20 Kts.</td>
</tr>
<tr>
<td>Length, overall</td>
<td>260'</td>
<td>493'</td>
<td>273'</td>
</tr>
<tr>
<td>Beam</td>
<td>36'</td>
<td>73'</td>
<td>23'</td>
</tr>
<tr>
<td>Displacement</td>
<td>1700 T.</td>
<td>17,000 T.</td>
<td>2600 T.</td>
</tr>
<tr>
<td>Propulsion</td>
<td>4000 SHP</td>
<td>8500 SHP</td>
<td>2500 SHP</td>
</tr>
<tr>
<td></td>
<td>Diesel</td>
<td>Steam Turbine</td>
<td>Nuclear</td>
</tr>
<tr>
<td>Estimated Cost</td>
<td>$8 M.</td>
<td>For Total Electronics Installation $3 M.</td>
<td>$41 M.</td>
</tr>
<tr>
<td>of follow ship</td>
<td></td>
<td>Add $0.5 M. for DASH Facilities</td>
<td>$15 M.</td>
</tr>
</tbody>
</table>
the additional requirement that they would be economical to produce in quantity. Optimization of ASW was the basic precept of the SEAHAWK program as seen by CNO. A two-phase program was planned; SEAHAWK I and SEAHAWK II. The plan was to design a ship for the FY 1965 shipbuilding program (SEAHAWK I) which would not push the state-of-the-art too much and concurrently to carry on an R&D program which would yield improvements in a variety of ship systems. These improvements would then be incorporated in the FY 1968 shipbuilding program (SEAHAWK II).

By December 1961, the Machinery Design Division completed a study of a DE-size ship of approximately 37,000 shp. This study demonstrated that the CODAG power plant had the greatest potential of any power plant in a ship of the displacement of the DE 1040 (Pressure Fired Boiler Plant). Quoting, in part the abstract from the study, reference [4-101],

"CODAG, a diesel base plant with gas turbine booster, offers a package type plant that can be sound mounted and automated, and that promises the greatest gains: about 90 percent increase in 15 knot endurance and a significant saving in operating costs."

The Chief of the Bureau of Ships in response emphasized the importance of development planning to assure availability of reliable major machinery items for CODAG and placed the diesel and gas turbine prime movers and the CRP in a critical development category, urging that development be started, "... immediately, using such FY 1962 funds as can be made available."
The Bureau of Naval Personnel made clear in its 4 January 1962 SCB presentation that the reliability of shipboard equipment was a prime determinant in the numbers and intelligence levels of the men required to man the Navy's ships. To insure the maximum reliability, and thus the ultimate success of the ship, the Bureau of Ships felt that it was essential that shore testing of propulsion components be conducted before shipboard installation.

The Bureau went on with further studies of alternative propulsion plants. By July 1962, they had narrowed the options to four [4-102]:

**Scheme A** was a single screw design consisting of three base plant diesel engines, each rated at 3,800 shp, and one gas turbine, rated at 23,600 shp (see Figure 4-13). To permit the diesel engines to develop their rated horsepower at both full power and an intermediate ship speed, a two-speed gear had been incorporated in the design of the diesel engine transmission. The machinery box length for this scheme was 100 feet. Three 750 kW gas turbine ships' service generators were used in this study for weight and endurance calculations. A CRP propeller had also been included in the design.

**Scheme B** was similar to Scheme A, except two 750 kW diesel generator sets and one 750 kW gas turbine generator set had been used.

**Scheme C** was similar to Scheme A, except three 500 kW diesel generator sets and one 750 kW gas turbine generator set had been used.
FIGURE 4-13 SCHEME A - SINGLE SCREW DESIGN WITH THREE BASE PLANT DIESELs AND ONE GAS TURBINE
Scheme D was a twin screw design using two base plant diesel engines, each rated at 3,800 shp and one gas turbine, rated at 20,400 shp per shaft (see Figure 4-14). Two-speed gears for the diesel engines and CRP propeller had been included in this design. The machinery box length for this study was also 100 feet. Three 500 kW diesel generators and one 750 kW gas turbine generator had been included.

The various cost comparisons of the four schemes compared with the DEG 1 are shown on Table 4-18. Table 4-19 depicts base plant capabilities with various combinations of propeller and gear types. For the best overall operating capabilities of a CODAG system, both the two-speed gear and CRP propeller were recommended for installation. Figure 4-15 is an endurance comparison of the various schemes studies. All endurance calculations were based on oil stowage of 620 tons. Since the greatest percentage of underway hours are spent operating at speeds of 20 knots or less, the low specific fuel rates of the diesel engines give the CODAG machinery plant marked increases in cruising radius. The summary of all comparative characteristics of Schemes A through D are presented in Table 4-20. The final conclusion drawn from the study by the Machinery Design Branch was that Scheme D, the twin screw propulsion plant, in a hull similar to the DEG, was the best choice.

While these machinery designs were being developed by the Machinery Design Branch, new requirements emerged from OPNAV. A requirement for speed in excess of 30 knots was established. The design now
FIGURE 4-14 SCHEME D - TWIN SCREW DESIGN USING TWO BASE PLANT DIESELS AND ONE GAS TURBINE
<table>
<thead>
<tr>
<th>CODAG Schemes</th>
<th>DEG 1 (1000's)</th>
<th>A (1000's)</th>
<th>B (1000's)</th>
<th>C (1000's)</th>
<th>D (1000's)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Fuel Cost</td>
<td>299</td>
<td>281</td>
<td>230</td>
<td>230</td>
<td>227</td>
</tr>
<tr>
<td>Annual Maintenance Cost*</td>
<td>32</td>
<td>51</td>
<td>38</td>
<td>38</td>
<td>51</td>
</tr>
<tr>
<td>Annual Manning Cost</td>
<td>300</td>
<td>240</td>
<td>240</td>
<td>240</td>
<td>240</td>
</tr>
<tr>
<td>Initial Machinery Cost</td>
<td>2,075</td>
<td>3,540</td>
<td>3,581</td>
<td>3,572</td>
<td>4,691</td>
</tr>
<tr>
<td>Present Worth Cost Fuel (30 year cycle)</td>
<td>5,175</td>
<td>4,860</td>
<td>3,980</td>
<td>3,980</td>
<td>3,930</td>
</tr>
<tr>
<td>Present Worth Cost Maintenance (30 year life)</td>
<td>553</td>
<td>882</td>
<td>657</td>
<td>657</td>
<td>882</td>
</tr>
<tr>
<td>Present Worth Cost Manning (30 year life)</td>
<td>5,185</td>
<td>4,150</td>
<td>4,150</td>
<td>4,150</td>
<td>4,150</td>
</tr>
<tr>
<td>Total Present Worth Cost, Machinery, Fuel, Maintenance, Manning</td>
<td>12,988</td>
<td>13,432</td>
<td>12,368</td>
<td>12,359</td>
<td>13,653</td>
</tr>
</tbody>
</table>

* Maintenance cost for the DEG 1 was based on data from Bethlehem Steel Report on optimum steam conditions. Maintenance costs for the other schemes are based on estimated overhaul costs for the propulsion diesel engines, gas turbines, and ship's service generator sets.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>21.5</td>
<td>21.5/6.5</td>
<td>18.5/0</td>
<td>17.5/9</td>
</tr>
<tr>
<td>B</td>
<td>21.5</td>
<td>21.5/6.5</td>
<td>18.5/0</td>
<td>17.5/9</td>
</tr>
<tr>
<td>C</td>
<td>21.5</td>
<td>21.5/6.5</td>
<td>18.5/0</td>
<td>17.5/9</td>
</tr>
<tr>
<td>D</td>
<td>23.5</td>
<td>23.5/7.2</td>
<td>22/0</td>
<td>20.5/9.6</td>
</tr>
</tbody>
</table>
FIGURE 4-15  ENDURANCE COMPARISON OF SCHEMES A THROUGH D
<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>F. P. SHP</td>
<td>35,000</td>
<td>35,000</td>
<td>35,000</td>
<td>56,000</td>
</tr>
<tr>
<td>Base Plant SHP</td>
<td>3-diesel</td>
<td>3-diesel</td>
<td>3-diesel</td>
<td>4-diesel</td>
</tr>
<tr>
<td></td>
<td>11,400 SHP</td>
<td>11,400 SHP</td>
<td>11,400 SHP</td>
<td>15,200 SHP</td>
</tr>
<tr>
<td>Boost Plant SHP</td>
<td>1-gas turb.</td>
<td>1-gas turb.</td>
<td>1-gas turb.</td>
<td>2-gas turb.</td>
</tr>
<tr>
<td></td>
<td>23,600 SHP</td>
<td>23,600 SHP</td>
<td>23,600 SHP</td>
<td>40,800 SHP</td>
</tr>
<tr>
<td>Base Plant</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed, Kts.</td>
<td>21.5</td>
<td>21.5</td>
<td>21.5</td>
<td>23.7</td>
</tr>
<tr>
<td>Sustained</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed, Kts.</td>
<td>27.7</td>
<td>27.7</td>
<td>27.7</td>
<td>31</td>
</tr>
<tr>
<td>Propellers-No.</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Type Prop.</td>
<td>Fixed Pitch</td>
<td>Fixed Pitch</td>
<td>Fixed Pitch</td>
<td>Fixed Pitch</td>
</tr>
<tr>
<td></td>
<td>or CRP</td>
<td>or CRP</td>
<td>or CRP</td>
<td>or CRP</td>
</tr>
<tr>
<td>Mach. Box Length</td>
<td>100'</td>
<td>100'</td>
<td>100'</td>
<td>100'</td>
</tr>
<tr>
<td>Mach. Wt., Tons</td>
<td>592 tons</td>
<td>635 tons</td>
<td>602 tons</td>
<td>790 tons</td>
</tr>
<tr>
<td>20K Endurance</td>
<td>5200</td>
<td>5700</td>
<td>5700</td>
<td>5850</td>
</tr>
<tr>
<td>15K Endurance</td>
<td>6300</td>
<td>7400</td>
<td>7400</td>
<td>7400</td>
</tr>
<tr>
<td>10K Endurance</td>
<td>7300</td>
<td>9850</td>
<td>9850</td>
<td>9850</td>
</tr>
<tr>
<td>S. S. Generator</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sets</td>
<td>3-750 KW</td>
<td>2-750 KW D</td>
<td>3-500KW D</td>
<td>3-500KW D</td>
</tr>
<tr>
<td></td>
<td>Gas Turb.</td>
<td>1-750 KW GT</td>
<td>1-750KW GT</td>
<td>1-750KW GT</td>
</tr>
<tr>
<td>Reduction Gears</td>
<td>L T D R - G T</td>
<td>L T D R - G T</td>
<td>L T D R - G T</td>
<td>L T D R - G T</td>
</tr>
<tr>
<td></td>
<td>2-Speed-D</td>
<td>2-Speed-D</td>
<td>2-Speed-D</td>
<td>2-Speed-D</td>
</tr>
<tr>
<td>Auxiliary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boilers</td>
<td>2-5000</td>
<td>2-5000</td>
<td>2-5000</td>
<td>2-5000</td>
</tr>
<tr>
<td></td>
<td>1b/hr</td>
<td>1b/hr</td>
<td>1b/hr</td>
<td>1b/hr</td>
</tr>
<tr>
<td>Gas turbine Ov'hl</td>
<td>5000 Hr</td>
<td>5000 Hr</td>
<td>5000 Hr</td>
<td>5000 Hr</td>
</tr>
<tr>
<td>Diesel Ov'hl</td>
<td>5000 Hr</td>
<td>5000 Hr</td>
<td>5000 Hr</td>
<td>5000 Hr</td>
</tr>
<tr>
<td>Sound Isolation</td>
<td>Diesels +</td>
<td>Diesels +</td>
<td>Diesels +</td>
<td>Diesels +</td>
</tr>
<tr>
<td>Mach. Space</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Manning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

211
leaned toward a ship of destroyer (DD) size, with total shaft horsepower requirements ranging from 50,000 to 80,000 as opposed to the DE size ship with approximately 37,000 horsepower. The propulsion system envisioned is shown on Figure 4-16.

By mid-July 1962, there was no assurance that the power plant, determined to be optimum for the DE size ship, would be a Combined Diesel and Gas Turbine (CODAG) plant. Consideration was also being given to Combined Steam and Gas Turbine (COSAG), Combined Gas Turbine and Gas Turbine (COGAG), conventional steam, and pressure-fired boiler plants. To further lend uncertainties, there were several different machinery arrangement concepts of the CODAG, COSAG, and COGAG plants. Time did not permit delay in planning the development program for the major machinery items, and since it appeared that the CODAG plant was still the most promising, the Machinery Division's planning was based on a CODAG plant for the higher speed ship. Because of the accelerated time scale, it was mandatory that parallel efforts be supported to provide an adequate fall-back position.

It was intended that developmental and suitability work on the Pratt and Whitney FT4A engine be pursued on an accelerated basis because of the better potential of that engine and to pursue work on the General Electric (G.E.) MS 240 engine on a reduced funding and priority basis. Experience gained with the G.E. engine in the MARAD Hydrofoil boat DENNISON, which was being built, was thought to support this effort. Because of the
PLAN VIEW

<table>
<thead>
<tr>
<th>ITEM</th>
<th>DESCRIPTION</th>
<th>QTY/SHAFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>20,000 BHP BOOST GAS TURBINE</td>
<td>2</td>
</tr>
<tr>
<td>B</td>
<td>30,000 BHP CLUTCH</td>
<td>2</td>
</tr>
<tr>
<td>C</td>
<td>COMBINING REDUCTION GEAR</td>
<td>1</td>
</tr>
<tr>
<td>D</td>
<td>HYDRAULIC COUPLING</td>
<td>2</td>
</tr>
<tr>
<td>E</td>
<td>SOUND ISOLATION COUPLING</td>
<td>2</td>
</tr>
<tr>
<td>F</td>
<td>DIESELS FOR BASE LOAD OPERATION, 4,000 - 5,000 BHP</td>
<td>2</td>
</tr>
</tbody>
</table>

SOURCE: REF [4-102]

FIGURE 4-16 CODAG MACHINERY ARRANGEMENT

213
reduced power capability of the MS 240 engine (13,500 bhp versus 20,000 bhp for the PT4A), three MS 240 engines were required to provide the required 40,000 shp.

An entire shaft's worth of machinery was planned for installation at NBTL, to be operated for a period of approximately 24 months prior to operation of the same machinery in the FY 1965 ship. This was going to provide sufficient time to evaluate and debug the plant if procurement papers for the entire plant were processed by January 1963.

While machinery plant design was proceeding, the operational requirements were under almost constant re-evaluation. In mid-1962, the design division established a project manager for SEAHAWK and an R&D panel was established to review the Technical Development Plant (TDP) for the project. By the end of August 1962, the Machinery Division was still continuing study of pressure-fired boiler steam plants as well as those combining diesels and gas turbines. While the TDP indicated that combined plants would be used, the Machinery Division did not consider this to be a firm decision. Such things as the importance of a minimum cruising speed of 25 knots, an unspecified range at full speed, the effect of machinery and fuel weight and space requirements on the final hull design could have dictated a change in propulsion plant.

Inasmuch as the combined plant development was going to require the most time and money and offered the prospect of maximum improvement for the FY 1965 SEAHAWK, the Machinery Division felt that the TDP should
request funds for an approach which left the propulsion system question open. They felt that firming up the propulsion plant for the FY 1965 ship should not therefore preclude development of other schemes, which would surpass CODAG, for use in SEAHAWK programs after FY 1965, i.e., SEAHAWK II.

The following excerpts from the TDP indicate the prevailing attitude of the 1962 ship design community toward gas turbine propulsion [4-103].

"The propulsion plants studied encompass the power range necessary to drive an ASW ship at desired speeds with displacements likely to result from parametric ship designs now in process. Over the power range studied, the CODAG plant comes closest to meeting all of the requirements, namely mission reliability, limited manning, damage and casualty control, low specific weight, flexibility of control and fuel economy. For maximum simplicity, the gas turbine alone will be used for full power and the diesels alone for cruising. A controllable, reversible pitch propeller will be used with a conventional reduction gear.

"For later ships in the program, consideration will be given to the substitution of a lightweight, low fuel consumption, base load gas turbine plant, if further study shows that this unit can be developed in time.

"Within the space presently allocated to the combined plants, a pressure-fired boiler steam plant can be accommodated. This steam plant does not require development and will be available as a backup for the CODAG and COGAG plants, or as a primary plant if the characteristics of SEAHAWK, as finally developed, so indicate.

"The detailed research and development tasks presented in this area are intended first, to result in the design of an efficient hull and second, to allow proper selection of a propulsion system."
"A CODAG propulsion plant seems to offer the best overall operating characteristics. However, in view of the developmental work required, a steam plant will be available as a backup or as a primary plant if final SEAHAWK characteristics so dictate. It is to be noted that little or no development is required for a steam plant, although some testing may be in order if predicted component ratings change beyond certain limits.

"The tasks presented for the propulsion plant area are aimed at a CODAG installation."

By October 1962, the propulsion machinery plant for SEAHAWK I was still undefined. The tentative requirement for a 25-knot cruise capability tended to detract from the inherent advantages of the CODAG concept and to support the COGAG and pressure-fired boiler steam plants; however, the CODAG concept still appeared to offer significant promise. The COGAG concept was not pursued (other than as a paper study) because of the unavailability of a gas turbine with the combination of good fuel characteristics and demonstrated reliability in marine environment which was required of a base load propulsion plant for a combatant ship. The COGAG concept did offer some advantages and an effort was made to develop a base load gas turbine for SEAHAWK II (FY 1968). The CODAG plant being considered (16,000 bhp diesel) would be capable of providing a sustained speed of approximately 22.5 knots on the diesel plant and would rely on boost gas turbine power for additional speed. With the anticipated uprating of the base load diesel plant to 20,000 bhp by FY 1968, the cruise speed capability on the base load plant would approach 24 knots.

In October 1962 the Chief of the Bureau made the following recommendation to CNO [4-104]:

216
"In accordance with our recent discussion on SEAHAWK I, we have completed the ship feasibility studies relating to power plant selection. A twin screw CODAG (Combined Diesel and Gas Turbine) design has been selected as the optimum power plant for SEAHAWK I. This type of plant was selected because of its clear superiority in reliability of base plant components, ease and quality of sound isolation, good maneuvering characteristics. Other types studied were pressure-fired boiler, gas turbine electric and conventional steam plants. Both single screw and twin screw CODAG designs were studied. The Bureau of Ships, working closely with industry, will further develop the gas turbine for use as the base plant in SEAHAWK ships when its fuel rate and operational status are sufficiently improved to merit its adoption."

The CODAG plant design which the Bureau was proposing to use was based on the use of four Fairbanks Morse 38 ND 8-1/8, 12 cylinder, supercharged, diesel base plant engines and four Pratt and Whitney boost gas turbines per ship. The base plant engine had been used successfully in previous naval installations. The Pratt and Whitney gas turbines had been used successfully in many aircraft installations and were being adopted for marine installation. The arrangement of this power plant is shown on Figure 4-17.

The proposed ship characteristics were as follows:

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>420 feet</td>
</tr>
<tr>
<td>Full Load Displacement</td>
<td>4,200 tons</td>
</tr>
<tr>
<td>Endurance</td>
<td>4,000 miles @ 20 knots</td>
</tr>
<tr>
<td>Sustained Speed</td>
<td>28+ knots</td>
</tr>
<tr>
<td>Trial Speed</td>
<td>30+ knots</td>
</tr>
</tbody>
</table>
Figure 4-17 CODAG Plant Design Proposed for Seahawk I
The Bureau felt that although some changes in these characteristics were to be expected as the design developed, this ship hull would be able to accommodate a gas turbine base plant when its adoption was considered appropriate without change in the size of the machinery spaces. Further, it was expected that this hull would be suitable for all other uprated SEAHAWK II requirements, thus arresting the historical growth trend for destroyer escorts.

The Coast Guard became aware of the Navy's effort in the CODAG area and requested that four of their engineers witness some of the CODAG testing and design work. This event is significant because it is another instance when (as with the COSAG plant in the late 1950's when the British came to observe our experiment only to adopt the concept) the observers quickly adopted CODAG for their new class of cutters while the Navy continued to experiment and study.

Initial planning for the studies were to direct an analysis of three basic engine concepts for the base load plant.

Westinghouse approached the Bureau with a COSAG proposal; however, a Bureau report comparing the Westinghouse recommendations with the Bureau's CODAG study determined that further development of the COSAG plant for SEAHAWK I was not warranted.

A major turning point for the SEAHAWK program occurred at the end of October 1962, and, in effect, marked the eventual demise of the SEAHAWK project.
Two separate events caused this turn of events:

a. Heightened interest on the part of the R&D community in the SEAHAWK program.

b. Bethlehem Shipbuilding Company's eagerness to get work for their engineers coming off the DE 1040 program.

In his memorandum for the Chief of Naval Operations on the subject of "ASW Surface Ships and the SEAHAWK Program" dated 30 October 1962, the Secretary of the Navy stated [4-105]:

"Continue to construct ASW destroyer escort types as currently approved in our shipbuilding program. Major changes to our shipbuilding program will be considered only when more conclusive evidence is available from the R&D Program that such major and costly changes will result in a significantly improved ASW capability.

"We are about to finalize contract negotiations for the development of a propulsion plant of advanced design and for its prototype installation. Since one of the principal objectives to be obtained from such a plant is quiet operation at high ship speeds, it will be necessary to examine a number of propulsion systems in order to develop the one most suitable for an advanced type of destroyer escort optimized for ASW.

"Starting with FY 1963, accelerate and augment RDT&E efforts on surface ship ASW systems and projects presently in our program. This should include SQS-26, VDS, MK 46 torpedo, silencing steam plants, and DASH. We also should initiate and focus increased attention on selective R&D longer range ASW programs directed toward significant improvements in our ASW systems capability. As a minimum, this should include PADLOC or an active planar array sonar with integrated fire control system, and periscope detection radar. These new systems should be evaluated at sea in an experimental ship at the earliest practical date."
"If the development of our longer range ASW and propulsion systems proceeds at a satisfactory pace and significant improvements appear attainable, construct a SEAHAWK prototype ship at the earliest practicable date, but preferably not later than FY 1965."

These excerpts indicate a shift in emphasis toward ASW weapons and sensors, and away from the propulsion system. The record indicates that this took place largely as a result of the influence of the office of ASN R&D.

It was about this same time that Bethlehem Steel Corporation stated to CNO that it could design a 40-knot SEAHAWK.

Back in February 1962, Bethlehem Steel Shipbuilding Division proposed to the Navy a high-speed destroyer design propelled by gas turbines in a COGAG arrangement. The Bureau's evaluation of the proposal concluded that the design did not offer the major advantages indicated by the Bethlehem report. However, the Bureau agreed to continue studying the COGAG concept for FY 1965 ASW application in conjunction with its Preliminary Ship Design Branch. Based on the Bureau's studies to that time, the CODAG type of plant offered the largest anticipated gain in endurance for the same total weight of machinery plus fuel. The Bureau took issue with many other features of the Bethlehem proposal, such as stack height in view of the high exhaust temperature, the lack of air cooling for engines which the Bureau felt should be provided and the basing of engine reliability estimates on commercial aircraft service in lieu of marine service.
Before any commitment to the Bethlehem proposed gas turbine (FT3C) the Bureau wanted to have an extensive test program in a typical shipboard application such as a DE or DD. The Bureau thanked Bethlehem for its proposal and made no further move on the issue. However, Bethlehem's large engineering team was finishing the DE 1040 detail design and was looking for work. The size of a detail design team for a destroyer often numbers over 1000 or more people. As a result, when the project approaches completion, there are large numbers of people looking for new work. The first group finding itself out of work is not the draftsmen, but the engineers. It is natural fo: the company to try to retain the engineering talent it had built up to be available for the next job.

It was this precise situation which motivated Bethlehem to look ahead and make their gas turbine proposal. The proposal was premature because the Navy had not even considered the major requirements for a high speed destroyer. For the FY 1965 ASW destroyer, maximum speed was not the issue, quiet operation and reduced manning were.

Having received a cold shoulder from the Bureau, Bethlehem's vice president in charge of shipbuilding, in an effort to obtain further design work told the CNO that Bethlehem could design a 40-knot DE. This prompted the CNO to write a letter to the chairman of the Ship Characteristics Board in which he stated his concern [4-106]:

"I am apprehensive and have serious reservations that the study for SEAHAWK does not push the state-of-the-art far enough with particular regard to ship propulsion."
"While I recognize that certain minimum requirements would permit mass production at an early date such as to give us a ship capable of 28 knots maximum speed and a cruising range of 4,000 miles at 20 knots, I would like to see stiffer requirements imposed which would prescribe minimums of 6,000 miles at 25 knots and a 'burst speed' of 40 knots."

The SCB Chairman echoed the CNO to the Chief of the Bureau [4-107]:

"The Chief of Naval Operations is seriously concerned that designs represent essentially the present state-of-the-art in surface ships and not what can be reasonably expected of a vigorous research and development program in this field extending into the next decade.

"In the present environment of rapidly advancing technology, there is clear indication that it is feasible to achieve greater endurance and higher speeds than presently envisioned in destroyer and smaller sized ships in our future shipbuilding programs. In the advance design ASW destroyer, the goal should be to provide a range of 5,000 miles at 25 knots cruising speed and a burst speed of 40 knots within the approximate hull envelope now proposed.

"Accordingly, the Chief, Bureau of Ships is requested to review the surface ship propulsion area and to take vigorous and forward-looking steps to advance the state-of-the-art, particularly in destroyer size and smaller ships."

In response to CNO's directive for high speed, the R&D organization of the Bureau wrote to the machinery design and gas turbine organizations stating that gas turbine propulsion plant would be the only way to reach CNO's goal of high speed [4-108]:

"The gas turbine appears to be the only available prime mover with sufficiently high specific power and low specific volume which can fit into the SEAHAWK type ship to provide a major speed increase."
As a result, subsequent studies by the Bureau were based on the premise that the speed-power relationship and machinery box size of a DLG 6 class hull would closely approximate the projected 40 knot SEAHAWK hull. In the studies associated with the DLG 6 hull, a specified endurance of 5,000 miles at 25 knots, in addition to a 40 knot burst speed, were held as firm requirements. Only two plant types were considered "feasible" namely, the COGAG (electric) and COGAG (gear - with advanced base load gas turbine). It should be noted that these two studies required that the Pratt and Whitney FT4A be developed to a maximum continuous rating of 25,000 bhp. In addition, the COGAG (gear) concept presupposed the attainment of a 12,000 bhp, low specific fuel consumption, base load gas turbine.

Based on proposed SEAHAWK operational requirements considered current at that time, it was concluded that the ultimate SEAHAWK machinery objectives could not be met in the FY 1965 shipbuilding program. In fact, it was somewhat questionable that any type of combined machinery plant having a reasonable assurance of satisfactory operation should be associated with any shipbuilding program until some of the "unknowns" were first taken care of.

It was considered mandatory that the following components receive a certain degree of developmental type testing before committing them to a shipbuilding program:

a. At least two models of diesel engines
b. At least two models of propulsion gas turbines

c. Propulsion clutches and couplings including noise isolating types

d. Controllable reversible pitch propellers.

By early 1963, both Bethlehem Steel Corporation and Gibbs and Cox, Inc. had contracts with the Bureau to conduct SEAHAWK feasibility studies. These studies were to include CODAG, COSAG, COGAG, pressure-fired boilers and conventional steam plants, considering existing Bureau of Ships development efforts. The contractors completed studies were provided to the Bureau in July 1963.

Although there was considerable criticism of these studies, the two contractors were directed to proceed with additional studies. Bethlehem Steel was to develop a preliminary design of a ship with a COGAG Electric Propulsion System and conduct an alternate feasibility study using a CODAG Propulsion System. Gibbs and Cox was to develop a preliminary design of a ship with a CODAG Propulsion System and conduct an alternate feasibility study using a COGAG Electric Propulsion System.

The Bureau of Ship's SEAHAWK Task Group in the Machinery Division continued with several additional feasibility studies on variations of previously completed studies. Also several parametric studies were completed on such subjects as the comparison of diesel and gas turbine generators, the comparison of the advantages and disadvantages of
simple cycle gas turbines versus regenerative cycle units, and others as the need for such studies became apparent.

About six months later, by the middle of March 1964, the results of the Preliminary Designs were ready to be reviewed by the Bureau.

It was planned to use as much of the contractors design data in the evaluation as the Bureau considered feasible; however, after a first look it appeared that the ship designs presented were not comparable. In the case of Gibbs and Cox's CODAG design, Gibbs and Cox admitted that the machinery box was too tight and would grow more than 16 feet. This meant that there was not an acceptable CODAG machinery arrangement or ship for evaluation purposes. Bethlehem Steel's COGAG design also appeared to be too tight. In any case, there appeared to be nothing to compare without some rework; therefore, the Bureau used its own feasibility studies for the evaluation of the feasibility phase.

It was decided that the evaluation would be made on the basis of an endurance of 4,500 miles at 25 knots. The evaluation was to be completed by 1 May 1964. In addition, the Machinery Division evaluated the contractors' Preliminary Design Studies, with a view toward determining the contractor better qualified to proceed with the next phase. Gibbs and Cox was selected to continue with further power plant studies.

In the meantime, the R&D planning and paper work for funding was proceeding. Table 4-21 shows the Bureau's plans regarding machinery development given the availability of funds.
<table>
<thead>
<tr>
<th>Date</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/64</td>
<td>Contractors Submitted Preliminary Design Reports</td>
</tr>
<tr>
<td>6/64</td>
<td>Select Propulsion Plant and Award Contract for NBTL Prototype</td>
</tr>
<tr>
<td>8/64</td>
<td>Complete Ships Characteristics - Start In-House Ship Preliminary Design</td>
</tr>
<tr>
<td>1/65</td>
<td>Complete Ship Preliminary Design - Start Ship Contract Plans and Specifications</td>
</tr>
<tr>
<td>5/65</td>
<td>Complete 3,000 Hours Test on Boost Plant Engine (FT64A)</td>
</tr>
<tr>
<td>6/65</td>
<td>Complete NBTL Prototype Installation Working Plans</td>
</tr>
<tr>
<td>10/65</td>
<td>Start Installation NBTL Prototype</td>
</tr>
<tr>
<td>11/65</td>
<td>Complete Ship's Contract Plans and Specifications</td>
</tr>
<tr>
<td>3/66</td>
<td>Light-Off NBTL Prototype</td>
</tr>
<tr>
<td>4/66</td>
<td>Award Ship Contract</td>
</tr>
<tr>
<td>6/66</td>
<td>Complete 500 Hours Prototype Operation - Complete Gear Specification for Ship and Release for Production</td>
</tr>
<tr>
<td>12/67</td>
<td>Reduction Gear Dockside</td>
</tr>
<tr>
<td>6/68</td>
<td>Other Principal Machinery Dockside</td>
</tr>
<tr>
<td>6/69</td>
<td>Deliver Partial Ship</td>
</tr>
</tbody>
</table>
In April 1964, the Bureau requested Gibbs and Cox to perform additional studies of COGAG plants for both the FY 1966 and the FY 1968 ships. The FY 1966 ship was going to use the Pratt and Whitney FT4A gas turbine for base load operation. The FY 1968 ship was going to use a recuperative gas turbine for base load operation. The machinery plants for the FY 1966 and FY 1968 ships were going to be the same insofar as practicable and particularly with respect to shaft lines, bulkhead locations, and stack locations. This was going to permit conversion of the FY 1966 power plant to FY 1968 power plant and also permit the FY 1966 power plant to be considered as a backup to the FY 1968 power plant. The Bureau provided outlines, weights, and performance data for the base load turbine. The Bureau also requested that the base load gas turbines be vibration mounted, that recuperators be kept below deck, and that diesel generators be used instead of gas turbine generators.

In May 1964, Gibbs and Cox, the Design Agent, reported to the Bureau that it did not appear practical to place the recuperator below deck in the flush deck ship. This was predicated on the need for a substantial separation between the base load gas turbine and its recuperator to accommodate expansion joints. Accordingly, it was agreed that the Design Agent would investigate an extended forecastle ship with the gas turbine rooms extending to the main deck and the gear rooms and auxiliary machinery room extending to the second deck. The Design Agent completed this study, and these machinery arrangements were reviewed by the Bureau. The machinery arrangements appeared to be satisfactory and the Bureau directed the Design Agent to proceed with ship arrangement studies.
Of the installations which the Design Agent studied, the scheme which appeared to be the best was the alternating current geared plant with recuperative base load gas turbines and four boost gas turbines installed in an extended forecastle deck ship. The Bureau agreed with this conclusion and, in October 1964, presented its recommendations in a meeting with the SEAHAWK program sponsor in OPNAV. The Bureau pointed out that the most attractive concept was the regenerative gas turbine with electric drive; however, it was clear that, for a FY 1966 ship, the concept would not be ready. So the question was: What could be ready by FY 1966? The conclusion the Bureau reached was to use the same plant but without the regenerative base load gas turbine, recognizing that the fuel rate on a simple cycle gas turbine like the Pratt and Whitney FT4A would require larger quantities of oil and would result in increased ship size to make the specified endurance. The displacement of this ship was up to 6,450 tons.

One of the primary development goals had been increased endurance without increased ship size. Since attainment of this goal was dependent on the development of the regenerative gas turbine, the Bureau outlined a shore based test plan, recognizing that it would not quite duplicate at sea realities. The Bureau requested ASN (R&D) to agree with the plan and to allow the longest lead item, the gears, to be procured, and to forward the package to DDR&E. The plan submitted to ASN (R&D) argued that a great amount of useful heat was exhausted to the atmosphere by modified aircraft engine which utilized a simple, single pass cycle in which the hot combustion gases were expanded through several turbine stages to produce usable shaft power. Efficiency appeared to be significantly improved by utilizing
what had been used as prime movers for compressors and pumps in natural
gas and oil pumping stations since before 1954; however, the industrial
regenerative gas turbine engine was heavy, cumbersome, non-shock resistant,
and was not suited to naval installations. Therefore, the Navy was proposing
to develop a regenerative cycle power plant using aircraft derivative
engines. This development, if approved, was going to result in a shaft's
worth of equipment to be installed at NBTL by 1966 followed by a ship
installation as shown on the schedule displayed on Figure 4-18 at a program
cost as shown on Figure 4-19.

The fuel consumption comparisons were indeed impressive as
shown on Figure 4-20. At very little added machinery weight in comparison
to a non-regenerative power plant (Figure 4-21) the fuel consumption was
reduced by as much as one third.

ASN (R&D) endorsed the Bureau's plan and sent it on to DDR&E
even though he felt that the effort should not completely stop further
investigations of other options [4-109]:

"Such items as the division of effort between simple
cycle and regenerative cycle, the final selection of the
basic engine, the test criteria and responsibilities, the
noise level criteria, and the trade-offs between risks,
costs, and requirements will be given further careful
review and determination before proceeding with installation
of a seagoing test unit. However, it is important that
we proceed now with the construction of prototypes and the
plans for operational tests at sea. Accordingly, it is
requested that $5.5 million of the funds now deferred
under Element 64203392 be released and that the
Navy be authorized to proceed with this development."
<table>
<thead>
<tr>
<th>TASK DESCRIPTION</th>
<th>FY</th>
<th>65</th>
<th>66</th>
<th>67</th>
<th>68</th>
<th>69</th>
<th>70</th>
<th>71</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>FT4A Gas Turbine Engine Development</td>
<td></td>
<td>.80</td>
<td>1.042</td>
<td>.910</td>
<td>.03</td>
<td>--</td>
<td>--</td>
<td></td>
<td>2.782</td>
</tr>
<tr>
<td>Clutch Development</td>
<td></td>
<td>.50</td>
<td>.258</td>
<td>.010</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td></td>
<td>.768</td>
</tr>
<tr>
<td>Regenerative Gas Turbine Engine</td>
<td></td>
<td>5.000</td>
<td>10.9</td>
<td>11.000</td>
<td>7.000</td>
<td>5.000</td>
<td>3.000</td>
<td></td>
<td>41.9</td>
</tr>
<tr>
<td>Propulsion System Test</td>
<td></td>
<td>--</td>
<td>2.600</td>
<td>2.700</td>
<td>1.80</td>
<td>.600</td>
<td>--</td>
<td></td>
<td>7.70</td>
</tr>
<tr>
<td>Ship Installation Design</td>
<td></td>
<td>.20</td>
<td>1.4</td>
<td>.58</td>
<td>.37</td>
<td>--</td>
<td>--</td>
<td></td>
<td>2.55</td>
</tr>
<tr>
<td>TOTALS</td>
<td></td>
<td>6.5</td>
<td>16.2</td>
<td>15.2</td>
<td>9.2</td>
<td>5.6</td>
<td>3.0</td>
<td></td>
<td>55.7</td>
</tr>
</tbody>
</table>

MILLIONS OF DOLLARS

SOURCE: REF [4-109]

FIGURE 4-19 ESTIMATED RDT&E FUNDS REQUIRED FOR THE COMBINED GAS TURBINE PROPULSION PLANT DEVELOPMENT
FIGURE 4-20 FUEL CONSUMPTION COMPARISON CURVES

SOURCE: REF 4-109
FIGURE 4-21 PROPULSION PLANT WEIGHT COMPARISON CURVES
DDR&E's endorsement did not come. On February 23, 1965, DDR&E responded by releasing 3.5 million dollars, not for the purpose the Navy asked for, but for [4-110]:

"1. The continuation of the FT4A tests, and such modifications of this turbine as may be essential for naval applications requiring a simple cycle gas turbine.

"2. Additional preparatory design work on the more promising alternative new machinery plant systems for ASW surface ships and other naval applications, and on the task of selecting the most promising of these new systems. This may well be the regenerative turbine system, but this remains to be proved.

"3. Additional work on recycling the design of the selected machinery system, and on the closely related task of defining the desired specific performance characteristics of the various elements of the complete propulsion and auxiliary equipment for the ship. Additional emphasis should be placed upon the objectives of achieving the acoustic self-noise levels specified by sonar design and noise reduction engineers, high reliability, maintainability and availability, and economical manning levels. The overall control and auxiliary machinery system design problems should also receive much more attention before there is any major commitment to new hardware development.

"4. The task of developing better cost estimates for the alternative systems considered. Before approval is granted for development of a new propulsion system for use in a large number of ships, I believe we need a statement of all RDT&E costs, related SCN and at-sea test costs, initial machinery plant costs for the intended application(s), and 20 year fuel and lube, M&O, and personnel operating costs. In judging various systems, both the Navy and OSD will need, and the Navy should immediately begin to generate, better estimates of the average current cost of recruiting, training, and supporting the personnel required to man the engineering plants of the Navy's present destroyers and destroyer escorts.

"Until then the specific turbine system development proposed is not approved or authorized."
DDR&E also encouraged the Bureau to augment its in-house machinery plant system design work by contracting for system design as well as for component designs. This decision of DDR&E was based on a staff report which concluded that the studies which had been performed on the SEAHAWK program over the previous three years did not justify the conclusion that a combined gas turbine plant, with a base load regenerative cycle gas turbo-electric base unit and a simple cycle gas turbine boost unit, represented the optimum power plant design for the next generation of destroyers. It did not appear to DDR&E that enough work had yet been accomplished to identify the most promising new naval propulsion system, nor did it appear that the Navy had devoted enough effort to the problem of standardizing on a given type of propulsion system.

A cost comparison was also made by DDR&E (Table 4-22) which showed that, from a cost standpoint, steam looked better than the various gas turbine options.

It is very interesting to note that, in interviewing two senior project SEAHAWK people at the Bureau, both independently brought up the subject that at the time of this DDR&E and ASN (R&D) involvement in the SEAHAWK program, one of the active DDR&E staffers was an ex-Rickover man from the very original inner circle and the other was a staunch professed "nuclear propulsion-for-warships" proponent. The direction from DDR&E put the SEAHAWK propulsion system work, which had by then been active for four years, back to almost ground zero.
<table>
<thead>
<tr>
<th>TYPE SHIP</th>
<th>DE 1052</th>
<th>CODAG</th>
<th>&quot;SEA HAWK&quot;-Type</th>
<th>&quot;SEA HAWK&quot;-Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RGT</td>
<td>All-FT&lt;sup&gt;4&lt;/sup&gt;</td>
<td>2 Shaft Base/Shaft</td>
<td>2 Shaft Base/Shaft</td>
</tr>
<tr>
<td>Ship Length</td>
<td>Ft.</td>
<td>Distillate</td>
<td>Ft.</td>
<td>Distillate</td>
</tr>
<tr>
<td>Displacement</td>
<td>Tons</td>
<td>3,900</td>
<td>5,580</td>
<td>6,025</td>
</tr>
<tr>
<td>Endurance Speed</td>
<td>Knots</td>
<td>20</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Endurance @ Above</td>
<td>Miles</td>
<td>6,540</td>
<td>4,000</td>
<td>4,000</td>
</tr>
<tr>
<td>Cumulative or Profile</td>
<td>Miles</td>
<td>6,335</td>
<td>4,200</td>
<td>4,200</td>
</tr>
<tr>
<td>Weight Mach</td>
<td>Tons</td>
<td>523</td>
<td>979</td>
<td>880</td>
</tr>
<tr>
<td>Weight Oil</td>
<td>Tons</td>
<td>900</td>
<td>996</td>
<td>1,550</td>
</tr>
<tr>
<td>Max Speed</td>
<td>Knots</td>
<td>29.3</td>
<td>33.3</td>
<td>32.9</td>
</tr>
<tr>
<td>Fuel &amp; Lube Cost</td>
<td>$/Yr</td>
<td>342,634</td>
<td>643,130</td>
<td>983,200</td>
</tr>
<tr>
<td>Machinery 1st Cost</td>
<td>$(1000's)</td>
<td>6,900</td>
<td>12,700</td>
<td>14,900</td>
</tr>
<tr>
<td>Repeat Buy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ship First Cost (Millions)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td>$17.0</td>
<td>$16.3</td>
<td>$26.4</td>
<td>$24.5</td>
</tr>
<tr>
<td>20 Yr. Fuel &amp; Lube Costs (Millions)</td>
<td>6.8</td>
<td>9.5</td>
<td>12.9</td>
<td>19.6</td>
</tr>
<tr>
<td>(2)</td>
<td>0.64</td>
<td>0.64</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Personnel (Engineering Dept. Only)</td>
<td>4.8</td>
<td>4.8</td>
<td>5.8</td>
<td>5.8</td>
</tr>
<tr>
<td>(3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total 20 Yr. Costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$29.2</td>
<td>$31.2</td>
<td>$46.4</td>
<td>$51.2</td>
</tr>
</tbody>
</table>

(1) From Enclosure (a) of Gibbs & Cox Conference Report of 29 July 1964; Does not include RDT&E or CFE costs. The CFE costs are usually about 50% of final total capital costs.
(2) Fuel Cost Estimates assume typical operating speed-time profiles, and do not allow for inflationary cost increases.
(5) These estimates assume the same M&O costs for the Regenerative Cycle and FT4A Turbines.

Source: Ref [4-110]
The Bureau following the DDR&E directive for further study, got the following machinery contractors involved:

Fairbanks, Morse & Company
General Electric Company
Pratt and Whitney Aircraft Division, United Aircraft Corporation
Westinghouse Electric Corporation

The Bureau then selected the following propulsion systems for further study:

**Propulsion System I** - Conventional steam propulsion system with conventional natural circulation boilers operating at 1,200 psig and 950°F.

**Propulsion System II** - Steam propulsion system with pressure-fired boilers operating at 1,200 psig and 950°F.

**Propulsion System III** - COSAG propulsion system using pressure-fired boilers in the base load plant and four 25,000 bhp simple cycle gas turbines for boost operation.

**Propulsion System IV** - CODAG propulsion system using two 12,000 bhp V-12 type medium speed diesel engines for base load operation and four 25,000 bhp simple cycle gas turbines for boost operation.
Propulsion System V - COGAG propulsion system using two simple cycle gas turbines for base load operation and four 25,000 bhp simple cycle gas turbines for boost operation.

Propulsion System VI - COGAG propulsion system using two recuperative gas turbines for base load operation and four 25,000 bhp simple cycle gas turbines for boost operation.

Propulsion System VII - COGAS propulsion system utilizing simple cycle gas turbines providing waste heat to steam propulsion systems.

Propulsion System VIII - COGAS propulsion system utilizing base load simple cycle gas turbines exhausting to waste heat boilers supplying auxiliary services and four 25,000 bhp simple cycle gas turbines for boost operation.

Upon completion of the work by the four Machinery Contractors and by the Bureau and its Design Agent, the Bureau intended to conduct an evaluation of the propulsion systems which had been studied. A report would then be prepared for DDR&E which would include all of these propulsion systems together with the Bureau of Ships' recommendations concerning the steps to be taken to provide the optimum propulsion system for destroyer type ships. This work never progressed to any stage of completion because of the following circumstances.
Just as DDR&E and the Navy's R&D community were questioning the assumptions on which the Bureau would base a selection of a destroyer propulsion plant, they also questioned, as had been done at the very outset of the program in 1961, whether it was a surface ship that was required to do the ASW job. They broadened the study to examine the basic allocation of resources. They felt that maybe ASW airplanes, either carrier based or land based, were the best answer to the ASW problem or maybe the job ought to be done by submarines.

At that same time, the Naval Material (NAVMAT) organization, which was to have responsibility over the Bureau of Ships, Weapons and Air for all Navy procurement was being established. As a result, the SEAHAWK project was assigned to a new NAVMAT program manager. Most of the senior people in the Bureau associated with the SEAHAWK program became discouraged and opted out of the project. The new project manager was established as the "Program Manager for ASW"; his horizons were indeed much higher than the development of SEAHAWK and funds were invested in projects other than propulsion system development. Once more the issue of the gas turbine adoption for U.S. warships was left behind, and the SEAHAWK ships were never realized.
The Last Failure Preceding the Successful Adoption

The characteristics development for the FY 1967 DDG started in January 1965. Guidance provided by the chairman of the Ship Characteristics Board (SCB) included a CNO-directed goal of a ship displacement of less than 6,000 tons and a follow-ship cost of less than $60 million.

The first studies based on these characteristics were on a "single-ended" TARTAR ship. Various propulsion plants were considered during the completion of these studies, including steam, COSAG, and all gas turbine plants. Steam plant studies were based on a 1,200 psi plant.

Steam and gas turbine propulsion plants were studied throughout the characteristics development. In July 1965, the SCB recommended to CNO a gas turbine propulsion plant for the 1967 DDG; however, in August, CNO directed that the design be based on steam propulsion.

As a result of CNO's decision and maintenance problems encountered with most of the 1,200 psi plants in the fleet, the decision was made in the Bureau to install 600 psi boilers in lieu of 1,200 psi boilers. The Preliminary Characteristics issued on 31 August 1965 reflected this choice. The Navy's retreat to 600 psi, 850°F, the conditions of World War II construction, certainly appeared like a major step backward. More space had to be allowed for maintenance and the machinery space of the FY 1967 had to be 172 feet long, whereas, 144 feet would have sufficed for a 1,200 psi plant.
In December 1965, the Secretary of the Navy asked that he be briefed on the choice of power plant for the FY 1967 DDG, including a comparison with other power plants. The Bureau submitted such a report in January to the Chief of Naval Operations together with a technical evaluation of the relative costs and significant characteristics of DDG's with steam and gas turbine propulsion plants, as shown on Table 4-23 [4-111].

Figures 4-22 and 4-23 represent the machinery arrangement sketches of the various power plant types considered and Figure 4-24 shows their Specific Fuel Consumption (SFC) as a function of ship speed. Their life-cycle cost comparison as well as the development cost comparison of the Regenerative Gas Turbine (RGT) versus simple-cycle gas turbine plants are shown on Table 4-24 and Table 4-25 respectively.

In March 1966, at the completion of the Preliminary Design of the steam ship, the Secretary of the Navy (SECNAV) asked to be given more information on the status of gas turbines world-wide as well as information relative to studies comparing steam with gas turbines for the main propulsion of the FY 1967 DDG.

In response to this request, the Chief of the Bureau reviewed the gas turbine development program of the Navy and the earlier studies made regarding use of gas turbines for propulsion. The information provided to SECNAV, can be summarized as follows:
<table>
<thead>
<tr>
<th>MACHINERY TYPE</th>
<th>600# STEAM</th>
<th>1,200# STEAM</th>
<th>5,000 Mi R.G.T.</th>
<th>5,000 Mi S. CYC.</th>
<th>7,000 Mi S. CYC.</th>
</tr>
</thead>
<tbody>
<tr>
<td>L.B.P. (Feet)</td>
<td>530</td>
<td>525</td>
<td>516</td>
<td>516</td>
<td>527</td>
</tr>
<tr>
<td>BEAM (Feet)</td>
<td>57</td>
<td>57</td>
<td>56</td>
<td>56</td>
<td>57</td>
</tr>
<tr>
<td>Δ F.L. (Tons)</td>
<td>7,630</td>
<td>7,482</td>
<td>6,630</td>
<td>6,900</td>
<td>7,670</td>
</tr>
<tr>
<td>SPEED (Knots)</td>
<td>30</td>
<td>30</td>
<td>30+</td>
<td>30+</td>
<td>30</td>
</tr>
<tr>
<td>SHP</td>
<td>75,000</td>
<td>75,000</td>
<td>76,000</td>
<td>76,000</td>
<td>76,000</td>
</tr>
<tr>
<td>END. FUEL (Tons)</td>
<td>1,445</td>
<td>1,380</td>
<td>935</td>
<td>1,340</td>
<td>1,950</td>
</tr>
<tr>
<td>LEAD ($M)</td>
<td>84.1</td>
<td>83.9</td>
<td>87.8</td>
<td>85.1</td>
<td>85.6</td>
</tr>
<tr>
<td>END COST</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FOLLOWS ($M)</td>
<td>61.0</td>
<td>60.8</td>
<td>64.3</td>
<td>62.9</td>
<td>63.4</td>
</tr>
<tr>
<td>SHORE BASED ($M)</td>
<td>0</td>
<td>0</td>
<td>11.4</td>
<td>10.5</td>
<td>10.5</td>
</tr>
<tr>
<td>PLANT TEST</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SOURCE REF (4-111)
FIGURE 4-23 GAS TURBINE PLANTS (SIMPLE CYCLE AND REGENERATIVE GAS TURBINE).
FIGURE 4-24 FY 1967 DDG - COMPARISON OF S.F.C. VS SPEED FOR STEAM AND COGAG PLANTS.

NOTES:
STEAM - NSFO
COGAG - E - DIESEL OR JP-5
ELECTRIC LOADS INCL AS FOLLOWS:
STEAM 2330 KW
COGAG 2315 KW
COGAG AUX. BOILER F.C. - 100 LBS/HR
S.F.C. VALUES ARE SPECIFIED VALUES
5% ENDURANCE MARGIN NOT INCL.

SOURCE: REF [4-111]
### TABLE 4-24  OPERATIONAL COST ANALYSIS 25 YEAR COST ($ MILLIONS)

<table>
<thead>
<tr>
<th>MACHINERY TYPE</th>
<th>600# STEAM</th>
<th>1,200# STEAM</th>
<th>5,000 Mi R.G.T.</th>
<th>5,000 Mi S. CYC.</th>
<th>7,000 Mi S. CYC.</th>
</tr>
</thead>
<tbody>
<tr>
<td>F.O. JP-5</td>
<td>10.9</td>
<td>10.4</td>
<td>11.7</td>
<td>17.3</td>
<td>17.5</td>
</tr>
<tr>
<td>MAINTENANCE</td>
<td>2.30</td>
<td>2.70</td>
<td>2.00</td>
<td>2.10</td>
<td>2.10</td>
</tr>
<tr>
<td>INITIAL SHIP COST</td>
<td>61.0</td>
<td>60.8</td>
<td>64.3</td>
<td>62.9</td>
<td>63.4</td>
</tr>
<tr>
<td>*ENGINEERING PERSONNEL</td>
<td>12.3</td>
<td>12.3</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>86.5</td>
<td>86.2</td>
<td>88.0</td>
<td>92.3</td>
<td>93.0</td>
</tr>
</tbody>
</table>

**NOTES:**

1. MAINTENANCE COSTS FOR STEAM PLANTS BASED ON OVERHAUL COSTS OF 15 DESTROYERS.

2. MAINTENANCE COSTS FOR GAS TURBINES BASED ON DATA DEVELOPED BY BUSHIPS AND INDUSTRY.

3. ENGINEERING PERSONNEL COSTS BASED ON $5,564/MAN/YR AND $11,544/YR FOR EACH OFFICER.

4. INITIAL SHIP COST IS THE END COST ESTIMATE FOR A BUY OF ONE FOLLOW SHIP.

5. R&D COSTS NOT INCLUDED.

* THIS COST IS FOR ENLISTED PERSONNEL ONLY.

**SOURCE REF (4-111)**

247
TABLE 4-25  R&D COST ANALYSIS
R.G.T. VS SIMPLE CYCLE

\[ \Delta \text{CD} = \text{DIFFERENTIAL DEV. COSTS, R.G.T. VS S.C.} \]
\[ \Delta \text{CM} = \text{DIFFERENTIAL MACH. FIRST COST, R.G.T. VS S.C.} \]
\[ \Delta \text{CF} = \text{DIFFERENTIAL FUEL COSTS, S.C. VS R.G.T.} \]
\[ X = \text{NUMBER OF SHIPS} \]

WHEN:
\[ \Delta \text{CD} = $23,800,000 \]
\[ \Delta \text{CM} = $\ 930,000 \]
\[ \Delta \text{CF} = $\ 223,500 \]

THE NUMBER OF SHIPS (X), FOR A 25 YEAR PERIOD IS AS FOLLOWS:

\[
X = \frac{\Delta \text{CD}}{\frac{25 (\Delta \text{CF}) - \Delta \text{CM}}{25 (\Delta \text{CF}) - \Delta \text{CM}}} = \frac{$23,800,000}{25 (\Delta \text{CF}) - \Delta \text{CM}} = 5.11 \text{ or at least 5 ships}
\]

If 6 or more ships are built with R.G.T. the initial R&D investment would be recovered.
a. A simple-cycle gas turbine of reasonably high power (16,000 hp as a base plant, 25,000 hp for short intervals as a boost plant) was available as a main propulsion engine. This engine was already installed as a boost plant in a Danish frigate, was going to be installed in the HAMILTON class Coast Guard cutters that year as a boost engine, and was designated as the main propulsion turbine for the roll-on/roll-off ship then under construction for charter to MSTS.

b. The gas turbine had many potential advantages over a steam plant for destroyer type ships. These included a higher degree of ship availability, rapid starting and acceleration, reduced manning requirements, ease of automation, and lower self-noise for improved sonar performance. In addition, because of the light weight of the gas turbine it was possible to stow much more fuel in a gas turbine-powered ship than in a steam-powered ship of the same displacement, giving the gas turbine ship greater endurance.

The successful nuclear propulsion program had followed the practice of constructing a shore-based prototype for each new power plant design, using it both for debugging technical problems and for training of ships' crews prior to delivering a new propulsion plant to the Fleet. Therefore, the Bureau recommended such an approach for new design non-nuclear propulsion plants. As a part of the regenerative gas turbine (RGT) development program, a shore prototype of the combined plant was planned. This prototype was going to contain the same clutch, the same boost gas turbine and essentially the same electrical controls as those required for a
simple-cycle gas turbine plant. Therefore, the Bureau did not consider it necessary to build and test a second complete shore prototype for the simple-cycle plant.

The Bureau of Ships felt that the greatest shortcoming of the simple-cycle plant for a destroyer type ship was its relatively high fuel consumption. For example, it had been estimated that the annual operating cost for a DDG with a simple-cycle gas turbine plant would be approximately $250,000 greater than for a steam propelled ship. However, due to the reduced machinery weight of the simple-cycle gas turbine ship as shown in Table 4-23 a simple-cycle gas turbine ship with a 7,000-mile endurance at 20 knots could be provided in approximately the same displacement as a steam ship with only 5,000 miles endurance.

Despite the apparent advantages of the gas turbine, the Chief of the Bureau did not want to see the shipbuilding program delayed [4-112]:

"However, as time has been marching on, the Bureau has virtually completed the preliminary design of a DDG with a steam propulsion plant. A change in characteristics to gas turbine propulsion at this time would require a new design and consequent repricing plus delay of ship award."

He proposed another plan to get a gas turbine propelled destroyer to sea [4-112]:

250
"The U.S. Navy will have large 14,000 hp gas turbines at sea this summer as the main propulsion boost plant for ASHEVILLE (PGM-34), GALLUP (PGM-35) and PLAINVIEW (AGEH-1). Three additional PGM's of ASHEVILLE Class are now building and ten more will be awarded this spring. Now that the Director, DDR&E, has released funds for development of a RGT, it is expected that approval will be forthcoming for the AGDE in the FY 1968 program to serve as a seagoing test platform for the RGT. If it is considered desirable by the CNO to have a high powered gas turbine in the Fleet at the earliest possible date it would be possible, by delayed award of one DE, to, install a simple cycle gas turbine (COGAG) plant in an ocean escort with the DE 1052 hull form and military characteristics in the FY 1967 program. This would require additional funds above those in the current FY 1967 budget submittal for this prototype DE. We are proceeding to examine the costs and time schedule for such a change and will report these as soon as possible for evaluation."

The Chief also supplied SECNAV with an up-to-date status of the world-wide utilization of gas turbines for main propulsion prime movers (see Table 4-26). From the table it is clear that even though the U.S. had a number of operational craft with gas turbines, they all were small craft, while other countries had operational destroyer size ships propelled by gas turbines.

Despite the reservations expressed by the Chief of the Bureau, in April 1966, SECNAV directed a change to gas turbine propulsion in the FY 1967 DDG's, and for DDG's in succeeding FY programs [4-113]:

"After a detailed review of the possible alternative propulsion systems for the 2 DDG's in the Fiscal Year 1967 Shipbuilding Program, I have made the decision that the Navy should construct these ships with a simple cycle gas turbine propulsion plant."
<table>
<thead>
<tr>
<th>NAVY</th>
<th>TYPE SHIP or CRAFT NO.</th>
<th>G.T. HP</th>
<th>STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S.</td>
<td>NSL</td>
<td>26</td>
<td>220</td>
</tr>
<tr>
<td>U.S.</td>
<td>PCH</td>
<td>1</td>
<td>2,800</td>
</tr>
<tr>
<td>U.S.</td>
<td>LCSR</td>
<td>14</td>
<td>1,000</td>
</tr>
<tr>
<td>U.S.</td>
<td>LVH</td>
<td>2</td>
<td>1,000</td>
</tr>
<tr>
<td>U.S.</td>
<td>LVW</td>
<td>2</td>
<td>1,500</td>
</tr>
<tr>
<td>U.S.</td>
<td>LVH</td>
<td>2</td>
<td>900</td>
</tr>
<tr>
<td>U.S.</td>
<td>SKMR</td>
<td>1</td>
<td>1,000</td>
</tr>
<tr>
<td>U.S.</td>
<td>LCM</td>
<td>1</td>
<td>3,000</td>
</tr>
<tr>
<td>U.S.</td>
<td>PGM</td>
<td>17</td>
<td>14,000</td>
</tr>
<tr>
<td>U.S.</td>
<td>AGEH</td>
<td>1</td>
<td>14,000</td>
</tr>
<tr>
<td>U.S.</td>
<td>PGM</td>
<td>2</td>
<td>2,800</td>
</tr>
<tr>
<td>USCG</td>
<td>210' Cutter</td>
<td>5</td>
<td>1,000</td>
</tr>
<tr>
<td>USCG</td>
<td>378' Cutter</td>
<td>8</td>
<td>17,000</td>
</tr>
<tr>
<td>U.K.</td>
<td>Patrol Boat</td>
<td>2</td>
<td>3,500</td>
</tr>
<tr>
<td>U.K.</td>
<td>Frigate</td>
<td>7</td>
<td>12,500</td>
</tr>
<tr>
<td>U.K.</td>
<td>DDG</td>
<td>8</td>
<td>7,500</td>
</tr>
<tr>
<td>U.K.</td>
<td>DE</td>
<td>1</td>
<td>15,000</td>
</tr>
<tr>
<td>Denmark</td>
<td>Frigate</td>
<td>2</td>
<td>17,000</td>
</tr>
<tr>
<td>Germany</td>
<td>Frigate</td>
<td>6</td>
<td>12,000</td>
</tr>
<tr>
<td>Italy</td>
<td>Gunboat</td>
<td>6</td>
<td>8,500</td>
</tr>
<tr>
<td>Italy</td>
<td>Gunboat</td>
<td>2</td>
<td>4,500</td>
</tr>
<tr>
<td>Italy</td>
<td>Frigate</td>
<td>3</td>
<td>7,500</td>
</tr>
<tr>
<td>Canada</td>
<td>Hydrofoil</td>
<td>1</td>
<td>17,000</td>
</tr>
<tr>
<td>Canada</td>
<td>DDM</td>
<td>4</td>
<td>17,000</td>
</tr>
<tr>
<td>Sweden</td>
<td>Patrol Boat</td>
<td>6</td>
<td>3,500</td>
</tr>
<tr>
<td>Russia</td>
<td>DLG</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Russia</td>
<td>DD Type</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>
"During the course of my review, I have received the advice of the Chief of Naval Operations and the Vice Chief of Naval Operations, as well as other senior officers of the Department with responsibilities for Fleet operations. The most significant single factor which emerged in all the discussions I have had with these various officers is that reliability in main propulsion plants is of paramount importance in construction of Navy ships.

"The Chief, Bureau of Ships, has advised me that the simple cycle gas turbine propulsion system is basically more reliable than high pressure steam plants of equal power. The FT4A gas turbine, which will be the power unit of the plant, has already been tested for thousands of hours under all sorts of conditions and its reliability has been validated. A sample of the clutch utilized to connect the 'boost' turbine when high power is required will be delivered shortly to the Boiler and Turbine Laboratory where it will undergo similar extensive testing. The electric drive generator/motor combination is a type of item which has already been proved reliable."

The preliminary design of the steam DDG, which was essentially complete, was put aside, and a preliminary design started for the gas turbine DDG.

The Chief of Naval Material (CNM) directed the Naval Ship Systems Command (NAVSIPS) (the successor of the Bureau of Ships after an organization change which occurred in 1966) to implement the Secretary's direction with additional requirements imposed [4-114]:

"In addition to the emphasis on reliability as stated by the Secretary of the Navy, the Chief of Naval Material desires that steps be taken in the design stage to make this engineering plant as quiet as possible so as not to interfere with the acoustic sensors or the habitability of the crew."
The new ship grew in size. Increased beam was required for stability because of the lighter propulsion machinery, coupled with the high weight of the large stacks required for the gas turbines. Also, the silencing requirements resulted in more volume. After increasing beam from 55 feet to 60 feet, it was necessary to also increase length in order to achieve the speed requirement. The snowballing effect added to the weight of other subsystems which also added to the total displacement increase.

The new displacement was over 8,000 tons and, by an unwritten rule, this necessitated that nuclear power be considered. This, in turn, resulted in a keen interest from the nuclear propulsion organization.

A telephone conversation between the Ship Design Project Manager and a senior official of the nuclear propulsion organization in July 1966 gives a rare insight into the interaction of these two organizations. The nuclear propulsion organization inquired about the truth of the fact that the ship had exceeded the "magic" 8,000 ton mark. Upon verification of this fact the caller attempted to convince the ship design leader that all the difficult problems confronting the design of the ship, having to somehow reduce the displacement to under 8,000 tons without changing the payload, would disappear if a switch was made to nuclear power.

In July 1966, the Deputy Commander for Ship Acquisition, NAVSHIPS, wrote to the Chairman of the SCB [4-115] and requested that he incorporate the following changes to the FY 1967 DDG characteristics:
"Change '----steam, geared turbine.' to '----simple-cycle gas turbine electric (COGAG-e)'.

"Change Length, overall, from 535 feet to 550 feet.

"Change Beam, extreme, from 55 feet to 60 feet.

"Change Displacement, light, from 5,400 tons to 6,200 tons.

"Change Displacement, full load, from 7,250 tons to 8,450 tons."

Table 4-27 shows the main features of the resulting gas turbine powered DDG; the DLG 28 features are also shown for comparison.

During that same month, the Secretary of the Navy received a presentation on the Preliminary Design results of the gas turbine ship. Figures 4-25 and 4-26 show a sketch of steam and gas turbine respectively. Figures 4-27 and 4-28 show the planned layout of the machinery spaces for the gas turbine ships, and Figure 4-29 shows a comparison between steam and gas turbine machinery space lengths. [4-116]

In August 1966, the contract design of the ship was awarded to Gibbs and Cox and in September the SCB working group met to discuss the issue of ship size.

The full load displacement of the DDG had increased to 8,450 tons, which was about 600 tons higher than the displacement predicted at the end of feasibility studies. CNO was concerned because of the cost
<table>
<thead>
<tr>
<th></th>
<th>DLG 28</th>
<th>FY 1967 DDG</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOA</td>
<td>547'–0&quot;</td>
<td>552'–6&quot;</td>
</tr>
<tr>
<td>LBP</td>
<td>524'–0&quot;</td>
<td>525'–0&quot;</td>
</tr>
<tr>
<td>Beam (Maximum)</td>
<td>53'–11&quot;</td>
<td>60'–0&quot;</td>
</tr>
<tr>
<td>Depth to Deck at Side</td>
<td>38'–6&quot;</td>
<td>41'–0&quot;</td>
</tr>
<tr>
<td>Displacement (F.L.)</td>
<td>7,930 tons</td>
<td>8,450 tons</td>
</tr>
<tr>
<td>Draft (F.L.)</td>
<td>18'–10&quot;</td>
<td>19.2'</td>
</tr>
<tr>
<td>SHP</td>
<td>equal</td>
<td>equal</td>
</tr>
<tr>
<td>Speed (Sustained)</td>
<td>equal knots</td>
<td>equal knots</td>
</tr>
<tr>
<td>Endurance @ 20 knots</td>
<td>equal miles</td>
<td>equal miles</td>
</tr>
<tr>
<td>Armament</td>
<td>2 – 3&quot;/50 single</td>
<td>1 – MK 13 GMLS</td>
</tr>
<tr>
<td></td>
<td>1 – 5&quot;/54 RF SM</td>
<td>2 – 5&quot;/54 LW SM</td>
</tr>
<tr>
<td></td>
<td>1 – TERRIER–ASROC TWIN ARM</td>
<td>1 – ASROC</td>
</tr>
<tr>
<td></td>
<td>2 – MK 32</td>
<td>2 – MK 32 Twin TT</td>
</tr>
<tr>
<td></td>
<td>2 – 25 Single Tube</td>
<td>2 – 5&quot;/54 LW SM</td>
</tr>
</tbody>
</table>

*SOURCE REF (4–116)*
FIGURE 4-26 SCB PROJECT NO. 223.67 COGAG-E
FIGURE 4-28 PLAN VIEW OF DDG MACHINERY SPACES
FIGURE 4-29 COMPARISON BETWEEN STEAM AND GAS TURBINE MACHINERY SPACE LENGTHS
implications of the larger ship and because of statements made before Congressional committees which indicated that nuclear power would be recommended for ships over 8,000 tons in displacement.

The Chairman of the SCB intended to ask NAVSHIPS to re-design the DDG to reduce displacement to 7,800 tons. In order to make this feasible, the SCB agreed to the following major changes:

a. Reduce habitability standards in some areas. Specifically reduce the 6 ft.-10 in. desired head room to something less, leaving 6 ft.-3 in. head room the mandatory criteria

b. Reduce endurance by 1,000 miles

c. Delete the emergency generator if NAVSHIPS agreed that it was not mandatory

d. Lower the base turbines from the main deck. This also implied more difficult installation of future regenerative turbines

e. Reduce or delete space margin.

Three days later, CNO sent a memorandum [4-117] to CNM in which he stated that:

"The full load displacement (8,400 tons) of the present DDG design with gas turbine is of great concern to me. I realize that this design would provide a very fine ship, with additional space margins for future growth and unusually good resistance to damage. The size and displacement of this ship could very well reduce its acceptability to SECDEF and to the Congress."
"The six foot-ten inch headroom in the ship, uptake requirements, the short time available for preliminary design, and other considerations have been cited as contributing reasons for the increase beyond 8,000 tons.

"Please repeat the DDG preliminary design process with the goal of attaining the optimum design in a hull with a full load displacement less than 8,000 tons. To ease the problem somewhat, a headroom of six feet-five inches vice six feet-ten inches is authorized. Other margins should be reduced where considered feasible and practicable."

In December 1966, NAVSHIPS presented results of their feasibility studies to the SCB. The Chairman stated that it appeared from the studies that a good ship could be developed within the 8,000-ton displacement limit but observed that, although it had been important to prove feasibility within this limit which had been accomplished, such limitation should not be allowed to affect adversely the capabilities of the ship as finally developed.

The concept chosen for further development differed from the 8,400 ton version in the following important features:

a. Hull Design. The 7,983-ton ship resulted in a design with less hull depth than that of the 8,450-ton design. This resulted in less internal space, less freeboard, and poorer seakeeping.

b. Machinery Vulnerability. The machinery box of both DDG's consisted of four major machinery spaces with a 20-foot separation space between the second and third machinery spaces. In either of the DDG designs, the ship would remain afloat after sustaining the complete
flooding of any three adjacent machinery spaces (including the separation space). In the 8,450 ton design, the elements of the base load propulsion system which were below the main deck were located at the extreme ends of the machinery box. This meant that even with any three adjacent machinery spaces completely flooded one space with base load propulsion machinery would not be flooded. Neither the 7,983-ton design, nor any existing destroyer design for that matter, offered this capability.

c. Machinery Access. The 8,450 ton design had each of the two base load gas turbines and their associated propulsion generators located in separate rooms on the main deck. This location of base load machinery allowed easy access for maintenance and for replacement of gas turbines, and permitted short runs of air inlet and exhaust ducting. It further minimized the disruptive effects which would be caused by the eventual backfitting of Regenerative Gas Turbines (RGT) when more economical units of this type became available. With the turbine rooms on the main deck, this effort could have been accomplished with the ship waterborne. Furthermore, this arrangement permitted underway maintenance of either base load gas turbine or propulsion generator in a space unencumbered by other operating elements of the propulsion machinery. The 7,983-ton ship had one base load gas turbine and one boost gas turbine located in the same machinery space. Access for maintenance was poorer in this design and the air inlet and exhaust ducting was more complicated. Since one base gas turbine and one boost gas turbine were located in the same machinery space, underway maintenance had to be performed in an operating space.

d. Self-Noise Characteristics. The 8,450-ton lent itself beautifully to a "quiet ship" mode of operation. With the base load
gas turbine and generator on the main deck, the propulsion motor and reduction gear were the only major propulsion units located below decks. In the 7,983-ton ship, all the propulsion machinery was located below decks.

e. Capacity to Accept Future Requirements. The 8,450-ton design included a usable space margin of 4 percent of the space outside the machinery box. This margin would have permitted the later addition of equipment either to improve existing capabilities or to add additional functions over and above those included in the 7,983-ton design. Additions to the 7,983-ton design would probably have to be accomplished at the expense of reduced endurance range.

f. Centralization of Functions. The increased space available in the 8,450-ton design made possible the more optimal arrangement of functions, and could possibly have resulted in a manning reduction.

g. Ship Cost. The Bureau felt that two of the 7,983-ton ships could have been built for the budgeted cost of $166.6 million. Two of the larger ships would have required an additional $2.1 million.

Despite the advantages of the 8,450-ton design, preliminary design was started in January 1967 for a DDG with less than 8,000-ton displacement. Because of the delays caused by the additional feasibility studies, it was necessary to redesignate the ship as the FY 1968 DDG.

In March 1967, NAVSHIPS was directed by the Secretary of the Navy to advance the procurement schedule for the subject ships so they could be awarded in the third quarter of FY 1968. This acceleration of the ship design and procurement-cycle could have only been accomplished if one of the following courses was adopted:
a. Authorize the design of the gas turbine powered DDG of 8,450-tons full load displacement, for which a completed preliminary design was already available.

b. For a ship with full load displacement less than 8,000 tons, authorize award of the ships on a sole source, negotiated basis to a selected private shipyard. The additional cost of such an award over the normal competitive bidding method was difficult to estimate, but was probably in the order of $8 million.

In a memorandum to CNO, COMNAVSHIPS stated [4-118]:

"Pending the decision as to which course to take, the Naval Ship Systems Command will continue to work through the design agent on the preliminary design of a DDG with a new arrangement resulting in a full load displacement less than 8,000 tons, as directed by the Chief of Naval Operations in reference [4-117]."

In the meantime, what Admiral Rickover did not achieve with persuasion within the confines of the Navy Department, he achieved through Congress. The House of Representatives authorized construction of two DLGN's in lieu of the DDG's and the Chairman of the House Armed Services Committee used the opportunity to make some very strong statements concerning the benefits of nuclear power for Naval Surface Ship propulsion.

Therefore, it is not surprising that COMNAVSHIPS, on the 18th of May 1967, wrote the following to CNM [4-119]:

266
"In view of the more recent action of the joint conferences in sustaining the House action, it would be inappropriate to obligate SCN funds for the contract design and we could be criticized for continuing to expend O&MN funds. In view of the foregoing, I intend to terminate the DDG design effort unless otherwise directed by 1 June."

In June 1967, the Secretary of the Navy terminated the FY 1968 DDG design effort. Thus the end of two and a half years of effort to bring about a major innovation i.e., gas turbines for main propulsion prime movers of a major warship, ended in defeat. However, it was not quite the end.

In the same memorandum in which the Secretary of the Navy terminated FY 1968 DDG design effort, he requested further consideration for redirecting the efforts to a DE 1052 type ship with gas turbine propulsion. Accordingly, CNO recommended that one DE be selected from the FY 1968 program and be redesigned for gas turbine propulsion. [4-120]

NAVSEC studies recommended a COGAG mechanical (vice electric) propulsion system with a CRP propeller because of space, arrangement, and cost considerations. At that time, the ship was to be designated an AGDE to allow for a suitable test program at sea in lieu of prior shore based testing of the complete plant. This would minimize cost and provide the shortest schedule. Subsequently, NAVSEC was notified that the ship would not carry an AGDE designation, but would be a follow-on DE 1078 class ship with a gas turbine propulsion.
In August 1967, NAVSHIPS directed NAVSEC to procure the Propulsion System as Government Furnished Equipment and to commence Contract Design using the DE 1078 as a baseline. The propulsion machinery procurement specification for FY 1968 DDG was used as a guide in preparing the DE 1101 to a repeat DE 1078 with only those changes necessitated by the new propulsion plant. Contract design commenced once the parameters for the propulsion system were established. [4-121]

These plans were never fully executed. Prior to their completion in 1968, it became quite clear that the DD 963, the newest destroyer in design, would incorporate gas turbines as the main propulsion prime movers. Therefore, there was no longer a strong incentive to use the DE 1101 as a test platform for gas turbine propulsion. Because it was too late to cancel some of the propulsion hardware for the DE 1101, the CRP propeller was eventually put on a DE 1052 class ship leaving the steam plant intact, thus just testing the full scale CRP only.

Once again, after several years of study, another gas turbine ship was cancelled, and a design spanning several years was terminated before its results were incorporated into a Navy ship.

A July 1967 memorandum prepared by the chairman of the SCB to CNO is very revealing about the existing conservatism as well as of the strong influence of nuclear propulsion proponents on the Navy at that time [4-122].
"In the past few years, we have had many problems in convincing OSD of our need to build major fleet escorts. Some of these problems may have been brought on by some of our own activities. For example, various proposals for the use of gas turbine propulsion have been the cause of division of opinion within the Navy itself.

"As you know, I fully support the recent decision of SECNAV to install an experimental simple cycle gas turbine propulsion plant in an AGDE. However, until the results of at-sea tests of that installation are known, I believe that we should consider for our escort ship program just two types of propulsion plants; namely, conventional steam plants and nuclear-powered steam plants. We should not permit ourselves or higher authority to be distracted from the main issues by consideration of experimental or advance propulsion schemes which, although having great potential value, at present, are unproven.

"I am by no means hereby saying that new ideas are no longer welcome in ship propulsion; rather, I am saying that our need to proceed with building numbers of escorts must not be impeded by consideration of untried and unproven propulsion schemes."

This statement was made at a time when the Soviets and Royal Navy had several destroyers with combined gas turbine and steam power plants operating for over five years and for which the decisions to proceed with gas turbine designs had to have been made at least another five years earlier.

This was the state of affairs with respect to gas turbines at a time when the design decisions were taken out of the hands of the Navy and put into private industry by DOD policy.
In 1965, DOD Instruction 3200.19 established the Total Package Procurement (TPP) concept for major weapon systems, including naval ships. The process in comparison with the current practice and the pre-TPP time, consisted of the phases shown in Figure 4-30. The Concept Formulation phase, which was intended to verify the compatibility of all the performance requirements, was performed by the Navy. Its results were not passed directly to the competing contractors. At the outset of the next, or Contract Definition phase, the Navy's requirement for a new ship design was transmitted to the prospective contractors in terms of ranges of performance characteristics. Their responses were to reflect a balanced design solution considering performance criteria, design standards, and production techniques. This process emphasized the industry's responsibility for the ultimate satisfactory performance of the ship. The Navy's role during this phase was to monitor and guide the builder should his endeavor take a turn which experience had shown to be disadvantageous. The end product of Contract Definition was a proposal from each competing contractor for Total Package Procurement. The proposal included a set of ship plans and specifications developed by the contractor in response to the Navy's requirements, together with detailed management, facility, logistic support, and other plans which were to be implemented during the detail development and production phase. As a result of a lengthy source selection process, the Navy then chose that contractor whose ship design and plans for construction were considered the most cost effective and technically adequate.
FIGURE 4-30 ALTERNATIVE METHODS FOR THE DEVELOPMENT OF NAVAL SHIP DESIGN
Briefly, the objectives of the new procedures were: (1) to infuse innovation in the naval ship design process not only from shipbuilders, but from other segments of private industry, (2) to introduce producibility into early design decisions, (3) to define precisely the responsibilities of the government and the contractor to provide a good basis for firm fixed price or fixed price incentive contracts, (4) to establish realistic performance requirements, and (5) to strengthen industry and equip it to be responsive to future naval programs.

Three ship designs were developed using this process prior to the cancellation of the DOD Instruction in 1971: the FDL, the LHA, and the DD 963. The FDL program was cancelled after the completion of the Concept Formulation/Contract Definition (CF/CD) phase. The other two programs went forward and both lead ships, the DD 963 and LHA-1, had joined the Fleet by 1976.

The contractor performed trade-off studies in every major subsystem of the ship and the propulsion system was no exception. In fact, the propulsion trade-off studies were very extensive in nature and encompassed every reasonable non-nuclear option. For each of the three ship designs, all three contractors selected variations of the same type of power plant, i.e., steam for both FDL and LHA and gas turbines for the DD 963.

In order to decide which propulsion plant was better (using the criteria and specific factors), it was not possible to just deal with the
propulsion system alone. Each and every change, be it manning or fuel weight, had a cascading effect on the hull, ship support, and human support systems, which in turn had an effect on the overall ship requirements and on all other ship subsystems. Therefore, to determine the effect of a parameter such as Specific Fuel Consumption (SFC) on ship size and cost, it was necessary to go through several iterations of sizing to "balance" the ship and to cost it. This process is accomplished today with so-called mathematical synthesis models which have been computerized to enable rapid evaluation.

A simplified flow chart, Figure 4-31, depicts the impact of this ship design procedure on propulsion system selection and cost relationships. It also shows the percentages of the costs contributing to the total propulsion system life-cycle cost. These various costs strongly influence the particular power plant selection.

The Contract Definition Phase for DD 963 was awarded to Litton and commenced on 3 July 1968. General operating requirements and specific ship system requirements were invoked by the Navy's request for proposals (RFP). Insofar as propulsion selection and design was concerned, the principal ship system requirements included [4-129]:

a. A sustained speed capability at full load displacement when two years out of dock in Sea State 4

b. Cruising radius and the associated endurance speed

c. The requirements for shock resistance, damage control segregation of functions, stability, and reserve buoyancy
FIGURE 4-31 IMPACT OF SHIP DESIGN ON PROPULSION SYSTEM
d. Radiated, self, and structureborne noise requirements

e. The lowest level of shipboard manning commensurate with effective operations and maintenance. Engineering manning constituted approximately 20 percent of a destroyer's total complement. Therefore, the manning requirements for operation and maintenance were important in evaluating alternate propulsion concepts.

f. Twin screw, steam turbine, gas turbine, diesel engine or combined plants incorporating either fixed pitch or CRP propellers were permitted. None of the RFP requirements were assessed as favoring any one type of type of propulsion subsystem.

g. The propulsion plants and ship service auxiliaries were required to be capable of burning either NSFO or NDF.

h. Propulsion subsystem control was required to be automated consistent with reliability, maintainability, personnel, vulnerability, and cost consideration. In order to provide for improved maneuvering and more rapid response, control of ship speed and direction from the bridge was required.

i. The necessity for minimum maintenance of propulsion machinery while underway.

The selection of gas turbine propulsion was made after considering more than 50 alternate plant configurations ranging in size from 60,000 to 120,000 shp. These included steam, diesel, gas turbine, CODAG, CODOG, COSAG and COGAS installations. The final choice was made after comparing the characteristics of the best DD 963 class ship which could be designed employing each of the lead candidate propulsion plants.
The major steps in this process which led to the selection of a gas turbine propulsion subsystem are shown in Figure 4-32. This iterative systems engineering and analyses procedure provided for consideration of a wide range of alternate propulsion subsystem concepts. Several iterations of the design of the various candidates were completed in the process of developing and refining the propulsion machinery space, weight, cost and performance data.

Concurrent systems analysis involved development of parametric relationships among all principal ship system and propulsion subsystem characteristics such as displacement, length, beam, speed draft, fuel consumption, and power (all factors required to define alternate ship concepts). Similarly, preliminary costs relationships were established and continually refined in evolving parametric representation of the total ship system. Employing computer techniques to exercise the resulting ship system parametric model permitted developing the conceptual design and calculating the life-cycle cost of optimum ships incorporating each candidate propulsion plant and satisfying the basic DD 963 class ship requirements and constraints. The object of this effort was to assess the impact of a wide variety of candidate propulsion plants on the DD 963 class ship system and to converge on the optimum combination of hull and machinery parameters. It did not involve simply fitting different propulsion plants in the same ship.

During the next major phase of the trade-off studies, the design of each of the lead concepts was developed to the level of detail normally
FIGURE 4-32 PROPULSION SUBSYSTEM SELECTION AND DESIGN PROCEDURE
associated with a preliminary design effort. Definitive specifications, equipment lists, arrangement drawings, fuel consumption curves and weight estimates were developed. This weight, space, and performance data permitted refining the ship system parametric model. The model, in conjunction with supporting reliability/maintainability/availability maintenance and manning analyses as well as shipyard developed acquisition cost data, was then employed to calculate more accurately the life-cycle costs associated with the best ships that could be designed accommodating each candidate plant.

The last major phase of the propulsion trade-off consisted of a more detailed examination of the performance and risk factors associated with the lead ship and propulsion subsystems designs. Although emphasis was placed on quantitative analyses, the evaluation also included a qualitative assessment of the technical, schedule, and cost risk presented by each alternative. Only those propulsion plants which could be shown unequivocally to provide the required performance with acceptable risk were considered in the final life-cycle cost analyses. Once these studies were completed, plant selection followed logically.

Figure 4-33 lists the 48 different propulsion subsystem concepts which were subsequently defined and considered in the original analyses. These included steam, gas turbine, diesel, CODAG, and COGAS installation covering a power range of 70,000 to 120,000 shp. Not all possible component combinations are represented, but the practical range of alternatives is covered.
GENERAL NOTES

1. THE PROPULSION SUBSYSTEM CONCEPTS CONCEPTS INCLUDE:
   A. STEAM TURBINE
   B. GAS TURBINE
   C. COGAS
   D. COMBINED GAS TURBINE AND STEAM TURBINE
   E. DIESEL

2. ALL STUDIES ARE WITH SIMULATIONS.

3. UNLESS OTHERWISE STATED ALL STUDIES HAVE CONVENTIONAL FIXED PITCH PROPELLERS AS THRUSTERS.

4. CONTROL SYSTEMS FOR ALL STUDIES CONSISTS OF:
   A. STEAM AND COGAS: PROPELLER CONTROL, SINGLE LEVER THROTTLE CONTROL, AHEAD AND ASTERN, FOR EACH SHAFT.
   B. GAS TURBINE: GAS TURBINE BASE PLANT PROPERTIES AND DISTANCE FROM THE NEXT PLANT.
   C. DIESEL: ELECTRIC BASE DRIVE.

5. ALL STUDIES CONTAIN ELECTRICAL EQUIPMENT.

6. PROPULSION PLANTS FOR ALL STUDIES CONSISTS OF:
   A. STEAM: COGAS: FOUR 5.5 TURBO GENERATORS, 1000 HP EACH, 1750 RPM EQUIPMENT.
   B. GAS TURBINE: BASE PLANT: FOUR 5.5 TURBO GENERATORS, 1000 HP EACH, 1750 RPM EQUIPMENT.
   C. DIESEL: BASE PLANT: FOUR 5.5 TURBO GENERATORS, 1000 HP EACH, 1750 RPM EQUIPMENT.

7. FUELS:
   A. STEAM STUDIES: NO DIESEL.
   B. OTHERS: DIESEL.

8. EMERGENCY GENERATORS:
   A. STEAM STUDIES: NO DIESEL.
   B. OTHERS: DIESEL.

9. RATING: RATING INCLUDES CONVENTIONAL STEAM TURBINES, 5% AND EMERGENCY GENERATORS, DISTILLING UNITS, ETC., ARE INITIAL ESTIMATES AND ARE INCLUDED FOR COMPARISON PURPOSES ONLY.

<table>
<thead>
<tr>
<th>Study</th>
<th>Concept Type</th>
<th>R.P. Ship</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>STEAM</td>
<td>85,000</td>
<td>GEARED TURBINE: STEAM CONDITIONS: 120000 PSI/900°F, ONE STAGE FEED HEATING, FOUR CONVENTIONAL BOILERS, D-TYPE, WATERWALL PIPES, INTEGRAL SUPERHEATER, ECONOMIZERS, STEAM/ROD TURBINE WITH STEAM ATOMIZING BURNER, TWO 45,000 HP CROSS-COMPUND SERIES-ParALLEL TURBINES EXHAUSTING INTO TWO MAIN CONDENSERS AT 5% A.F.P. AND DRIVING THROUGH TWO LOCKED TRAIN DOUBLE REDUCTION GEARS. REVERSING: ASTERN ELEMENT IN LP TURBINES. BASE PLANT: 35,000 HP ON TWO BOILERS CROSS-CONNECTED AT 75% OVERLOAD.</td>
</tr>
<tr>
<td>II</td>
<td>STEAM</td>
<td>85,000</td>
<td>GEARED TURBINE: STEAM CONDITIONS: 120000 PSI/900°F, ONE STAGE FEED HEATING, FOUR CONVENTIONAL BOILERS, D-TYPE, WATERWALL PIPES, INTEGRAL SUPERHEATER, ECONOMIZERS, STEAM/ROD TURBINE WITH STEAM ATOMIZING BURNER, TWO 45,000 HP CROSS-COMPUND SERIES-ParALLEL TURBINES EXHAUSTING INTO TWO MAIN CONDENSERS AT 5% A.F.P. AND DRIVING THROUGH TWO LOCKED TRAIN DOUBLE REDUCTION GEARS. REVERSING: ASTERN ELEMENT IN LP TURBINES. BASE PLANT: 35,000 HP ON TWO BOILERS CROSS-CONNECTED AT 75% OVERLOAD.</td>
</tr>
<tr>
<td>III</td>
<td>STEAM</td>
<td>85,000</td>
<td>GEARED TURBINE: STEAM CONDITIONS: 120000 PSI/900°F, ONE STAGE FEED HEATING, FOUR CONVENTIONAL BOILERS, D-TYPE, WATERWALL PIPES, INTEGRAL SUPERHEATER, ECONOMIZERS, STEAM/ROD TURBINE WITH STEAM ATOMIZING BURNER, TWO 45,000 HP CROSS-COMPUND SERIES-ParALLEL TURBINES EXHAUSTING INTO TWO MAIN CONDENSERS AT 5% A.F.P. AND DRIVING THROUGH TWO LOCKED TRAIN DOUBLE REDUCTION GEARS. REVERSING: ASTERN ELEMENT IN LP TURBINES. BASE PLANT: 35,000 HP ON TWO BOILERS CROSS-CONNECTED AT 75% OVERLOAD.</td>
</tr>
<tr>
<td>IV</td>
<td>STEAM</td>
<td>85,000</td>
<td>GEARED TURBINE: STEAM CONDITIONS: 120000 PSI/900°F, ONE STAGE FEED HEATING, FOUR CONVENTIONAL BOILERS, D-TYPE, WATERWALL PIPES, INTEGRAL SUPERHEATER, ECONOMIZERS, STEAM/ROD TURBINE WITH STEAM ATOMIZING BURNER, TWO 45,000 HP CROSS-COMPUND SERIES-ParALLEL TURBINES EXHAUSTING INTO TWO MAIN CONDENSERS AT 5% A.F.P. AND DRIVING THROUGH TWO LOCKED TRAIN DOUBLE REDUCTION GEARS. REVERSING: ASTERN ELEMENT IN LP TURBINES. BASE PLANT: 35,000 HP ON TWO BOILERS CROSS-CONNECTED AT 75% OVERLOAD.</td>
</tr>
<tr>
<td>V</td>
<td>GAS TURBINE</td>
<td>97,500</td>
<td>GEARED TURBINE: SIMPLE CYCLE GAS TURBINE, PINNA AXIAL-FLOW, GE-43000 HP, EACH ONE 25,000 HP MAX, DRIVING 2-LOCKED TRAIN DOUBLE REDUCTION GEARS THROUGH POSITIVE ENGAGEMENT CLUTCHES. REVERSING: 2-CONTROLABLE, REVERSIBLE PITCH PROPELLERS. CRUISING: ONE GAS TURBINE DRIVING 2 SHARPS AT 23,700 HP MAX. VIA A CLUTCHING COMPUND GEAR. BASE PLANT: 47,000 HP MAXIMUM 12-GAS TURBINES, ONE PER SHIP.</td>
</tr>
<tr>
<td>VI</td>
<td>GAS TURBINE</td>
<td>97,500</td>
<td>GEARED TURBINE: SIMPLE CYCLE GAS TURBINE, PINNA AXIAL-FLOW, GE-43000 HP, EACH ONE 25,000 HP MAX, DRIVING 2-LOCKED TRAIN DOUBLE REDUCTION GEARS THROUGH POSITIVE ENGAGEMENT CLUTCHES. REVERSING: 2-CONTROLABLE, REVERSIBLE PITCH PROPELLERS. CRUISING: ONE GAS TURBINE DRIVING 2 SHARPS AT 23,700 HP MAX. VIA A CLUTCHING COMPUND GEAR. BASE PLANT: 47,000 HP MAXIMUM 12-GAS TURBINES, ONE PER SHIP.</td>
</tr>
<tr>
<td>VII</td>
<td>GAS TURBINE</td>
<td>97,500</td>
<td>GEARED TURBINE: SIMPLE CYCLE GAS TURBINE, PINNA AXIAL-FLOW, GE-43000 HP, EACH ONE 25,000 HP MAX, DRIVING 2-LOCKED TRAIN DOUBLE REDUCTION GEARS THROUGH POSITIVE ENGAGEMENT CLUTCHES. REVERSING: 2-CONTROLABLE, REVERSIBLE PITCH PROPELLERS. CRUISING: ONE GAS TURBINE DRIVING 2 SHARPS AT 23,700 HP MAX. VIA A CLUTCHING COMPUND GEAR. BASE PLANT: 47,000 HP MAXIMUM 12-GAS TURBINES, ONE PER SHIP.</td>
</tr>
<tr>
<td>VIII</td>
<td>GAS TURBINE</td>
<td>97,500</td>
<td>GEARED TURBINE: SIMPLE CYCLE GAS TURBINE, PINNA AXIAL-FLOW, GE-43000 HP, EACH ONE 25,000 HP MAX, DRIVING 2-LOCKED TRAIN DOUBLE REDUCTION GEARS THROUGH POSITIVE ENGAGEMENT CLUTCHES. REVERSING: 2-CONTROLABLE, REVERSIBLE PITCH PROPELLERS. CRUISING: ONE GAS TURBINE DRIVING 2 SHARPS AT 23,700 HP MAX. VIA A CLUTCHING COMPUND GEAR. BASE PLANT: 47,000 HP MAXIMUM 12-GAS TURBINES, ONE PER SHIP.</td>
</tr>
</tbody>
</table>

SOURCE: REF [4-123]

FIGURE 4-33 PROPULSION SUBSYSTEM CONCEPTS (SHEET 1 OF 4)

279
<table>
<thead>
<tr>
<th>STUDY</th>
<th>CONCEPT #</th>
<th>Y, Z, N</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>COGAG-G</td>
<td>67,300</td>
<td>GEARED TURBINE: 5 SPICE CYCLE GAS TURBINE (FRM F-TA OR FT) GE-LM/2B0 EACH RATED AT 23,3000HP MAX. DRIVING 2 LOCKED TRAIN DOUBLE REDUCTION GEARS THROUGH POSITIVE ENGAGEMENT CLUTCHES. REVERSING: 2 SPICE CYCLE GAS TURBINE (FRM F-TA OR FT) GE-LM/2B0 EACH RATED AT 23,3000HP MAX. DRIVING 2 LOCKED TRAIN DOUBLE REDUCTION GEARS THROUGH POSITIVE ENGAGEMENT CLUTCHES. BASE PLANE: 47,5000HP MAX. USES GAS TURBINE, ONE REW. THROUGH REVERSING GEAR.</td>
</tr>
<tr>
<td>XI</td>
<td>COGAG-G</td>
<td>67,300</td>
<td>GEARED TURBINE: 1 SPICE CYCLE GAS TURBINE (FRM F-TA OR FT) GE-LM/2B0 EACH RATED AT 23,3000HP MAX. DRIVING 2 LOCKED TRAIN DOUBLE REDUCTION GEARS THROUGH POSITIVE ENGAGEMENT CLUTCHES. REVERSING: 2 SPICE CYCLE GAS TURBINE (FRM F-TA OR FT) GE-LM/2B0 EACH RATED AT 23,3000HP MAX. DRIVING 2 LOCKED TRAIN DOUBLE REDUCTION GEARS THROUGH POSITIVE ENGAGEMENT CLUTCHES. BASE PLANE: 47,5000HP MAX. USES GAS TURBINE, ONE REW. THROUGH REVERSING GEAR.</td>
</tr>
<tr>
<td>XII</td>
<td>COGAG-E</td>
<td>77,500</td>
<td>2 SPICE CYCLE GAS TURBINE (FRM F-TA OR FT) GE-LM/2B0 EACH RATED AT 23,3000HP MAX. DRIVING 2 LOCKED TRAIN DOUBLE REDUCTION GEARS THROUGH POSITIVE ENGAGEMENT CLUTCHES. REVERSING: 2 SPICE CYCLE GAS TURBINE (FRM F-TA OR FT) GE-LM/2B0 EACH RATED AT 23,3000HP MAX. DRIVING 2 LOCKED TRAIN DOUBLE REDUCTION GEARS THROUGH POSITIVE ENGAGEMENT CLUTCHES. BASE PLANE: 47,5000HP MAX. USES GAS TURBINE, ONE REW. THROUGH REVERSING GEAR.</td>
</tr>
<tr>
<td>XIII</td>
<td>COGAG-G</td>
<td>77,500</td>
<td>GEARED TURBINE, BASE PLANE. 2 SPICE CYCLE GAS TURBINE (FRM F-TA OR FT) GE-LM/2B0 EACH RATED AT 23,3000HP MAX. DRIVING 2 LOCKED TRAIN DOUBLE REDUCTION GEARS THROUGH POSITIVE ENGAGEMENT CLUTCHES. BASE PLANE: 47,5000HP MAX. USES GAS TURBINE, ONE REW. THROUGH REVERSING GEAR.</td>
</tr>
<tr>
<td>XIV</td>
<td>COGAG-G</td>
<td>77,500</td>
<td>GEARED TURBINE, BASE PLANE. 2 SPICE CYCLE GAS TURBINE (FRM F-TA OR FT) GE-LM/2B0 EACH RATED AT 23,3000HP MAX. DRIVING 2 LOCKED TRAIN DOUBLE REDUCTION GEARS THROUGH POSITIVE ENGAGEMENT CLUTCHES. BASE PLANE: 47,5000HP MAX. USES GAS TURBINE, ONE REW. THROUGH REVERSING GEAR.</td>
</tr>
<tr>
<td>XV</td>
<td>COGAG-E</td>
<td>111,000</td>
<td>GEARED TURBINE, BASE PLANE. 2 SPICE CYCLE GAS TURBINE (FRM F-TA OR FT) GE-LM/2B0 EACH RATED AT 23,3000HP MAX. DRIVING 2 LOCKED TRAIN DOUBLE REDUCTION GEARS THROUGH POSITIVE ENGAGEMENT CLUTCHES. BASE PLANE: 47,5000HP MAX. USES GAS TURBINE, ONE REW. THROUGH REVERSING GEAR.</td>
</tr>
<tr>
<td>XVI</td>
<td>COGAG-E</td>
<td>116,000</td>
<td>GEARED TURBINE, BASE PLANE. 2 SPICE CYCLE GAS TURBINE (FRM F-TA OR FT) GE-LM/2B0 EACH RATED AT 23,3000HP MAX. DRIVING 2 LOCKED TRAIN DOUBLE REDUCTION GEARS THROUGH POSITIVE ENGAGEMENT CLUTCHES. BASE PLANE: 47,5000HP MAX. USES GAS TURBINE, ONE REW. THROUGH REVERSING GEAR.</td>
</tr>
<tr>
<td>XVII</td>
<td>COGAG-E</td>
<td>93,000</td>
<td>GEARED TURBINE, BASE PLANE. 2 SPICE CYCLE GAS TURBINE (FRM F-TA OR FT) GE-LM/2B0 EACH RATED AT 23,3000HP MAX. DRIVING 2 LOCKED TRAIN DOUBLE REDUCTION GEARS THROUGH POSITIVE ENGAGEMENT CLUTCHES. BASE PLANE: 47,5000HP MAX. USES GAS TURBINE, ONE REW. THROUGH REVERSING GEAR.</td>
</tr>
<tr>
<td>XVIII</td>
<td>COGAG-E</td>
<td>93,000</td>
<td>GEARED TURBINE, BASE PLANE. 2 SPICE CYCLE GAS TURBINE (FRM F-TA OR FT) GE-LM/2B0 EACH RATED AT 23,3000HP MAX. DRIVING 2 LOCKED TRAIN DOUBLE REDUCTION GEARS THROUGH POSITIVE ENGAGEMENT CLUTCHES. BASE PLANE: 47,5000HP MAX. USES GAS TURBINE, ONE REW. THROUGH REVERSING GEAR.</td>
</tr>
<tr>
<td>XIX</td>
<td>COGAG-G</td>
<td>96,000</td>
<td>GEARED TURBINE, BASE PLANE. 2 SPICE CYCLE GAS TURBINE (FRM F-TA OR FT) GE-LM/2B0 EACH RATED AT 23,3000HP MAX. DRIVING 2 LOCKED TRAIN DOUBLE REDUCTION GEARS THROUGH POSITIVE ENGAGEMENT CLUTCHES. BASE PLANE: 47,5000HP MAX. USES GAS TURBINE, ONE REW. THROUGH REVERSING GEAR.</td>
</tr>
<tr>
<td>XX</td>
<td>COGAG-G</td>
<td>96,000</td>
<td>GEARED TURBINE, BASE PLANE. 2 SPICE CYCLE GAS TURBINE (FRM F-TA OR FT) GE-LM/2B0 EACH RATED AT 23,3000HP MAX. DRIVING 2 LOCKED TRAIN DOUBLE REDUCTION GEARS THROUGH POSITIVE ENGAGEMENT CLUTCHES. BASE PLANE: 47,5000HP MAX. USES GAS TURBINE, ONE REW. THROUGH REVERSING GEAR.</td>
</tr>
<tr>
<td>XXI</td>
<td>COGAG-E</td>
<td>76,000</td>
<td>GEARED TURBINE, BASE PLANE. 2 SPICE CYCLE GAS TURBINE (FRM F-TA OR FT) GE-LM/2B0 EACH RATED AT 23,3000HP MAX. DRIVING 2 LOCKED TRAIN DOUBLE REDUCTION GEARS THROUGH POSITIVE ENGAGEMENT CLUTCHES. BASE PLANE: 47,5000HP MAX. USES GAS TURBINE, ONE REW. THROUGH REVERSING GEAR.</td>
</tr>
<tr>
<td>XXII</td>
<td>COGAG-G</td>
<td>76,000</td>
<td>GEARED TURBINE, BASE PLANE. 2 SPICE CYCLE GAS TURBINE (FRM F-TA OR FT) GE-LM/2B0 EACH RATED AT 23,3000HP MAX. DRIVING 2 LOCKED TRAIN DOUBLE REDUCTION GEARS THROUGH POSITIVE ENGAGEMENT CLUTCHES. BASE PLANE: 47,5000HP MAX. USES GAS TURBINE, ONE REW. THROUGH REVERSING GEAR.</td>
</tr>
<tr>
<td>XXIII</td>
<td>COGAG-E</td>
<td>110,000</td>
<td>GEARED TURBINE, BASE PLANE. 2 SPICE CYCLE GAS TURBINE (FRM F-TA OR FT) GE-LM/2B0 EACH RATED AT 23,3000HP MAX. DRIVING 2 LOCKED TRAIN DOUBLE REDUCTION GEARS THROUGH POSITIVE ENGAGEMENT CLUTCHES. BASE PLANE: 47,5000HP MAX. USES GAS TURBINE, ONE REW. THROUGH REVERSING GEAR.</td>
</tr>
</tbody>
</table>

**FIGURE 4-33** PROPELLATION SUBSYSTEM CONCEPTS (SHEET 2 OF 4)
<table>
<thead>
<tr>
<th>STUDY #</th>
<th>CONCEPT GROUP</th>
<th>F, P, SH</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>XIXV</td>
<td>LUXAG</td>
<td>111,750</td>
<td>Combined diesel and gas turbine base plant, 80% Opposed piston model. 2-cycle diesel engines at 17,000 rpm each connected to the main reduction gears via a two speed gear and positive engagement clutches. Boost plant: four single cycle gas turbines (1,200 rpm or 1000 rpm) GE-6000 each at 25,000 rpm geared to the main reduction gears. Locked train double reduction through positive engagement clutches. Reversing: reversing diesel engines. Cruising: 16,000 rpm max. ON the base plant engines.</td>
</tr>
<tr>
<td>XIXV</td>
<td>COGAD</td>
<td>90,300</td>
<td>Combined diesel and gas turbine base plant: 80% Opposed piston model. 2-cycle diesel engines at 11,000 rpm each connected to the main reduction gears via a two speed gear and positive engagement clutches. Boost plant: two single cycle gas turbines at 3,600 rpm or 2,400 rpm GE-6000 each at 25,000 rpm geared to the main reduction gears. Locked train double reduction through positive engagement clutches. Reversing: reversing diesel engines. Cruising: 15,000 rpm max. On the base plant engines.</td>
</tr>
<tr>
<td>XIXV</td>
<td>COGAD</td>
<td>76,000</td>
<td>Combined diesel and gas turbine base plant: 90% Opposed piston model. 2-cycle diesel engines at 13,000 rpm each connected to the main reduction gears via a two speed gear and positive engagement clutches. Boost plant: two single cycle gas turbines at 1,800 rpm or 1,200 rpm GE-6000 each at 25,000 rpm geared to the main reduction gears. Locked train double reduction through positive engagement clutches. Reversing: reversing diesel engines. Cruising: 14,000 rpm max. ON the base plant engines.</td>
</tr>
<tr>
<td>XIXVII</td>
<td>COGAD</td>
<td>76,000</td>
<td>Combined diesel and gas turbine base plant: 80% Opposed piston model. 2-cycle diesel engines at 7,000 rpm each connected to the main reduction gears via a two speed gear and positive engagement clutches. Boost plant: two single cycle gas turbines at 1,200 rpm or 800 rpm GE-6000 each at 25,000 rpm geared to the main reduction gears. Locked train double reduction through positive engagement clutches. Reversing: reversing diesel engines. Cruising: 12,000 rpm max. ON the base plant engines.</td>
</tr>
<tr>
<td>XXX</td>
<td>COGAD</td>
<td>91,200</td>
<td>Combined diesel and gas turbine base plant: 80% Opposed piston model. 8-cycle diesel engines at 18,000 rpm each connected to the main reduction gears via a two speed gear and positive engagement clutches. Boost plant: two single cycle gas turbines at 3,600 rpm or 2,400 rpm GE-6000 each at 25,000 rpm geared to the main reduction gears. Locked train double reduction through positive engagement clutches. Base plant secured during boost operation. Reversing: reversing diesel engines. Cruising: base plant: 15,000 rpm max. From four diesel engines (two per shaft).</td>
</tr>
<tr>
<td>XXX</td>
<td>COGAD</td>
<td>87,500</td>
<td>Combined diesel and gas turbine base plant: 80% Opposed piston model. 8-cycle diesel engines at 17,000 rpm each connected to the main reduction gears via a two speed gear and positive engagement clutches. Boost plant: two single cycle gas turbines at 1,800 rpm or 1,200 rpm GE-6000 each at 25,000 rpm geared to the main reduction gears. Locked train double reduction through positive engagement clutches. Base plant secured during boost operation. Reversing: reversing diesel engines. Cruising: base plant: 15,000 rpm max. From four diesel engines (two per shaft).</td>
</tr>
<tr>
<td>XXX</td>
<td>COGAD</td>
<td>97,500</td>
<td>Combined diesel and gas turbine base plant: 80% Opposed piston model. 8-cycle diesel engines at 15,000 rpm each connected to the main reduction gears via a two speed gear and positive engagement clutches. Boost plant: two single cycle gas turbines at 1,800 rpm or 1,200 rpm GE-6000 each at 25,000 rpm geared to the main reduction gears. Locked train double reduction through positive engagement clutches. Base plant secured during boost operation. Reversing: reversing diesel engines. Cruising: base plant: 15,000 rpm max. From four diesel engines (two per shaft).</td>
</tr>
<tr>
<td>XXXIII</td>
<td>COGAD</td>
<td>93,250</td>
<td>Combined gas turbine and steam, Vestinghville cogas concept. Base plant: two simple cycle gas turbines (20% Opposed Venturi) each providing 4,000 hp to 2 shafts through positive engagement clutches and locked train double reduction gears. Two single cycle gas turbines for emergency power. Boost plant: two single cycle gas turbines at 1,800 rpm or 1,200 rpm GE-6000 each at 25,000 rpm geared to the main reduction gears. Locked train double reduction through positive engagement clutches. Reversing: reversing diesel engines. Cruising: base plant: 15,000 rpm max. From two simple cycle gas turbines (20% Opposed Venturi).</td>
</tr>
</tbody>
</table>

**Figure 4-33 Propulsion Subsystem Concepts (Sheet 3 of 4)**

281
<table>
<thead>
<tr>
<th>STUDY #</th>
<th>CONCEPT GROUP</th>
<th>F.P. SHIP</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>8XVIII</td>
<td>COSAG</td>
<td>82,500</td>
<td>Combined steam and gas turbine, base plant. Natural circulation. 36,000 BHP with integral superheater, economizer, material furnaces, steam generators. Two single-shaft, straight-through, condensing steam turbines. 20,000 BHP each. Two single-shaft, straight-through, condensing steam turbines. 30,000 BHP each.</td>
</tr>
<tr>
<td>9XVIII</td>
<td>COSAG</td>
<td>90,000</td>
<td>Combined steam and gas turbine, base plant. One natural circulation. 20,000 BHP with integral superheater, economizer, material furnaces, steam generators. Two single-shaft, straight-through, condensing steam turbines. 30,000 BHP each.</td>
</tr>
<tr>
<td>10XVIII</td>
<td>COSAG</td>
<td>111,000</td>
<td>Combined steam and gas turbine, base plant. One pressure-fired boiler with integral superheater, economizer, material furnaces, steam generator, steam turbogenerators. Straight-through, condensing steam turbines. 30,000 BHP each.</td>
</tr>
<tr>
<td>XLI</td>
<td>COSAG</td>
<td>111,000</td>
<td>Combined steam and gas turbine, base plant. One pressure-fired boiler with integral superheater, economizer, material furnaces, steam generator, steam turbogenerators. Straight-through, condensing steam turbines. 30,000 BHP each.</td>
</tr>
<tr>
<td>12XVIII</td>
<td>COSAG</td>
<td>74,300</td>
<td>Combined steam and gas turbine, base plant. One pressure-fired boiler with integral superheater, economizer, material furnaces, steam generator, steam turbogenerators. Straight-through, condensing steam turbines. 30,000 BHP each.</td>
</tr>
<tr>
<td>XIIX</td>
<td>DIESEL</td>
<td>85,400</td>
<td>Geared diesel engine. Four fatigue piston models. 3800 BHP cylinder diesel engines rated at 37,000 BHP each connected to two single speed, single reduction gears through positive displacement clutches or electric hydraulic couplings.</td>
</tr>
<tr>
<td>14XV</td>
<td>DIESEL</td>
<td>79,600</td>
<td>Geared diesel, base plant. Two fatigue piston models. 3800 BHP cylinder diesel engines rated at 37,000 BHP each connected to two single speed, single reduction gears through positive displacement clutches or electric hydraulic couplings.</td>
</tr>
<tr>
<td>16XV</td>
<td>DIESEL</td>
<td>78,500</td>
<td>Diesel-electric, base plant. Two fatigue piston models. 3800 BHP cylinder diesel engine-generator sets. Each furnishing power to two motors geared to the main reduction gears. Boost plant: four fatigue piston models. 3800 BHP cylinder diesel engines rated at 15,000 BHP each driving the main reduction gears through positive displacement clutches or electric hydraulic couplings.</td>
</tr>
<tr>
<td>17XV</td>
<td>DIESEL</td>
<td>72,500</td>
<td>Geared diesel, base plant. Two fatigue piston models. 3800 BHP cylinder diesel engines rated at 37,000 BHP each connected to two single speed, single reduction gears through positive displacement clutches or electric hydraulic couplings.</td>
</tr>
<tr>
<td>18XV</td>
<td>DIESEL</td>
<td>71,700</td>
<td>Diesel-electric, base plant. Two fatigue piston models. 3800 BHP cylinder diesel engine-generator sets. Each furnishing power to two motors geared to the main reduction gears. Boost plant: four fatigue piston models. 3800 BHP cylinder diesel engines rated at 15,000 BHP each driving the main reduction gears through positive displacement clutches or electric hydraulic couplings.</td>
</tr>
<tr>
<td>19XVII</td>
<td>STEAM</td>
<td>83,000</td>
<td>Geared turbines. Same as study I except that two conventional boilers, one per shaft are substituted for the four of study I. Reversing: same as study I. Base plant: 50,000 BHP on one boiler (cross connected) at 175% overload.</td>
</tr>
</tbody>
</table>

**FIGURE 4-33** PROPELLION SUBSYSTEM CONCEPTS (SHEET 4 OF 4)
Development of the preliminary weight, space, cost, and performance characteristics for these initial 48 alternate concepts provided an indication of the significant parameters in the selection process. These analyses also made it possible to exclude those plants (e.g., diesel and COGAS) from further consideration which appeared relatively unsuitable or not sufficiently developed for the DD 963 class ship.

In initially assessing the impact of alternate propulsion systems on a destroyer design, two factors are of particular significance; specific machinery weight and SFC. No other machinery parameter or combination of parameters has more important influence on the ship design configuration. The improvements possible through increased power concentration are well documented.

The relationships among these parameters for conventional destroyers satisfying the broad DD 963 performance requirements are illustrated in Figure 4-34 [4-130]. The range of specific machinery weights and specific fuel consumptions permitted by the state-of-the-art within the program time frame are indicated.

The 15 lb/shp to 30 lb/shp specific weight range extends from that projected for advanced concept aircraft gas turbine plants to that calculated for conventional 1,200 psig/950°F destroyer steam plants. Similarly, the endurance power SFC range extends from that considered practical for CODAG plants with base load medium speed diesel to that possible with a conventional destroyer steam plant. These ranges
FIGURE 4-34  IMPACT OF PROPULSION SUBSYSTEM ON DESTROYER SIZE SPECIFIC WEIGHT VERSUS ENDURANCE SPECIFIC FUEL CONSUMPTION

SOURCE: REF [4-123]
established a domain of permissible DD ship displacements which ranged from 6,200 tons to over 8,500 tons. This corresponded to a maximum installed power range of 70,000 shp to 120,000 shp. Although this analysis was preliminary, it provided a valuable measure of the principal constraints imposed by the propulsion machinery technology, bounded the feasible range of key design parameters, and highlighted profitable areas for investigation.

In addition to the revised ship systems parametric analyses, the final phase of the propulsion trade-off included more comprehensive technical analyses, and detailed reliability/maintainability/availability, integrated logistic support and life-cycle cost studies of each lead concept. The results substantiated earlier investigations and indicated that a DD 963 class ship designed for gas turbine propulsion would provide improved operational capabilities and reduced life-cycle costs.

In the final analyses, the choice of DD 963 ship propulsion subsystems became one among three geared gas turbine concepts, each incorporating controllable reversible pitch propellers. These included:

a. A three Pratt and Whitney FT4A2 concept
b. A three General Electric LM 2500 concept
c. A four General Electric LM 2500 concept.
The 20 percent lower fuel rate of the LM 2500 engines and the fact that fuel costs constituted approximately 25 percent of total propulsion related life-cycle costs resulted in significantly lower life-cycle costs for the concepts utilizing these newer engines. In addition, concurrent system analyses and detailed hydrodynamic design had resulted in a gas turbine ship design requiring less than 65,000 maximum shp. This permitted achieving the substantial cost savings, which resulted from the specification of three rather than four engines.

Since the LM 2500 was not fully tested in the marine environment at the time, the Litton prime proposal for development and production of the DD 963 class ships included Pratt and Whitney FT4A2 gas turbines as the main propulsion engines. Because Litton believed the General Electric LM 2500 offered potential for lower life-cycle costs, an alternate proposal for utilization of LM 2500 main propulsion engines was presented separately but as part of the proposal.

The apparent absence of intra-organizational political influence during propulsion plant selection can be explained by a number of factors.

A number of groups in the Litton engineering organization for the DD 963 had participated in performing pre-decision analyses. Litton also operated the computer ship synthesis program which produced the total ship design gross characteristics for each alternative propulsion plant and performed the costings and economic analyses. These groups each reported directly to the Program Manager. All those organizations reported directly
to the Program Manager thereby avoiding a matrix organization which normally characterizes large engineering firms.

Since terms of the contract prevented Navy guidance until the submittal of the proposal, these decisions were almost completely removed from the variety of DOD politics.

The Navy selected an in-house group of naval engineers to evaluate DD 963 proposals. This group was not in favor of the three gas turbine electrically cross-connected solution and directed the contractors to add the fourth turbine. Later, the contractor suggested eliminating the electrical cross-connect as an acquisition cost-saving step.

The politics among various prime mover manufacturers was very heated. In fact, divisions of General Electric (i.e., the one manufacturing steam turbines versus the other manufacturing gas turbines) were testifying against each other on Capitol Hill at one point. Representative Mendel Rivers of the House Armed Services Committee requested the Seapower Subcommittee to hold a hearing on propulsion alternatives for the DD 963 program in May 1969. The hearing was apparently in response to pressure brought by steam equipment manufacturers seeking to reverse the gas turbine decision of the major bidders (all of whom submitted proposals specifying gas turbine propulsion plants for the destroyer).

During the subcommittee hearing the CNO testified that [4-130]:

287
"I believe that in the present state-of-the-art I would prefer to have these gas turbines for two reasons: One, because of the response time and maintainability and so on, as we mentioned. Secondly, because of the safety aspect, wherein the steam line is subject to penetration by shrapnel from bombs and shells."

Subcommittee recommendations included [4-124]:

"a. The Navy will provide to the House Armed Services Committee as agreed, quarterly reports on the progress being made on the test program agreed upon with the final contractor, and on the scheduling, cost and engineering progress of the program.

"b. The Navy should continue to investigate steam propulsion employing a single, high-performance boiler per shaft. The Navy should make the same periodic quarterly reports on the progress of such investigations to the House Armed Services Committee. The purpose of such investigations will be to provide a competitive backup in the event of trouble with the selected propulsion system.

"c. The Navy should be allowed to decide whether in its opinion the total package concept for contracting should be employed in this procurement. However, before making this decision final, the Navy shall inform the House Armed Services Committee as to its determination and the reasons therefore."

These recommendations were made in May 1969, a year and a half after the Navy had expended $30 million on a very careful process of deriving an optimum set of DD 963 characteristics. Had Congress demanded a change to steam, the ship would have had to be completely redesigned, resulting in a substantial increase in size.

In spite of this situation, two subcommittee members wrote a dissenting statement [4-124]:

288
"1. As in the case of C5A and the Sheridan-Shillelagh system, the Navy will be conducting developmental work and testing concurrently with production. This course of action has proven risky and I personally favor a return to prototype development to avoid controversies like those which occupy today's headlines. While the construction of three ships is a total package procurement in a lesser degree, the stakes are not as high. Authorization of three ships, with long lead-time components for two more, would not delay the shipbuilding program the Navy so urgently needs and which I concur is needed.

2. The savings in authorization would be more than sufficient to pay for Recommendation B calling for investigation of a backup propulsion system.

3. By effecting the savings mentioned above and continuing research on steam propulsion, we could well hasten the day when we could plan toward an all-nuclear Navy, including nuclear-steam powered destroyers."

During DOD appropriations hearings of the 91st Congress in 1971, after the contract was awarded to Litton for the DD 963, the Navy responded to a Congressional query about using G.E. or Pratt and Whitney engines for the DD 963 [4-125]:

Mr. Minshall. "Will the Navy decide what type of propulsion unit you will use whether it be G.E. or Pratt and Whitney?"

Admiral Sonenshein. "I will be as precise as I can about this.

"We have told each contractor that he can use either one, but in each case he must accept total system responsibility for the performance. They have bid accordingly. The final determination on this with the successful contractor will be a matter of mutual agreement, because we do not want to vitiate the total system responsibility to which he agreed.

"One other point is very important. These ships as designed can accept either one. One of them, the Pratt and Whitney, requires a larger ship. We have deliberately made it possible to accept either one. Even if one doesn't work out it would be possible later on to shift to another."
"The reason I bring this point into play is, that, in making the comparison, the G. E., the new and young engine I have described, has a much better fuel consumption rate than the Pratt and Whitney engine, some 20 to 30 percent better. It is a second generation engine.

"So, it will be a matter for mutual agreement between the successful contractor and the Navy as to which way he will go initially, but it does not preclude his shifting over later on at the 10th ship, or something like that.

"Both units require shore-based testing with clutches and gears, on a system basis. Mr. Minshall. "I hope you get all these wrinkles out of it before you get seaborne."

Admiral Sonenshein. "The contract costs that are projected here include this extensive shore-based testing program which will take about a year and a half for one shaft, including clutches, gears, and control systems."

Admiral Cousins. "I think it is important to point out that the CALLAGHAN in the first year of operations completed 17 round trips between Europe and the United States with the Pratt and Whitney engine."

Table 4-28 showing the state of gas turbine adoption by other nations in 1971 indicates how cautious and late the U.S. Navy was in its adoption process.

In addition to the numerous advantages of gas turbines mentioned throughout this study, several significant changes took place in the 1969-1970 time frame:

a. The Navy had decided to change fuel for all ships to Navy distillate fuel (NDF), thus eliminating use of the cheap NSFO for steam (which had previously enhanced the steam propulsion option in the trade-offs).
<table>
<thead>
<tr>
<th>Country</th>
<th>Class Name</th>
<th>Number ships in class</th>
<th>Ship type</th>
<th>Number of gas turbines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>Iroquois¹</td>
<td>4</td>
<td>Destroyer</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Bras d'Or</td>
<td>1</td>
<td>Hydrofoil escort</td>
<td>1</td>
</tr>
<tr>
<td>Denmark</td>
<td>Peder Skram</td>
<td>2</td>
<td>Destroyer</td>
<td>4</td>
</tr>
<tr>
<td>France</td>
<td>Balny</td>
<td>1</td>
<td>Destroyer</td>
<td>1</td>
</tr>
<tr>
<td>Holland</td>
<td>Turummaa</td>
<td>2</td>
<td>Patrol escort</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>SAAM¹</td>
<td>4</td>
<td>Destroyer</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>MK-7 frigate¹</td>
<td>1</td>
<td>Destroyer escort</td>
<td>2</td>
</tr>
<tr>
<td>Malaysia</td>
<td>Han Jebat</td>
<td>1</td>
<td>Destroyer escort</td>
<td>1</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>County</td>
<td>8</td>
<td>Guided missile frigate</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Bristol¹</td>
<td>1</td>
<td>Guided missile frigate</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Type 42³</td>
<td>15</td>
<td>Guided missile frigate</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Type 21³</td>
<td>12</td>
<td>Destroyer escort</td>
<td>24</td>
</tr>
<tr>
<td>U.S.S.R.</td>
<td>Kashin</td>
<td>--</td>
<td>Guided missile frigate</td>
<td>--</td>
</tr>
<tr>
<td>West Germany</td>
<td>Seatrain lines¹,⁴</td>
<td>4-8</td>
<td>Fast containership</td>
<td>8-16</td>
</tr>
</tbody>
</table>

1 Under construction  
2 Planned for construction  
3 Being built in Germany for a U.S. company  
4 30,000 hp per turbine

SOURCE REF (4-125)
b. The LM 2500 second generation engine with substantially improved SFC was regarded as a feasible engine for marine use.

c. LM 2500 volume requirements for air intake and exhaust were 50 percent of FT4A requirements.

d. Operational experience in the Military Sea Lift Command ship, CALAGHAN, had lessened the technical risk of gas turbine use.

e. The Navy was projecting future manning of ships by volunteers not draftees. Thus a higher level of automation was more acceptable to the operating forces of the Navy. This factor favored gas turbine propulsion because of its increased amenability to high level automation.

As a result of these new conditions, strong lobbying by the Navy in Congress and DOD, and the recognition that the DD 963 destroyers were badly needed and that any change would have set back the program seriously, the decision was made to adopt gas turbines as main propulsion prime movers for U.S. Navy warships. The first ship of the class was delivered to the Navy four years later in September 1975.

A number of respectable organizations, such as the National Academy of Science and the Navy Research Advisory Council (NRAC), composed of university professors and various industry representatives, were asked in the early seventies to review the gas turbine decision for the DD 963, thus closing the circle which was started more than 35 years earlier when the Academy was asked to review the state-of-the-art for gas turbines and recommend the course of action the Navy should take (as described at the beginning of this study).
The Academy's report issued in late 1971 [4-126] supported the Navy's decision to use gas turbines on the DD 963. It did express concern about future Navy development of gas turbines along with proper operational and maintenance practices to yield high reliability gas turbine propulsion for the DD 963 class and future naval ships. The report listed 25 points the Navy had to consider if this new prime mover were to succeed and it also discussed internal organization problems the Navy might have in managing the future development effort.

The NRAC report issued a year prior to the Academy's report did not deal specifically with gas turbines or the DD 963 but provided a failure analysis for propulsion systems aboard fleet units at that time. The NRAC concluded that the Navy had given insufficient attention to good solid engineering development and testing with respect to innovative non-nuclear power plants [4-127]:

"The various factors contributing to the unsatisfactory state of power plants in the Navy could be summarized as follows: Diffused management combined with inadequate engineering development and crew training which was further aggravated by spotty and inadequate funding."

Though this is true, it addresses only the symptoms rather than the causes for the Navy's difficulty in adopting innovations. These causes are discussed in Chapter 6. One fact emerges without doubt: The gas turbine innovation adoption process was extremely long, difficult and complex, before its final success in the DD 963 class destroyers.
4.11 The First Five Years of the Post Adoption Period

During the early stages of the DD 963 class concept formulation, when a much less ambitious ship was considered, the follow-ship cost was believed to be around $30 million. As the ship developed and the requirements became solidified, it became clear that the cost of the DD 963 would be more nearly $100 million per ship. As a result, the DD 963 could not be the ship which would replace the large number of aging destroyers in the fleet.

Therefore, on 30 September 1970, the CNO initiated a set of feasibility studies which were intended to produce a new destroyer which could be bought in very large numbers. At first, the idea was to design a destroyer which could be configured either for an Anti-Submarine Warfare (ASW) or an Anti-Aircraft Warfare (AAW) role by having common hull propulsion and auxiliary systems but different weapons/sensor configurations. Later this idea was dropped and the primary weapon system for the new design became a MK 13 missile launcher, a 76 mm gun, torpedo tubes, and two helicopters.

By this time, the Total Package Procurement concept had been dropped by DOD and the Navy brought back the concept of in-house design of its ships. By December 1970, NAVSEC had completed feasibility studies which showed that an austere ship with a full load displacement of about 3,500 tons could be built for a cost of $40-50 million.
CNO approved the conceptual design effort for the ship which was named PF 109 (later FFG 7). As part of this effort, the Machinery Division performed a number of trade-off studies for twin screw and single screw ships, all with gas turbine propulsion alternatives [4-134].

By January 1971, the design proposed by NAVSEC was a twin screw COGOG plant of 48,500 shp which would have propelled the ship at as high a sustained speed as the DD 963. However, since this was to be an austere ship in all respects and its mission was to protect only merchant ship convoys or underway replenishment groups, its speed could be reduced. The question became not what kind of prime mover to use but how many shafts and what precise configuration. During the first three months of 1971, a series of machinery trade-off studies of single versus twin screw ships had been made for the optimum, most cost effective propulsion plant for the PF. From the more than 30 studies conducted for candidate propulsion systems, two single screw and two twin screw were selected for further study. The candidate systems, all gas turbine plants configured either as COGAG or COGOG, were the following:

a. COGAG, Single Screw. The propulsion plant consisted of two gas turbine engines driving through their respective clutches and a single-locked train double-reduction gear to a Controllable-Reversible Pitch (CRP) propeller. Either gas turbine engine could be used as a cruise plant to drive the ship to speeds up to 25+ knots.

b. COGOG, Single Screw. The plant differed from the COGAG plant in that the propulsion system incorporated a 3,250 bhp cruise gas turbine engine to allow for an economical mode of operation up to approximately 14.7 knots.
c. COGAG, Twin Screw. This study used two single gas turbine engines driving through their respective clutches and reduction gears to CRP propellers. A main propulsion A.C. generator/motor was coupled to each reduction gear to permit electrical cross-connection of the shafts for economical operation of both shafts with either gas turbines up to speed of approximately 23 knots.

d. COGOG, Twin Screw. This study differed from the COGAG in that, in lieu of a motor/generator electrical cross-connect, a single 3,250 bhp cruise gas turbine engine was connected to each reduction gear to provide an economical mode of operation up to approximately 17.3 knots.

These configurations are shown on Figures 4-35, 4-36, 4-37, and 4-38. The General Electric LM 2500 gas turbine engine was selected for main propulsion. By 1971, the LM 2500 was in the process of qualification and additional testing to a total of 4,500 hours was planned. In addition, a LM 2500 engine had by then accumulated over 8,000 hours in the MSC CALLAGHAN and was to continue in operation until 18,000 hours were accumulated. Fuel was commercial diesel although it was expected that Navy Distillate (N.D.) would be used to obtain some operating experience at sea with that fuel. Anticipated risk was considered minimal from the standpoint of satisfactory engine operation. In the event of failure of the LM 2500, the PF was to be designed to accommodate the Pratt and Whitney (P&W) FT4, a fully qualified engine (except for Navy Distillate fuel).
For the single screw concepts, take-home propulsion units were also incorporated in case of damage or failure of the main propulsion train. This consisted of a diesel engine driving a retractable propeller.

After review of the four concepts, NAVSEC's Machinery Division came to the following conclusions [4-128]:

"NAVSEC concludes that the additional cost of the twin screw ship cannot be justified for the PF.

"On the basis of the machinery system studies conducted, the single screw COGAG propulsion system is recommended for selection from the four candidate systems considered. This system provides the highest sustained speed, meets the specified endurance and has the lowest ship acquisition cost. In addition, the simplicity of the system further provides for a less costly, less complex control system."

In fact, what was being proposed was that the new ship use one shaft's worth of the DD 963 power plant.

The recommendation was accepted and on 6 May 1971 the CNO approved the single shaft gas turbine concept. Preliminary Design began in June. Bath Iron Works was the winner of the lead ship production contract in April 1973. The lead ship had not been completed at this time but was launched on September 27, 1976.

In 1971, another ship design, not a destroyer but again an austere "design to cost" ship, had been started. Its mission was also to protect merchant convoys and underway replenishment groups but its weapons were
to be 14 helicopters and 3 V/STOL aircraft. A displacement limit of
14,000 tons was imposed and again the struggle to determine propulsion
plant type was not a lengthy one. It was decided to make it single
screw COGOG with a somewhat uprated LM 2500. The ship was to be called
"SEA CONTROL SHIP" but it was cancelled after a Contract Design Package
had been completed by NAVSEC on 28 December 1973.

While the design-to-cost concept was still in effect, the Navy
initiated design for an austere destroyer (DG) to carry a new AAW weapon
system (AEGIS). The DG/AEGIS design, which emerged late in 1974, included
two FT9A gas turbines (70,000 shp) for propulsion at a sustained speed
of about 30 knots. The ship was eliminated from the FY 1976 budget as
being too austere, even with a follow-ship cost of about $200 million.

Attention turned instead to nuclear-powered alternatives. After
mid-1973, a more powerful nuclear AEGIS ship, the strike cruiser, began
to evolve. Proponents of nuclear power objected strongly to the use of
conventional power for any unit so important as an AEGIS ship. In 1974,
Title VIII became part of the FY 1975 Defense Authorization Act [4-129]:

"New construction major combatant vessels for the strike
forces of the United States Navy authorized subsequent to
the date of the enactment of this Act shall be nuclear
powered ... unless and until the President has fully ad-
vised the Congress that construction of nuclear powered
vessels for such purpose is not in the national interest...."
Thus presidential authorization would be necessary for construction of the DG/AEGIS. Though the Navy preferred a high-low mix of air defense ships, the president requested long lead items for a strike cruiser in FY 1976. The sudden presidential decision in favor of the CSGN, a ship Congress thought was ill-defined, caused Congress not to approve any long lead items, delaying the decision until FY 1978.

Meanwhile, CNO ordered a new non-nuclear AEGIS destroyer design, a less austere type evolved from the SPRUANCE class destroyer and designated DDG 47. The DDG 47 (which is the DD 963 with a new weapon suite), has had a similar fate. One of the primary driving forces behind the disapprovals concerns the propulsion system decision.

The House Armed Services Committee is very strongly influenced by Admiral Rickover and is in favor of nuclear propulsion; it is a strong CSGN supporter. The Senate Armed Services Committee believes that the Navy needs ships which are cheap enough so that they can be bought in sufficient numbers; it supports the DDG 47. Because of this conflict, the annual joint conference of these committees has thus far failed to select either or both designs.

The situation which led to easy victories by gas turbine proponents for the PF and SCS in the immediate post-adoption period was over by the time of the DG/AEGIS design decisions. The conditions of the preceding 30 years prevailed; the selection of the power plant type for a new Navy ship again became an involved political process during the early design period.
Though gas turbine propulsion has been selected for all nonnuclear warship designs since 1969, further improvements must be made in gas turbine technology if they are to continue to win future trade-offs (even though as this case study showed the technical issues are not the decisive ones in the decision to adopt or reject a specific prime mover). Gas turbines will not necessarily be selected in future ship design trade-off outcomes, as Table 4-29 shows. Had it not been for the development of the PT9 engine (a derivative of the Boeing 747 aircraft engine) sponsored by the Navy, steam propulsion would have won the trade-off for the DG/AEGIS on an acquisition cost basis.

Table 4-30 presents some of the areas needing improvements to maintain the superiority of gas turbine technology for naval ship propulsion.

Using fuel consumption as an example and considering the expected spiraling cost of fuel, Table 4-31 indicates that either Specific Fuel Consumption (SFC) curves for future engines must be flattened over the whole range of partial power or the absolute value of SFC must be reduced even further. Without either development, high fuel consumption at off-design power levels, combined with high fuel prices, may force the return to steam propulsion in certain power ranges.

Unless intensive materials research is pursued toward advances in engine life and reliability, the adoption of gas turbines into future naval ships could be threatened again.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4LM 2500</td>
<td>Full Power</td>
<td>86,000</td>
<td>43,000</td>
<td>659</td>
<td>213,000</td>
<td>2/3/35</td>
<td>0.845</td>
<td>950/500</td>
<td>BASE</td>
</tr>
<tr>
<td></td>
<td>Full Power</td>
<td>62,500</td>
<td>10,000</td>
<td>553</td>
<td>205,000</td>
<td>2/3/35</td>
<td>0.809</td>
<td>840/430</td>
<td>- 1.9</td>
</tr>
<tr>
<td>3LM 2500 (3 SHAFT)</td>
<td>Full Power</td>
<td>64,000</td>
<td>21,500</td>
<td>633</td>
<td>215,000</td>
<td>2/3/34</td>
<td>0.628</td>
<td>940/375</td>
<td>- 0.9</td>
</tr>
<tr>
<td>DUAL 30K HP G.T.</td>
<td>Full Power</td>
<td>70,000</td>
<td>35,000</td>
<td>534</td>
<td>188,000</td>
<td>2/3/32</td>
<td>0.883</td>
<td>840/430</td>
<td>- 3.2</td>
</tr>
<tr>
<td>CODOG</td>
<td>Full Power</td>
<td>62,500</td>
<td>14,000</td>
<td>680</td>
<td>245,000</td>
<td>2/3/36</td>
<td>0.560</td>
<td>840/430</td>
<td>- 0.6</td>
</tr>
<tr>
<td>STEAM (850 PSI)</td>
<td>Full Power</td>
<td>63,000</td>
<td>-</td>
<td>767</td>
<td>202,000</td>
<td>2/3/44</td>
<td>0.741</td>
<td>500/200</td>
<td>- 2.2</td>
</tr>
</tbody>
</table>

SOURCE REF (4-16)
<table>
<thead>
<tr>
<th>CURRENT STATE-OF-THE-ART ACCEPTABLE</th>
<th>NEEDS ADVANCE ON THE STATE-OF-THE-ART</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Structureborne noise signature</td>
<td>1. Fuel consumption</td>
</tr>
<tr>
<td>2. Time to get underway</td>
<td>2. Engine life</td>
</tr>
<tr>
<td>3. Weight characteristics</td>
<td>3. Air flow requirements</td>
</tr>
<tr>
<td>4. Control characteristics</td>
<td>4. Reversing</td>
</tr>
<tr>
<td>5. Maintenance characteristics</td>
<td>5. Exhaust gas temperature</td>
</tr>
</tbody>
</table>
### Table 4-31: Power/Specific Fuel Consumption Requirements as a Function of Ship Speed (5)(6)

<table>
<thead>
<tr>
<th>Ship</th>
<th>SCS</th>
<th>DD-963</th>
<th>PF</th>
<th>DG/Aegis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement (L. tons)</td>
<td>14,000</td>
<td>7,600</td>
<td>3,500</td>
<td>6,000</td>
</tr>
<tr>
<td>Engine</td>
<td>LM2500</td>
<td>LM2500</td>
<td>LM2500</td>
<td>FT-9</td>
</tr>
<tr>
<td>No. Engines</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>No. Shafts</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ship Speed (% Max. Speed)</th>
<th>% of Max. SHP</th>
<th>SFC</th>
<th>% of Max. SFC</th>
<th>% of Max. SFC</th>
<th>% of Max. SFC</th>
<th>SFC</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>4.0</td>
<td>(1)</td>
<td>2.5</td>
<td>(1)</td>
<td>(1)</td>
<td>(4)</td>
</tr>
<tr>
<td>50</td>
<td>11</td>
<td>(1)</td>
<td>0.79</td>
<td>(2)</td>
<td>0.80</td>
<td>10</td>
</tr>
<tr>
<td>60</td>
<td>20</td>
<td>(1)</td>
<td>0.68</td>
<td>(2)</td>
<td>0.71</td>
<td>17</td>
</tr>
<tr>
<td>80</td>
<td>40</td>
<td>(2)</td>
<td>0.51</td>
<td>(3)</td>
<td>0.48</td>
<td>45</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
<td>(2)</td>
<td>0.40</td>
<td>(3)</td>
<td>0.41</td>
<td>100</td>
</tr>
</tbody>
</table>

**NOTES:**

1. Assumes one engine operation/ shaft.
2. Assumes two engine operation.
3. Assumes four engine operation.
4. SFC for idle operations not available.
5. Standard conditions: $T_a = 80^\circ F$
   Duct Losses = 4" H₂O inlet, 6" H₂O Exit
6. Comparison should not be made among the four ships since 100% power levels and engine ratings in each case are different.
A third area needing technology improvement (important from a ship designer viewpoint) is the air flow requirement. The ship types most amenable to gas turbine propulsion are the so-called "volume-limited" ships, i.e., ships which require a large volume above the waterline to accommodate all the required functions of the particular ship. The current high air flow requirements of aircraft-derivative gas turbines penalize the ship in the most valuable locations. Since there may be very little that technological development could do towards reducing the air flow for gas turbines, a new transmission system (cryogenic motors) which could enable placing the prime mover not in line with the propeller would enhance the gas turbines competitive position.

Insufficient advance of gas turbine reversing technology could prevent the future selection of gas turbines. If the ship design is restricted to CRP propellers for reversing, the power level is limited to 40,000 shp (the level for which a CRP is currently available). Thus, a four-shaft ship would be necessary for the gas turbine version which would be evaluated against a two-shaft steam-powered ship, since the latter can use fixed pitch propellers (state-of-the-art, 70,000 shp) because reversing does not depend on the propellers. Additional shafts, gears, auxiliaries for the gas turbine version and their attendant spiraling impact on overall ship size, make the steam-powered version cheaper to buy, thereby eliminating the gas turbine as a viable option.

Another technological problem presented by the gas turbine is its characteristic high temperature of exhaust gases. Topside electronic equipment, such as communication and radar antennas, is not designed
to withstand these temperature levels. In addition, stacks are normally located forward of helicopter pads, thus creating an aerodynamically unstable environment for the main rotor blades at a critical height just prior to landing. With today's heat-seeking weapon guidance, infrared signature is an important ship design consideration, making reduced exhaust temperature a design objective. However, this problem may have to remain in the ship design rather than engine design area, since temperature reduction as part of engine design will work against some of the other desired state-of-the-art improvements previously discussed.

However in spite of technological improvement for gas turbines, without a policy similar to the Royal Navy's requirement that all of its post-1967 warships be propelled by gas turbines, the selection of power plant type by the U.S. Navy will be reenacted for every new warship design. Advocates will continue to exist, industry will continue to use its influence, and economic analyses will continue showing little marginal value for one or another plant type (other than nuclear). Under these circumstances i.e. lack of policy, the changing ground rules, (such as from design-to-life cycle cost to design-to-acquisition cost) the existence or lack of an advocate for gas turbines, and in-house Navy politics will remain as strong influencing factors on propulsion plant decision making.
INNOVATION IN NAVAL SHIP DESIGN

VOLUME II
"The policy of installing anti-roll fin stabilizers appears to have proven effective for the Soviet, British, French, Italian, Canadian, and other major foreign navies. We should buy in on their experience in this area and proceed to harness our available talent and technology to do better. Proving that we need fins at this stage in the state-of-the-art seems redundant, and we should stipulate it as a requirement in our ships."

VADM Adamson
CONNAVSURFLANT, 1975

CHAPTER 5

SHIP ROLL STABILIZATION - CASE STUDY

5.1 Introduction

Ships operating on the high seas are subjected to forces imposed on them by waves which induce ship motions. The motion of a ship at sea is a function of the sea itself and of such factors as the shape of the ship's hull and its loading and stability characteristics. These factors, for all practical purposes, are fixed once a mission has commenced, assuming that consumables reduced during a voyage (such as fuel, food, and fresh water) are compensated by taking on sufficient seawater ballast. Two further factors, course and speed, may be adjusted such that dangerous or unpleasant motions of the vessel are avoided. A ship, when considered as a rigid body, has six degrees of freedom of motion. The three angular motions are roll, pitch, and yaw; translational oscillations along the three axes are heave, surge, and sway (see Figure 5-1). All of these motions are undesirable, but some are more objectionable and uncontrollable than others. For a more detailed explanation of roll motion of a ship in a seaway and equipment options for its stabilization see Appendix B.

In the past, there have been sporadic attempts to control all types of motion. Relative success has been achieved in stabilization of
FIGURE 5-1  THE SHIP AS A DYNAMIC SYSTEM
yaw by the use of automatic steering devices which have improved course-keeping qualities; for certain ships, methods of reducing pitch have also been considered, but without widespread success and quite understandably so. The required stabilizing forces are extremely large. They can be developed with fins mounted on the bow, but the fins can cause structural and vibration problems and interfere with anchor handling. A properly loaded intact ship will not capsize, so that roll stabilization means roll angle, roll velocity, and roll acceleration limitation. In contrast to the yaw case, as long as rolling is a stable motion, it need not be controlled for the ship to continue to operate in a stable mode. However, it is roll that has fascinated inventors since steamships were invented. The history of the subject is replete with inventions, and literature is littered with articles and reports on the subject, but very little has been said about the reasons for the sporadic adoption of these devices in the U.S. Navy compared with other Western and Soviet Navies.

Prior to delving into the history of the adoption of this innovation in the U.S. Navy, a brief review of the current state of adoption of this innovation in destroyers is in order.

Fin stabilizers were first adopted in the U.S. Navy in 1958 for a new construction destroyer class, the DE 1037. Since that time, only three more classes of destroyers (the DE 1040, the DEG-1, and the DE 1052 classes) have incorporated roll stabilizing devices, specifically fins. These classes are derivatives of the DE 1037 class. This limited adoption pattern is in spite of the fact that a large number of other destroyer/cruiser classes have been designed and built during the last 15 years,
(DD 963, FFG-7, CGN 36 and 37, CGN 38 classes) for which roll stabilization has considered but not adopted. Much more will be said about the circumstances which led to the decisions to adopt or to reject.

In 1973, Captain Kehoe, in a paper published in the Naval Institute [5-1], effectively illustrated that the practice of fitting roll stabilizer fins along with well designed bow forms is the reason that Soviet and British destroyers are able to maintain speed in a seaway, while U.S. destroyers in the same operational area are forced to reduce speed.

This publication had the effect of increasing the support for establishing improved seakeeping criteria for new designs. One of the first signs of this interest was a visit by Captain Kehoe and a few senior engineers from the Naval Ship Engineering Center (NAVSEC) and researchers from the Naval Ship Research and Development Center (NSRDC) to both the Atlantic and Pacific Fleets. The objective of this visit was to:

a. Interview Commanding Officers of various destroyers for their experienced seamen's judgment regarding ship handling and crew/equipment performance problems in rough weather.

b. Understand the improvement required in the design criteria for the slam, deck wetness, and roll characteristics of future destroyers.

c. Obtain insights into destroyer seakeeping requirements which might be of immediate application to ships currently under design.
Collective shipboard experience represented by the Commanding Officers interviewed included all currently operational destroyers from the World War II era, (DD 692 SUMNER Class) to the most recent (DE 1052 KNOX Class). It was the unanimous opinion of these operators that rolling motions are their most frequent source of tactical, material and personnel limitations. They strongly recommended anti-roll stabilizing fins for all destroyer-type ships.

Captain Kehoe and the engineers and researchers who accompanied him [5-2] expressed their detailed findings as follows:

"The enthusiasm of Commanding Officers from DE 1040 and DE 1052 Class ships for fin stabilizers was particularly illuminating in terms of the benefits attributable to roll stabilization in addition to acceptable weapon and sensor performance. Some of the significant benefits highlighted were:

(1) They allow the crew to perform 40-60 percent more maintenance and repairs during underway operating periods.

(2) They reduce crew fatigue and improve watchstanding performance with a consequent reduction in personnel induced equipment casualties.

(3) They improve equipment performance and reduce equipment degradation as a result of reduced lateral accelerations and oscillations associated with rolling.

(4) They enable a ship to conduct alongside ship-to-ship transfers safely in higher sea states and at higher speeds than ships without fins.

(5) They improve the sailors' perception of the good habitability we are now incorporating in newer ships as a result of providing an environment free
from excessive ship motion. One Commanding Officer speculated that while he could not directly attribute an improvement in re-enlistments to fins, he could not recall any sailors on his DE 1052 wanting to get out or a transfer to a bigger ship because of sea sickness as had been his previous experience in ships without fin stabilizers."

In July 1975, a conference was sponsored by NAVSEC on the subject of "Seakeeping in the Ship Design Process," to which personnel from naval laboratories as well as university professors and other private research firms were invited. The conference [5-3] addressed roll stabilization among many other issues. The conclusion with respect to roll stabilization of U.S. destroyers was summed up by stating that:

"The lag in the U.S. Navy's adoption of such a policy (i.e. that roll stabilization be required in all destroyers) appears to be the result of the complex, lengthy and expensive process of cost-benefit evaluation, and of the research and development it has undertaken on this item. The cost of this process alone will approach that of initially installing such fins on the entire FFG 7 Class. But the delay is even more serious in that a large number of ships are being and will continue to be built which will have seakeeping qualities inferior to those of our allies and, more importantly, to those of our possible adversaries."

In January 1976, the Commander Naval Sea Systems Command, in a talk delivered to the Navy's ship design community [5-4], offered another explanation in addressing the DD 963 class of destroyers:

"Will we put fin stabilizers on the DD 963 Class?"
"An engineer, or maybe two or ten for all I know, said that the 963 rolls excessively for good helo operations and so the ships need fin stabilizers. That's the engineer's statement - it's factual, clear, precise - he's right that the ship rolls a bit more than we would like. And from an engineering standpoint, fin stabilizers are a good, sound answer. So will we do it? Nope, we are not going to. Why?

"'Why' is a management question. Don't ask management questions unless you want management answers. The manager has said we don't want fin stabilizers on the 963's and, in one sense, that's the end of the engineer's job. He's done what he was supposed to do - he found the problem, diagnosed it, and found the engineering solution.

"Of course, life isn't that simple - it's not all that clear-cut. The engineer at NAVSEC wants to know why, because he's a good engineer - he cares about his work . . . he's proud of it . . . he did a good job and he knows it . . . so why is he getting turned down?

"Having asked management's 'why' questions, I'll give you management's 'because' answer: Because of economics . . . economics and politics. Pure and simple, it costs more than we can afford. And it could cause a delay in the published schedules, and politically, we - both the Navy and NAVSEC - can't afford still another delay in the 963, if we can avoid it."

This study traces the 60-year development of the awareness of the need for roll stabilization, describes the technological and political forces behind its eventual acceptance, and analyzes the case in terms of its application to innovation adoption in the U.S. Navy. As we will see, it is an unfinished story. The innovation is again in danger of becoming orphaned since, on one hand, as recently as 1976, the Ship Logistic Manager of the DE 1037 and 1038, the first warships using fin stabilizers in the U.S. Navy, ordered the stabilizers permanently removed and on the other, attempts to introduce roll stabilization into new U.S. warships have been consistently thwarted since its initial adoption almost 20 years ago.
5.2 Early History

There are records of very early attempts made at ship roll stabilization; but in the days of sailing vessels, these attempts were not developed to any extent, because the sails themselves were a deterrent to roll. Even today, the skipper of a fishing trawler or yacht will hoist a small sail for its steadying effect. With the advent of steam propulsion, the ideas on stabilizing ships—primarily to prevent seasickness—came fast and furiously.

In 1880, the Royal Yacht LIVIDIA, was built on the river Clyde in Scotland for Czar Alexander of Russia. This vessel, with its broad beam and shallow draft (see Figure 5-2), hardly rolled in 25-foot seas. But the pounding of the ship's bottom on the sea loosened its joints and exhausted its crew. LIVIDIA was soon relegated to the calm and peaceful waters of the Black Sea [5-5].

About 1874, Sir Henry Bessemer designed and had a steamer built, the BESSEMER, with a salon mounted on gimbals similar to the mounting of a ship's compass (see Figure 5-3). He believed that this part of the ship could be maintained in a steady and level position regardless of the roughness of the sea, but, in practice, the system did not work as planned. According to a contemporary report, when the vessel rolled one way, the cabin rolled the other, as opposed to remaining upright.
FIGURE 5-3 THE STEAMER BESSEMER (SALON MOUNTED ON GIMBALS)
While sail was being superseded by steam, and wood by iron, warship armament was changing from broadside batteries to turrets placed on or just off centerline. These combined changes resulted in serious transverse stability problems, particularly in the warships. Sails had provided large damping in roll, and their removal resulted in large angles of roll. Bilge keels were added to ships to increase the hull damping, and so to lessen the roll [5-6].

In 1883, Watts in a paper read before the Institution of Naval Architects in England [5-7], presented the design of the first roll stabilizing device internal to a ship's hull or what he called "water chambers." Watts' experiments were conducted on the warship INFLEXIBLE which had 9,200 tons displacement. Figure 5-4 shows the "water chambers" as designed, but during construction the design was altered because of pressures from other groups participating in the design and desiring "to get as much out of each vessel in the way of offensive and defensive power as she can be made to yield . . . the forward chamber, which was by far the larger of the two was necessarily appropriated for stowage so that only the after chamber is now available." [5-8]

This account by Watts will become a very familiar explanation for problems encountered in adopting stabilizers for warships in the following century, as this study will show. The experiments which Watts recounted in 1883 were interrupted when the INFLEXIBLE was required for service at the bombardment of Alexandria (not unlike future problems.
FIGURE 5-4 "WATER CHAMBERS" AS DESIGNED FOR THE WARSHIP HMS INFLEXIBLE
for naval applications). Later, further experiments were made by Watts on the EDINBURGH which was also of the INFLEXIBLE Class.

Watts' paper presented the results of experiments with and without the "water chambers" working to reduce roll and with and without deepened bilge keels. Both of these cases showed distinct improvements in rolling behavior.

At about the same time as Watts' work, some experimental studies were conducted at the University of Glasgow on a wide variety of stabilizer tanks. Additional restrictions were tried for controlling, to some extent, the flow of water across the tank. Biles [5-9] referred to tank stabilizers being fitted to a number of ships at the time; however, such tanks soon fell into disuse as a contemporary paper [5-10] stated:

"It is not clear from the literature why such tanks fell into disuse, although the inefficient steam engines and boilers of the day may have been contributory factors, since large quantities of coal were required and all available space was used to carry it. This was particularly true for naval vessels such as H.M.S. INFLEXIBLE and H.M.S. EDINBURGH. Noise generated in the tank may also have been a factor."

In 1911, Frahm [5-11] reported on the successful use of a U-tube system for roll stabilization, and, in subsequent years, a large number of vessels were fitted with tanks designed in accordance with his methodology. Previous tanks, of the surge type, had required excessive space and had caused serious loss of stability because of the "free surface effect."
Actually, the science of ship stabilization may be thought of as beginning with the invention of the Frahm tank. Frahm used model experiments to test the mathematical theories which he developed, and he performed full-scale tests at sea on YPIRANGA, CORCOVADO, and other vessels.

Trials at sea were conducted from December 1910 to February 1911, on a 10,000-ton ship, the YPIRANGA. The tanks which Frahm had designed for this ship required a total of 188 tons of water, which is 1.88 percent of the displacement of the ship.

Rolling records taken at sea under frequently encountered conditions showed that the average unstabilized amplitude of roll of about 3.1 degrees was reduced to an average residual roll of about 0.6 degree. The stabilization achieved was thus somewhat better than 80 percent, by actual measurement of a portion of the rolling records. This result was in surprisingly good agreement with previous laboratory results.

Rolling records also were taken at sea under very unfavorable conditions (hurricanes and exceedingly heavy seas). Amplitudes of unstabilized roll ranging up to 18 degrees were measured, but the average amplitude of unstabilized roll was much less than this. The average unstabilized amplitude of roll of about 5.2 degrees was reduced to an average residual roll of about 0.9 degree. The stabilization achieved was again somewhat better than 80 percent, by actual measurement of portions of the rolling records.
If Frahm had been obliged to conduct his experiments with but one pair of tanks instead of two, his achievement would have appeared considerably less brilliant. As he himself showed from model experiments and tests at sea, the average stabilization is only about 50 percent when one pair of tanks is used, rather than about 80 percent when two pairs of tanks are used.

Through some reasoning which is left unexplained, Minorsky and other proponents of activated tanks in the late 1920's seized upon the foregoing 50 percent average stabilization and advanced this as the measure of Frahm's achievement [5-12]. The justification for discrediting Frahm's success can only be surmised. Perhaps more extensive tests at sea gave somewhat different results from what Frahm reported in his paper. What appears more likely is that realization began to grow that the weight required by Frahm's methodology for two pairs of tanks is too great a price to pay for ship stabilization. The charge weight of water required by Frahm for both pairs of tanks of YPIRANGA was 1.9 percent of ship displacement but when structural weight of the tanks was included, the total was 2.2 percent of the displacement.

Frahm was the first person in history to bring ship stabilization to a stage of development which, at the time, commanded widespread public interest. Today, the world is inclined to duplicate what Frahm accomplished in 1910 to 1911. To have achieved, during voyages at sea, reductions of roll of about 80 percent, irrespective of whether the sea was that "often to be met" or "very unfavorable," was no mean accomplishment.
Another group of roll-reducing devices which was invented around the same period used high-speed rotation of massive weights to produce the required stabilizing couples. In 1907, Schlick [5-13] first used a steam-driven gyroscope to stabilize a ship. Though this early installation showed some promise, it encountered two major objections: excessive weight and poor controls. Later, the control deficiency was largely eliminated by the Sperry Gyroscope Company, who introduced a small, sensitive gyroscope, responsive to rolling accelerations, which controlled the main gyroscope through an electric motor.

Between 1913 and 1916 the prospect of a 16-inch gun dominated American battleship design as much as had the 14-inch five years earlier. The 16-inch gun meant, of course, added weight on the ship and made the General Board very sensitive to other heavy equipments. A potential source of substantial extra weight was a proposed gyroscopic stabilizer (about 500 tons), a large electrically-run gyroscope deep in the ship which was expected to reduce rolling without reducing the metacentric height. Previously, "steadiness", i.e., minimum roll motion, had been equated with low resistance to capsizing. The U.S. Navy had resisted calls for steadier ships in contrast to the Royal Navy which deliberately built top-weight into its R Class. A number of test installations were tried about 1914-1915, specifically in the destroyer WORDEN, [5-14] and in March 1916 an experimental gyro was ordered for the pre-dreadnought battleship OHIO. The cost of the Sperry gyro was $38,000. The various parts of the gyro were not delivered on time and the battleship was never
fully fitted with the stabilizer because of the U.S. entry in World War I in April 1917. In March 1917, the stabilizer parts were removed from the OHIO and installed on the U.S. transport HENDERSON, and sea trials were planned [5-15].

The General Board, in its deliberation in connection with the 1917 battleship design, approved a gyro stabilizer installation. The Newport News Shipbuilding and Dry Dock Company kept requesting status from the Bureau for the stabilizer equipments for the battleships MARYLAND and WEST VIRGINIA then under construction. The Bureau put the yard off hoping the results of the HENDERSON trials would become available. Since the Bureau of Ordnance said that it was not necessary to install the stabilizers in view of new fire control methods, the HENDERSON trials were delayed and, in January 1918, the Bureau told the yard to disregard the stabilizer and proceed with the battleship's construction. It is not clear from the historical records whether the HENDERSON trials were ever completed.

The Bureau of Engineering wanted to use the space left vacant for a distiller. Thus, while in 1915 the Bureau of Construction and Repair (BUC&R) regarded the gyrostabilizer as well worth the added weight, by the time the 1917 battleships were delivered, the gun fire directors had been improved to the point that additional roll damping was not considered necessary by the Bureau of Ordnance. Since the BUC&R
was not advocating the stabilizers for other reasons and they did not have an advocate elsewhere in the Navy, roll stabilizers for battleships lost out for the time being.

In 1917 Sperry introduced a tentative design for an improved device of the gyroscope stabilizer of capacity suitable for U.S. naval cruisers. This design indicated that such a stabilizer would weigh about 200 tons and would occupy a space approximately 25 feet long by 22 feet athwartships by 24 feet high. To install such an apparatus in an existing ship would involve a very extensive and costly rearrangement. In fact, in the application for which it was intended, space could only be found for the stabilizer by using spaces above the protective deck. This would expose the gear to damage by gunfire in action at sea during wartime, the very time when it was most useful.

Combined with these reasons against such an installation was the very definite opinion expressed by U.S. naval forces afloat that the disadvantages of such equipment aboard combatant ships outweighed any possible advantages because of the necessity of assigning personnel for operation and upkeep.

The Commander, Scouting Fleet, in March 1925, stated in an official letter that he was of the opinion that the additional weight, expense, and personnel involved in the installation of the gyroscopic
stabilizer in destroyers was not justified. The Commander felt that installation would have no value other than small, but problematic, added military value for gunnery purposes. Therefore, unless subsequent reports from the destroyer OSBORNE indicated a preponderant advantage of stabilization for gunnery, it was recommended that the OSBORNE be restored to its original condition and that no further roll stabilization tests be conducted on destroyers [5-16].

The Director of Fleet Training, in September 1925, stated that it did not appear to him that the increased gun platform stability provided to destroyers by the gyro stabilizer was of sufficient advantage to warrant the expenditure of space and funds which would be necessary to install that instrument. Therefore, he dictated that under no circumstances should a gyro stabilizer be installed at the expense of any part of the ship's armament.

In general, the conclusions regarding other types of moving weight stabilizers were similar. Space on a completed ship did not exist for such installations, and the gain did not promise to outweigh the obvious disadvantages.

The question of stabilizers was dropped until November 1929 when the SALT LAKE CITY, the first of a number of 10,000-ton cruisers, went on ship trials and subsequently was put into service. The trials of the NORTHAMPTON, the second ship of the class, were not favorable.
The NORTHAMPTON trials report made note of heavy rolling in beam seas on two occasions. Subsequently, reports were received from the Commander, Light Cruiser Division and the Commander, Scouting Fleet that very heavy rolling had been experienced by the various 10,000-ton cruisers in commission. Admiral Rock, Chief, BUC&R, in a paper delivered at the Naval War College discussed the motion problems of the 10,000-ton cruisers as reported by the Fleet [5-17]. He described the heavy rolling experienced by the SALT LAKE CITY during a winter cruise in 1931.

The experience of the SALT LAKE CITY added fuel to the rather smoldering fire of criticism of the rolling characteristics of the 10,000-ton cruisers. The Bureau of Construction and Repair began to realize that a thorough study of rolling, particularly as applied to these ships, was absolutely necessary. It was also recognized that if possible, other means of stabilization, in addition to extended bilge keels, had to be developed which could be installed experimentally on these ships.

A number of alternative remedies were examined and a great deal of model testing was conducted at the Experimental Model Basin during 1930 and 1931 [5-17]. There was no question but that the depth of the bilge keels should be increased over the original size. It was also shown that adding 40 to 42 tons of protective armor topside would not only improve the rolling situation but also would improve other characteristics at the same time. This work was authorized on all vessels of the designated type.
Passive anti-roll tanks were also considered. While the tanks had been effective in reducing rolling under some testing conditions, it was realized that on the ships themselves tanks could not be installed of the lengths and capacities used in the model tests. In order that, for test installations at least, every possibility should be tried, it was finally decided that tanks should be installed in the test ships.

At that time the PENSAEOLA and NORTHAMPTON were just beginning their respective overhauls. Moreover, these ships represented the two types of cruisers completed up to that point in time. The anti-rolling alterations for them were undertaken without greatly extending the overhaul periods, and the ships were back in service within a few months.

Increase of the bilge keels represented no particular problem. The deeper keel was to be of triangular rather than flat plate type. Similarly, the protective plating was simply added as a 1-inch or more thick envelope over the entire upper works forward and above the communication platform.

The size of the tanks installed was limited by constraints of metacentric height. On the NORTHAMPTON the limit was reached first. Because of the width of the double side on this ship, the tanks had to be limited to half the void spaces outboard in the way of one fireroom. This made the tanks one-fourth the length used in model tests, but it was felt that some effect from them should still be realized. On the
PENSACOLA, twice the NORTHAMPTON tank length could have been used, but it was decided to keep to the same general arrangements as on the NORTHAMPTON. Free flow had to be provided; so a series of flooding nozzles or pipes which could be opened to the sea were fitted at the bottoms of the tanks. In order that tests could be made with and without the tanks in operation, shut-off valves of the flapper type were provided at the flooding openings. These valves also gave the commanding officer a limited control over the stability of his ship. By closing the valves, he could eliminate the free surface that was present when the valves were open and the tanks were functioning. While the amount of control was small, it was felt that it might be of real benefit at a crucial time.

In September 1931, the PENSACOLA went to sea, and, from the beginning, a naval constructor was onboard much of the time with instruments to observe the roll and to obtain wave data and performance information with and without tanks.

The opinions of the commanding officer and of the admiral commanding the cruisers were to the effect that the performance of the ship was far better than as originally constructed, and that the tendency to an uncertain and jerky roll was much lessened. Unfortunately these ships were not set up to study the problem of roll stabilization in depth, because only limited instrumentation was allowed onboard which did not yield very clear conclusions [5-16].
The Bureau continued to be faced with poor rolling qualities of its ships and, at the same time, was besieged by offers of devices which were going to solve the problem. In December 1935 the Bureau turned, through the Secretary of the Navy, to the National Academy of Sciences for help [5-18].

The Bureau told the Academy that after extensive tests and analysis it had formed the opinion that no device other than bilge keels offered sufficient practical advantages to overcome its inherent disadvantages. However, the Bureau felt that it could use independent advice.

The outline of the Bureau's opinion is presented in Reference [5-19]. Interestingly, only four methods of roll stabilization were discussed in this document: gyroscopic stabilization, movable solid weights, and activated and non-activated anti-rolling tanks. Anti-roll fins were not mentioned.

The Bureau displayed a clear understanding of the drawbacks of the activated anti-roll tanks. In view of this, it is absolutely amazing that the Bureau went on to support more than ten years of experiments on such a device.

The Chief of the Bureau in the same communication [5-19] gave an extremely good definition of the problem, in fact such a good definition that I do not believe it could be much improved today, more than
forty years later. Many of the points made were unfortunately ignored over the years and are sources of problems even today.

"Is there available, or a likelihood of development, a method of ship stabilization that promises effective damping, or roll-preventing properties in moderately rough, irregular seas; that, considering the inertia of the compensating mass and the delicacy of the control apparatus, will be immediately responsive to variations in the rolling forces and will not, through lagging response to these forces, or to the activations of pitching, heaving, and yawing, occasionally seriously augment the effects of the normal rolling forces; that is sufficiently rugged to give trouble-free service over long periods of time and sufficiently simple in construction to permit repairs and adjustments by the usual naval personnel; that will not endanger the ship through erratic or uncontrolled behavior resulting from disarrangement of the control gear or from damage to the system or its control caused by gunfire or other casualty; and that will contribute sufficiently to accuracy of gunfire, to ease in launching and picking up aeroplanes, etc., to justify its cost in weight and space and in the expenditures necessary for installation, operation, and upkeep?"

As a result of the Navy's request for aid, the National Academy decided to establish a committee to study the problem [5-20]. Three distinguished professors were appointed to the Special Committee on Ship Stabilization: Dr. W. F. Durand of Stanford University, and Prof. J. C. Hunsucker and Prof. William Hovgaard, both from M.I.T. Two assistants were also appointed: Prof. F. M. Lewis and Prof. Lessells, both from M.I.T. The committee submitted its first report in February 1937 [5-21].
The first report shows definite awareness of the Denny-Brown activated fins system, developed in England and put on the market a few years before. However, the Committee concluded that [5-21]:

"It was agreed that no definite opinion regarding practicability could be reached without tentative design studies, and Prof. F. M. Lewis was requested to make such studies in time for the next meeting of the Committee, which is planned for the latter part of April next."

The Committee also decided to ask Dr. Minorsky, who was also at M.I.T., to prepare by April a comprehensive monograph on the whole problem of the dynamics of rolling and associated control and stabilizing devices.

Several points in the second progress report of May 1937, were especially interesting in view of the subsequent actions of both the Committee and the Navy. For example, the Committee quite correctly recognized that the key to the practicability of a roll stabilization device depended on the development of a method of control such that the applied moment shall always resist the rolling, regardless of the irregularity of the sea. With any device or method, there will be some small time lag inherent in the application of the damping moment, and the control device must be designed to compensate for this lag. The Committee felt that apparently it was possible to do this, and consequently in their opinion, the problem of stabilization was not impossible.

As we shall see later, not exploring this specific issue in depth at that point may have caused a 10 to 15 year delay in the adoption of the proper device by the Navy. By glossing over the time lag problem,
the Committee caused the Navy to invest in full-scale experiments with activated controlled anti-roll tanks, for which the necessary servo-mechanism was not readily available. The formidable problem of overcoming the time lag for the application of the anti-roll moment was delayed.

The Committee also correctly stated that [5-22]:

"The reason for the unsatisfactory results of past attempts to stabilize vessels seems to lie chiefly in an over-simplification of the problem. Attention is especially called to the effect of high speed and relative stiffness, in producing an irregular rolling motion whose damping requires a control based on continuous and anticipatory action."

The Committee then ignored its own perceptive observation as will become evident.

Prof. Lessells' preliminary investigation of activated tanks indicated that such a method of stabilization was not impractical, provided the control device could compensate for the somewhat large time lag inherent in the transfer of weight. The liquid to be transferred was suggested to be water or a light oil (diesel oil) rather than fuel oil. A possible means for actuation would be an impeller pump with reversing blades. The control device envisioned was a blade pitch adjustment with a continuously running rotor. The Committee stated that [5-22]:

"The weight, space, and power required for any scheme for shifting liquid will be substantial, and further consideration is needed before the Committee can recommend serious study of this means of stabilization."
The Committee refused to pass judgment on whether stabilization was worthwhile and suggested the easy way out, i.e. more experiments.

The Committee saw the potential in fin stabilizers and recommended an extensive experimental program to learn more about them. For the most effective pursuit of such a program of experimental work, the Committee thought that a comprehensive view of the whole problem and coordination of the various agencies of research was required. For these reasons, the Committee recommended [5-22]:

"Someone having such a comprehensive grasp of the problem (especially in its more abstruse and highly theoretical aspects) should be retained in continued relation with the experimental work outlined, perhaps as assistant to the engineer in charge. The Committee is much impressed by the ability of Dr. Minorsky for the theoretical part of this work, and recommends that, if possible, ways may be found for his employment in connection with the research program in some such capacity as above indicated."

Here is where the Committee committed a real error by overlooking the strength of an advocate in the innovation process. The Committee was recommending Dr. Minorsky for managing the experimental program on fins and interrupted bilge keels. The Committee overlooked the fact that Dr. Minorsky was an advocate of activated tanks with a number of patents to his credit on the subject. Somehow Dr. Minorsky managed to alter the Committee's negative attitude towards activated tanks and turned around their recommendation to experiment on fins into full concentration of the U.S. Navy on activated tanks. This delayed
adoption of active roll stabilization for U.S. Navy warships for at least 15 years.

The Committee did not meet or issue any subsequent reports until one full year after its second report. The third report was issued after the Navy had hired Dr. Minorsky and he had been at work for eight months. It is quite clear that by that time the Committee was relying solely on reports prepared by Dr. Minorsky [5-23]:

"For some weeks previous to our meeting on April 26th 1937, the documents covered by References [5-24], [5-25], [5-26], and [5-27] had been made available for our examination. The study of Reference [5-3] covers an examination of the possibilities of stabilization of several types of war vessels at various speeds and by the two methods of activated fins and activated tanks. This study, together with the requirement for stabilization over a range of speeds, led to the present concentration of further study on the method by activated tanks."

All the references of that report were authored by Dr. Minorsky, the advocate for years of activated tanks.

In one reference, Dr. Minorsky managed to shoot down fins because of the slow and zero speed deficiency of fins. Interestingly enough, the case the Committee's report made against the fins was based on aircraft carriers while the experiments proposed were to be performed on a destroyer [5-23]:

338
"This condition is of special importance in the case of airplane carriers where for suitable take-off or landing conditions, speeds may be reduced to very low figures, even to zero, or on occasion to speeds in reverse. Under these conditions it is obvious that the tank method is the only one offering any prospects of useful results.

"Regarding warships of all types, the available evidence points, then, to the conclusion that if stabilization in battle evolution is to be counted on, it should be available over a considerable range of speeds; and for airplane carriers, over the entire range from zero to full speed.

"These requirements appear to rule out of present consideration the method of stabilization by activated fins in favor of further detailed study of the possibilities with activated tanks."

Then in the next paragraph and with no explanation at all, the Committee endorsed the first introduction of an activated tank into a destroyer [5-23]:

"For these various reasons, later studies have been directed to the details of the application of the method of activated tanks, in the first instance to a vessel of the destroyer type."

The Committee proceeded to justify its reversal from the Committee's earlier stand by stating that [5-23]:

"Our earlier studies appeared to indicate that useful results might be looked for from two different types of anti-rolling equipment - (1) Activated Tanks and (2) Activated Fins. Since that time, information and opinion furnished by officers of the Fleet have served to indicate that if stabilization in Fleet maneuvers or in action is to be counted on as a significant factor, it should be available at speeds of 15 to 20 knots as well as at higher speeds and that its greater significance is more likely to be found at these lower speeds than at top speed."
As an aside, 15 to 20 knots is not low speed by any means and fins are quite effective in that range.

From the time of the second Committee report a year earlier, the direction of the study program was set in concrete and the Committee was faced with either endorsing the work directed and performed by the Committee's protege or redirecting it. The Committee strongly endorsed the direction of the work [5-23]:

"Regarding the work of the Committee generally, since its appointment in 1936, we have noted with satisfaction the excellent progress which has been made in the studies carried out by the Bureau of Construction and Repair, in accordance with our suggestions and recommendations as noted in earlier reports. We are confident that with the theoretical studies which have been made and with the information to be gained from the use of the accelerometer now under construction and from the model experiments as planned, a secure foundation will be laid for application of the method of activated tanks to vessels full scale, and we are confident that whatever may be the ultimate possibilities in the way of ship stabilization by this method, an installation full scale planned in the light of this information will be directly in the line of development toward such ultimate possibility."
5.3  *The Late 1930's and 1940's*

After study of the relative merits of various types of roll stabilization systems, in 1937 the Bureau of Construction & Repair (BUC&R), on the recommendations of Dr. Minorsky, decided to develop the activated anti-roll tank. The activated roll tank as a roll damping mechanism consisted of a tank containing a liquid which is oscillated by a reversing pitch impeller pump. The motion of the liquid was to be controlled in a suitable time-phase with the roll of the ship by an anticipatory control mechanism operating on the rate of acceleration of the roll. This scheme was selected because it gave promise of achieving the roll-quenching characteristics desired with fewer complications and under a wider range of conditions than gyro stabilizers or stabilizer fins.

Dr. Minorsky entered the Bureau of Construction & Repair 2 September 1937 as a contract employee to develop this roll stabilization scheme and was transferred to the New York Navy Yard on 10 October 1938.

From ship stabilization tests on a 1/5 scale model of the destroyer *HAMILTON*, Dr. Minorsky concluded that for the quenching of erratic rolling, a stabilization of 75 to 80 percent was about the best that could be achieved with his tank design. For the quenching of regular rolling, a stabilization of about 85 to 90 percent appeared to be possible.

One would have thought that with the experience of Frahm to guide him, Dr. Minorsky would have designed his tanks with a fluid charge
weight of 1.1 percent of the displacement of the ship. This he did not do. Instead, he chose a design which required a fluid charge weight of 3.4 percent of the displacement of the ship. The as-built weight of mechanical gear for activation ran to 18.7 tons per ship. The estimated structural weight for tanks and ducts was 5.7 tons per ship and diesel oils in the tanks were estimated at 40 tons. The total weight was 5.4 percent of the displacement of the ship. Dr. Minorsky defended this required weight on the grounds that the weight of diesel oil could be considered a part of ship's stores, and not a charge against the stabilizer. By his calculation, this left the weight of the stabilizer itself at 2 percent of the displacement of the ship.

By June 1939, full scale tests were requested by the Chief of the Bureau of Construction & Repair. The Chief of Naval Operations permitted the use of the HAMILTON from October 1939 to March 1940 for testing the Minorsky device. The last at-sea test was conducted in July 1940. Tests at-sea on the HAMILTON were quite unsatisfactory and further tests were discontinued pending extensive redesign of the pumps and control mechanisms. The program was transferred in December 1940 to the David Taylor Model Basin, whose engineers suggested in July 1941 [5-28] that the program be held in abeyance until the pumps could be perfected. This was approved by the Bureau. Dr. Minorsky and an aide were transferred in February 1941 to the David Taylor Model Basin [5-28].

Even though the tests were inconclusive, the Bureau of Ships, which was the successor of the Bureau of Construction and Repair, felt that
the concept promised the possibility of being developed into an acceptable shipboard installation if more development of certain components was achieved.

It is safe to predict that as the Minorsky efforts fall into historical perspective, they will more and more be recognized for their true value, i.e., they represented the attempt by a person, not himself an engineer, but rather a scientist, to design a ship stabilizer which would capitalize on the ship stabilization interest which existed at that time. This interest had been fostered by the success of Frahm many years before. The science of servomechanism theory and practice was only starting to develop. It seemed to be only a step from the passive tanks developed by Frahm to the activated tanks, proposed by Minorsky. The advantages claimed for activation were that not only would a greater percent stabilization be achieved, but also less weight and space would be required for a given maximum stabilizing moment. These hopes failed to materialize partly because of faulty engineering design, but mostly because the whole project took on the character of an improvisation. Almost nothing about the project was thought through in a manner befitting so important a project. The Bureau of Construction and Repair, by striving for quick, painless results, only succeeded in arousing disinterest in ship stabilization at the time.

In 1940, the British introduced the CORVETTE Class of small destroyers. These destroyers were designed to counter the German U-boats' threat. They were somewhat slower and smaller than other destroyers, but
they carried the same deadly anti-submarine weapons. Some were built also in Canada. Figure 5-5 appeared in the New York Times-Herald on 26 February 1941 showing one of the crew attempting to release a depth charge while the ship was rolling violently. This photo demonstrates vividly the impact on operations that large rolling can have.

The U.S. Navy inspected these CORVETTES in order to determine the potential for a possible U.S. Navy design. The Commanding Officer and some officers of the UTAH went aboard a Canadian 1150-ton CORVETTE the WELASKIWIN in the summer of 1941 at Long Beach, California. The Commanding Officer of the UTAH in his report to CNO [5-29] wrote:

"According to statements of officers onboard, the ship has a roll, reaching as much as forty-five degrees in heavy seas, and a very quick motion and a jerk at the end of the roll."

Complaints concerning the rolling characteristics of U.S. Navy destroyers were also being received at BuShips in 1940. For example, an annual material inspection report [5-30] concerning the destroyer STERET stated:

"The vessel rolls excessively in a moderate seaway and also when anchored where there are gound swells. It may be possible to reduce this rolling by extending or enlarging the bilge keels, although how effective this might be is not now known."

Other complaints were received from the British, who had received a few of the U.S. Navy's CAPTAIN class frigates. Several conferences were
FIGURE 5-5 IMPACT OF ROLLING ON A SHIP OF THE CORVETTE CLASS
held and the British decided on 10 November 1943 to adopt both a short and a long term policy regarding the CAPTAIN class [5-31]. The short term policy called for lengthening the bilge keels but not deepening them, while the long term policy was to deepen the bilge keels and to dispose of additional topside weight by removing some depth charges from the upper deck.

The U.S. Navy was informed of the adoption of these policies and, in fact, the Bureau of Ship's resident Captain at the U.S. Naval Attache in London traveled to Liverpool in January 1944 to discuss the problem with Admiral Horton, the Royal Navy's Commander-in-Chief, Western Approaches. The visit was recorded in a trip report [5-32] in which Admiral Horton was quoted saying that:

"Several dispatches were received from the ship's C.O.'s indicating violent and quick motions of the ships which strain and put out of action both officers and men."

The same source, i.e., the U.S. Naval Attache, had reported to the Bureau in early 1941 [5-33] that the British had incorporated the Denny-Brown fin stabilizers in their new HUNT class of destroyers. The same report stated that the stabilizer installation weighed 14.5 tons; also that 4 tons of buoyancy were lost because of the buoyancy loss of the pockets required for the equipment. However, back home, the failure of the Minorsky experiment on the HAMILTON did not deter the activated anti-roll tank proponents from continuing to spend time and money trying to prove its value rather than exploring the possibilities of fin stabilizers.
As mentioned earlier, Minorsky, his assistant, and all the equipment from the HAMILTON were transferred [5-28] to the Model Basin where Minorsky continued to plan and experiment. In May 1941, [5-34] Prof. Durand, the Chairman of the Special Committee on Ship Stabilization, wrote to the Chief of BuShips suggesting that using a barge for stabilization experiments would solve the problem of making a vessel available for experiments. Vessel availability was the major complaint about the HAMILTON since it had been taken away in the middle of the experiment because the ship was needed as part of the World War II effort. However, the Director of the Model Basin indicated that the time was not right to use barges since the recommended approach would introduce new problems, such as providing and installing a steam or diesel electric generating plant for operating the activated tank's pump motors together with all the necessary auxiliaries. Additionally, the New York Naval Shipyard had not found a barge and other equipment that could be made available. Instead the Shipyard recommended that the procurement of equipment for a barge be held in abeyance until such time as improvements in the existing blade shifting mechanisms were completed and the project could be given high priority [5-35].

The Bureau of Ships sent an inquiry, subsequent to the HAMILTON test, to the Bureau of Ordnance (BUORD) and the Bureau of Aeronautics (BUAER) about their interest in roll stabilization. The letter stated that the anticipated roll reduction that could be achieved was from 25 degrees to 5 degrees at the expense of 1.6 percent of the ship's
displacement. Specifically, the letter addressed the potential impact on BUORD and BUAER payloads by stating [5-36]:

"The weight distribution of a recent 1600-ton destroyer design allows 180 tons, or 11 percent of this displacement for the material under the Bureau of Ordnance. Similarly, the most recent airplane carrier design allows 538 tons, or 2 percent of the displacement for material under the Bureau of Aeronautics. It appears that such military advantages which may result from effective stabilization will primarily benefit the Ordnance installation in the case of the destroyer and the Aeronautics installation in the case of the carrier. It is probable that hull weights will increase appreciably in an indirect manner in order to care for the incidental increases in local and longitudinal stresses. Whether the power requirements for the installation would overbalance the saving in power for propulsion would depend upon the sea conditions, and the speed which the ship must maintain. It is doubtful if any reduction in engineering weights would be permitted. The space requirements will increase about in proportion throughout.

"The Bureau of Ordnance is requested to examine the advantages which ship stabilization in roll would contribute to the effectiveness of the armament of a destroyer, in the light of recent developments, and advise this Bureau (the Bureau of Ships) as to what concessions in other ordnance weights could be made to obtain this feature.

"Similarly, the Bureau of Aeronautics is requested to advise in the case of carriers."

Thus, although the Bureau of Ships was seeking advocates for the innovation of roll stabilizers, the response indicated very little interest. BuShips had no control over either the weapons or aviation payload its ships were to carry, and thus could not dictate or even trade
a pound of payload for a pound of roll stabilizer as a function of the overall effectiveness of the ship as a whole.

In December of 1943, Dr. Minorsky was still working on the HAMILTON equipment at the lavid Taylor Model Basin but without a ship to install it in. Several interesting statements were made by Minorsky in two memorandums [5-37], [5-38], of December 1943 concerning the status of his efforts. First, he claimed that the equipment installed in the HAMILTON was oversized [5-37]:

"In view of this, it is apparent that the equipment installed in the HAMILTON would probably be adequate for stabilizing (to $\psi = 4$ degrees) a ship of about 1,900 tons with the same GM as the HAMILTON, or a ship of the same displacement as the HAMILTON, but having a GM of about 2.5 feet."

The total weight of the HAMILTON stabilizer equipment was about 42,000 pounds. Minorsky thought that the equipment for the HAMILTON could have been made much lighter, specifically, he thought that as much as 4,500 pounds could have been saved on the stabilizer pumps and that 3,000 pounds could have been saved on the other items.

Since the equipment was oversized for the ship as well, Minorsky felt that altogether the 1.6 percent total weight figure could be reduced
to 1.0 percent of the ship's displacement. He felt that the unfinished work three years after the HAMILTON experiment was [5-38]:

"a. Replacement of the present unsatisfactory hydraulic blade actuating mechanism used in land installations by an electric drive from an amplidyne unit more appropriate for this use.

"b. Improvements in the accelerometer and, particularly, a better method of securing it to the ship by a shock-absorbing support."

Minorsky concluded the question of the usefulness of stabilization for naval vessels still remained a matter of controversy, going on for the last two or three decades. Very likely this controversy was due largely to a lack of any practical and efficient stabilizing equipment which would permit obtaining reliable data on stabilization in general, from which definite conclusions could be formulated. Minorsky continued,

"A stabilizing device weighing about 1 percent of the ship's displacement, absorbing about 0.2 percent of the propulsive power and representing, in cost about 3 percent of the total cost of the vessel, may be worth considering if it permits improving the efficiency of its anti-aircraft defenses by reducing heavy rolling by about 30 percent or so."

These statements appear fairly naive considering that Minorsky, by the time these statements were made, had been working on roll stabilization for more than 15 years and, the last 6 as a Navy employee. Sometimes
in 1944, Dr. Minorsky left the Model Basin to join the faculty of Stanford University (interestingly, Dr. Durand was also teaching there).

Proponents of the idea of using the leftover equipment from the HAMILTON succeeded in obtaining more funds for another ill-fated, poorly conceived and expensive test. In order to use as much of the special gear as possible which had been salvaged from the HAMILTON, the decision was made to carry out full-scale testing on a ship whose displacement, metacentric height and natural period of roll were very close to those of HAMILTON. This led to the selection of the PEREGRINE, one of the AM 371 Class of minesweepers. The PEREGRINE experiments, conducted in 1949, served only to confirm what the HAMILTON experiments had already demonstrated, namely, that only a thorough overhauling of the Minorsky ideas would result in a stabilizer with practical application. In a SNAME paper [5-34] the authors summarize the PEREGRINE story:

"Though the design of the stabilizer for PEREGRINE was predicated on maximum utilization of existing HAMILTON gear, new accelerometers were produced, and the control system was completely redesigned to suit the amplidyne drives needed to actuate the variable-pitch impellers. For simplicity of construction, the tanks were placed in blisters, outboard of the existing shell line, (see Figure 5-6). This proved to be a major error; the new water plane gave increased metacentric height, lowered the rolling period of the ship, and caused the impellers to work outside their range of maximum efficiency. Capacity for stabilization was thus comprised. In addition, many improvisations in equipment crept into the stabilizer design before their total effect on the capacity of the system was realized. As a consequence the sea trials of PEREGRINE should be considered merely the resumption of the 1940 tests."
FIGURE 5-6 GENERAL ARRANGEMENT OF ACTIVATED-TANK INSTALLATION ON USS PEREGRINE

SOURCE: REF [5-39]
Meanwhile, in England, during the decade which preceded the PEREGRINE experiment, numerous installations of the Denny-Brown fin stabilizer were made in British naval ships.

The Denny-Brown fin stabilizer was first fitted in the cross channel steamer ISLE OF SARK. This installation was inspected and observed in operation by Admiralty representatives in September 1936, and, as a result, it was decided to fit a trial naval installation in a sloop. The vessel selected was the BITTERN, which was then under construction and in which the gear could conveniently be fitted. This ship was one of the first to be fitted with high angle four-inch twin mountings for anti-aircraft fire, and, with the gunnery and fire control equipment then in use, it was considered by the British Director of Naval Ordnance that roll stabilization would produce a great improvement in the accuracy of anti-aircraft fire. (This was before the introduction of stabilized and power operated gun mountings and fire control systems, and the training and elevating of the gun mounts were done by hand with the gun layers following pointer instruments operated from the director via a fire control table.) The advantages of reducing rolling motion with such a system were obvious, with incidental advantage that such activities as ammunition handling were made easier. Furthermore, ships' officers had found stabilizers very useful for inducing forced rolling for gunnery training purposes.

Sea trials were carried out on the BITTERN in May 1938, and a report was made to the Royal Navy's equivalent of the Bureau of Ships [5-40]. Unfortunately, little rough weather was experienced during the trial period
and the amount of data obtained was limited. In 1939 a favorable report was received from the BITTERN's Commanding Officer relating his experience with the roll stabilizer equipment during a sea passage when rough weather was encountered [5-39]. From these limited trials and sea experience, it was decided that the Denny-Brown stabilizer was worthwhile fitting in small ships with a predominantly anti-air gun armament. The method of control of the stabilizer still left something to be desired.

During 1939 to 1940, the Royal Navy decided to fit the Denny-Brown stabilizer in a number of frigates. This policy was also applied to the HUNT class destroyers and certain BATTLE class destroyers. Table 5-1 summarizes all the ships which had been fitted with stabilizers by 1965 and gives the principal characteristics of the stabilizing equipment fitted.

In view of the limited amount of stabilizer sea trials and sea experience on which reports were available, the British decided, in 1943, to ask the commanding officers of the ships which had by then been fitted with roll stabilizers to report in detail on the performance and maintenance of the equipment [5-40]. Owing largely to the conditions prevailing during World War II, no useful reports were received until the end of the war.

During the later stages of WW II, when remote power control and stabilization of fire control and armament had been introduced, it was decided to remove the stabilizers from certain HUNT class destroyers in
<table>
<thead>
<tr>
<th>Date Circa</th>
<th>Designer</th>
<th>Ship</th>
<th>Stabilizer</th>
<th>Control Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1870</td>
<td>Almost All</td>
<td>Bilge Keels</td>
<td>Passive</td>
<td></td>
</tr>
<tr>
<td>1880</td>
<td>Bridge (England)</td>
<td>COLUSUS, EDINBURGH</td>
<td>Tanks (Slosh)</td>
<td>Passive</td>
</tr>
<tr>
<td>1883</td>
<td>Watts (England)</td>
<td>INFLEXIBLE</td>
<td>Tanks (Slosh)</td>
<td>Passive</td>
</tr>
<tr>
<td>1891</td>
<td>Thornycroft (England)</td>
<td>CECILE</td>
<td>Weight</td>
<td>Active</td>
</tr>
<tr>
<td>1906</td>
<td>Schlicke (Germany)</td>
<td>SEE-BAR and Others</td>
<td>Gyro</td>
<td>Passive</td>
</tr>
<tr>
<td>1909</td>
<td>Cremieux (France)</td>
<td>Channel Steamer</td>
<td>Weight</td>
<td>Passive</td>
</tr>
<tr>
<td>1910</td>
<td>Frahm (Germany)</td>
<td>YPIRANGA, EUROPA, and Many Others</td>
<td>Tanks (U-tube)</td>
<td>Passive</td>
</tr>
<tr>
<td>1912</td>
<td>Frahm (Germany)</td>
<td>DEUTSCHLAND, HAMBURG and Many Others</td>
<td>Tanks (Sea-ducted)</td>
<td>Passive</td>
</tr>
<tr>
<td>1915</td>
<td>Sperry (U.S.A.)</td>
<td>WORDEN, CONTE DE SAVOIA, and Many Others</td>
<td>Gyro</td>
<td>Active</td>
</tr>
<tr>
<td>1924</td>
<td>Fleux (France)</td>
<td>French Destroyer</td>
<td>Gyro</td>
<td>Passive</td>
</tr>
<tr>
<td>1925</td>
<td>Motora (Japan)</td>
<td>MUTSU MARU and Others</td>
<td>Fins (Variable angle)</td>
<td>Active</td>
</tr>
<tr>
<td>1929</td>
<td>Hort (Germany)</td>
<td>FUCHS, ROSSAROL</td>
<td>Weight</td>
<td>Active</td>
</tr>
<tr>
<td>1930</td>
<td>Hort (Germany)</td>
<td>KONICE LOUISE</td>
<td>Tanks (Sea-ducted)</td>
<td>Active</td>
</tr>
<tr>
<td>1933</td>
<td>Kefeli (Italy)</td>
<td>AVISO NOTURDI</td>
<td>Fins (Variable area)</td>
<td>Active</td>
</tr>
<tr>
<td>1935</td>
<td>Hort (Germany)</td>
<td>PRINZ EUGEN and Others</td>
<td>Tanks (U-tube)</td>
<td>Active</td>
</tr>
<tr>
<td>1936</td>
<td>Denny-Brown (England)</td>
<td>ISLE OF SARK, QUEEN ELIZABETH and Many Others</td>
<td>Fins (Variable angle)</td>
<td>Active</td>
</tr>
<tr>
<td>1938</td>
<td>Dutch Engineers (Holland)</td>
<td>?</td>
<td>Fins (Hydrofoil keels)</td>
<td>Passive</td>
</tr>
<tr>
<td>1939</td>
<td>Minorsky (U.S.A.)</td>
<td>HAMILTON</td>
<td>Tanks (U-tube)</td>
<td>Active</td>
</tr>
<tr>
<td>1949</td>
<td>U.S. Navy (U.S.A.)</td>
<td>PEREGRINE</td>
<td>Tanks (U-tube)</td>
<td>Active</td>
</tr>
<tr>
<td>1956</td>
<td>Sperry (U.S.A.)</td>
<td>MARIPOSA, COMPASS ISLAND and Others</td>
<td>Fins (Variable Angle)</td>
<td>Active</td>
</tr>
<tr>
<td>1956</td>
<td>Denny-Brown (England)</td>
<td>GYATT</td>
<td>Fins (Variable Angle)</td>
<td>Active</td>
</tr>
<tr>
<td>1960</td>
<td>Denny-Brown (England)</td>
<td>British Destroyers</td>
<td>Fins (Variable Angle)</td>
<td>Active</td>
</tr>
<tr>
<td>1960</td>
<td>Russia (U.S.S.R.)</td>
<td>Soviet Destroyers</td>
<td>Fins (Variable Angle)</td>
<td>Active</td>
</tr>
<tr>
<td>1960</td>
<td>Liderwood (U.S.A.)</td>
<td>DE 1037 and DE 1038 Classes</td>
<td>Fins (Variable Angle)</td>
<td>Active</td>
</tr>
<tr>
<td>1962</td>
<td>Sperry, Liderwood DE 1040 Class (U.S.A.)</td>
<td></td>
<td>Fins (Variable Angle)</td>
<td>Active</td>
</tr>
<tr>
<td>1965</td>
<td>Vickers, Liderwood DE 1052 Class (U.S.A.)</td>
<td></td>
<td>Fins (Variable Angle)</td>
<td>Active</td>
</tr>
</tbody>
</table>

355
order to carry extra fuel oil and to obtain a much needed increase in endurance. This decision was also applied to BATTLE class destroyers then in the building stage, and consequently, stabilizers were retained only in the first two BATTLE class destroyers, the CAMPERDOWN and the FINISTERRE, in which the fitting was well advanced.

In 1947, the Admiralty made a further attempt to obtain maintenance and performance data on ships fitted with stabilizers. A policy was developed on the basis of the reports that dictated fitting ship stabilizers in new construction AAW frigates only. The ASW and SUW frigates were not to be fitted with roll stabilizers. Soon after stabilizers were first introduced in the pre-war Royal Navy frigates, the question of fitting them in larger ships was raised and a scheme was worked out for fitting a large Denny-Brown fin stabilizer in the COVENTRY, which was then being converted to an anti-aircraft cruiser. This equipment actually had been ordered in 1938 but was later cancelled on the grounds that the sacrifice of 130 tons of fuel oil was too great a penalty where endurance was already quite limited. Installations in the DIDO and BELFAST class cruisers and the ILLUSTRIOUS class carriers were also considered, but the Admiralty determined that installations large enough to stabilize these larger ships to any useful extent would be prohibitive in size and weight.

In 1943, the Admiralty Gunnery Establishment suggested that the weight and size of the stabilizer gear could be reduced greatly by making a substitution in the Denny-Brown stabilizer. A number of smaller non-retractable fins operated from one central control would be fitted in the
line of the bilge keel, replacing the large retractable fins. Some rather optimistic estimates were made of the weight reduction achieved. The project was not worked out in detail until after the war when it was developed by Denny-Brown in conjunction with the equivalent of the U.S. Navy's Bureau of Ships and the Admiralty Experiment Works at Hasler. At that time, it was decided to fit a multi-fin stabilizer installation in the 10,000-ton cruiser CUMBERLAND for trials. The CUMBERLAND installation was comprised of four fins on each side of the ship, spaced about 30 feet apart and fitted in the line of the bilge keel, the bilge keel being removed in way of them. The electric-hydraulic drive machinery and control equipment was essentially the same as that fitted in the previous retractable fin installations. The multi-fin installation did reflect some improvements on the earlier frigate installations such as trailing edge flaps on the fins. These improvements were described in a paper presented to the Institution of Naval Architects in 1945 by J. F. Allan of Denny-Brown, Ltd. [5-41].

Although it has been said that, with the advent of stabilized gun and fire control systems, the need for fitting ship stabilization was greatly reduced, later developments in gunnery equipment have tended to counteract this. In 1948, the British found that to provide the high gun velocities and accelerations of training and elevating necessary to keep them on fast aircraft targets and guided missiles, the required power reached prohibitive values, with the ship rolling heavily. This was especially true when the guns were at high angles of elevation.
The British also attempted to assess the value of ship stabilizers and in the early 1950's carried out an intensive series of ship motion trials with suitable instrumentation for recording angle, velocity, and acceleration of rolling motion [5-42].

The British experience was constantly fed back to Washington through the U.S. Naval Attache and the British Naval Attache in Washington, but because of the U.S. Navy's preoccupation with the Minorsky experiment and inertia in the Model Basin and the Bureau of Ships, nothing was done about fins.

The PEREGRINE failure finally resulted in an inquiry from the Bureau of Ships to Denny-Brown in November 1948 [5-43], 10 years after the first British destroyer had incorporated a fin stabilizer and 20 years from the time the concept had been patented by Motora [72]. This inquiry resulted in a series of meetings between Denny-Brown and the Bureau of Ships. The resurgence of interest in roll stabilization at that time stemmed from a supposed need to stabilize the post-World War II guided missile ships; however, as we will see later, the reason given for the first U.S. Navy fin adoption, more than a decade later, was that the large SQS-26 sonar required roll stabilization.

The Bureau asked that Denny-Brown study the requirements for a destroyer escort, a destroyer, and a cruiser, and complete the preliminary design for the three sets of fin stabilizers. In March 1949 [5-44], the three Denny-Brown designs were sent to the Bureau. Subsequently, a meeting
was held in Washington to discuss the subject of fin stabilizers with Denny-Brown. The conference was attended by about 20 people including senior officers and senior civilians of the Ship Design Division of the Bureau of Ships and Sir Maurice Denny from England.

One of the points of discussion at the meeting dealt with the fin control system. One of the officers of the Bureau inquired concerning the method of control advocated by Prof. Rocard of France. (Rocard's method consisted of determining the instantaneous disturbing torque acting on the ship, measured by the difference in water pressure on the two sides of the ship.) Sir Maurice Denny replied that he did not "like the sound of the French scheme." The British experience had been that controls responsive only to angle of roll were ineffective for ship stabilization. (Note: Actually the Rocard method of control is responsive to angle of roll and angular velocity of roll as well as to hydrodynamic moment, as explained in U.S. Patent Number 2,130,929 dated 20 September 1938.)

Denny went on to explain that the British control system was primarily responsive to angular velocity of roll, and controls responsive to angle of roll were incorporated to gain smoother acceleration and deceleration of the fins. The control system provided fin angle to return the ship to the upright position when, because of a side wind, the ship tended to lie over at a steady angle of keel with the angular velocity of roll equal to zero.
While answering other questions posed by the Bureau (see Table 5-2), Sir Denny recalled a specific experience in World War II which demonstrated the effectiveness of the roll stabilizers [5-45]:

"The BITTERN (a British destroyer) was designed almost as a floating anti-aircraft battery. She carried six four-inch AAW guns and five smaller guns. She was the first vessel of her size (1,190 tons) to carry such heavy AAW armament and it was the stabilizer which made her shooting so effective; in fact, it led to her demise.

"When the King visited Brown's at Edinburgh after the war he said, 'Your stabilizer cost me a ship.' The BITTERN was engaged in the Battle of Hanson Fjord during the Norwegian campaign of May 1940, and her anti-aircraft fire was so deadly, that the Germans concentrated all their attacks on the sloop. In spite of their losses, they attacked repeatedly until the ship was out of ammunition, when low flying aircraft set her on fire. The crew were taken off without loss, and the BITTERN was sunk by our own gunfire to prevent her blocking the mouth of the fjord."

Captain Morgan, the senior officer of BUSHIPS attending the meeting, closed the meeting by stating that a control responsive to angular acceleration of roll and possibly to higher derivatives of roll might, in combination with the Denny-Brown method of control, result in a superior degree of ship stabilization. Captain Morgan went on to say [5-45]:

"If the Bureau of Ships will decide to procure a Denny-Brown unit for service tests, the control will have to start with the British scheme, because we must learn to walk before we run."
QUESTIONS PROPOSED FOR DISCUSSION

1. The following is the complete list of questions prepared beforehand for discussion at the conference with Messrs. Donny and Wallace, together with the replies received during the meeting of 17 March 1949:

(a) "How much is the angle of roll reduced for each installation?"

The average roll, out-to-out, is reduced by a maximum of about 20 degrees in experience to date, by reduction from a roll of 25 degrees to a residual roll of about 5 degrees. This record can be somewhat bettered now. A 9 second period of roll is short with respect to the 1 second period of moving from "hard up" to "hard down", and hence ships with short periods of roll are more difficult to stabilize satisfactorily than are ships with long periods of roll.

(b) "What limits the fin angle at speeds above average speed?"

The required arc of travel of the fins to develop a given stabilizing torque is decreased as ship speed is increased, but if excessive torque would occur, the relief valves operate.

(c) "What happens if a fin goes to full 20-degree angle at speeds above average speed?"

Even if both fins went to full 20-degree angle at top speed the heel of the ship would be only moderate.

(d) "Are fins able to be retracted and housed under any condition of distortion, that is, distortion of shafts as well as distortion of fins?"

No fin has ever been damaged at sea. One fin was damaged near shore when the ship ran onto a rock. The "keyhole" opening in hull of the ship provides clearance to allow retraction of fins even if bent. Fins should be pushed in and out occasionally to keep the sliding surfaces free of incrustation. Six months' idleness of the ship would require cleaning of surfaces. The time required for ejection of fins is 1-1/4 to 1-1/2 minutes. In a case where the ship had been out of use for two years, a jack was used to overcome fouling of the sliding surfaces.

(e) "Since activated fins are not effective when the ship is not underway, what is the relationship between effectiveness and ship's speed?"

At speeds up to the designed speed, the maximum torque developed varies as the square of the speed. The stabilization obtained varies directly with speed, or as the 1.1 to 1.2 power of speed.

(f) "How much weight of oil is eliminated by these installations and what is net effect on ships?"

This question can best be answered by the Bureau of Ships.

(g) "What is the effect of the fins on speed?"

(This question is a matter of design. The subject is discussed in a general way in paragraph 5 above, item (b)).

(h) "What are the costs of the installations?"

Costs depend on the size of the installation. Request was made to postpone discussion of cost.
TABLE 5-2 (CONT.) REPORT OF CONFERENCE, DATED 13 APRIL 1949

(1) "Should bilge keels be removed or retained?"

Bilge keels should be retained, to provide roll quenching when the forward speed of the ship is negligible. Twenty to twenty-five feet of bilge keel in way of each fin should come out.

(j) "Can we improve accessibility by providing additional space or by improvements in arrangements?"

The preferred arrangement is to install the gear as a factory assembled unit.

(k) "What are the coefficients of lift and drag of the different sizes of fins?"

This information for the flop type fin is given in Figure 20 of reference (a), for all main fin angles up to 22 degrees.

(l) "When will incipient cavitation of the fins occur?"

Cavitation is not usually met, but will reduce the lift force if encountered. Cavitation is regarded as "not a serious matter for design". The erosion will be on the nose instead of on the tail flap. Stainless steel inserts might be desirable to reduce erosion.

(m) "What damping is obtained against pitch?"

The damping obtained against pitch is theoretically small or negligible, depending upon location of the axis of pitch with respect to axis of the fins. The impression gained is that pitch is decreased. A stabilized ship is a dryer ship. The stresses on ship structure due to inertia effects in roll are much reduced by stabilization. This matter of dynamic forces due to roll is especially important on merchant ships.

(n) "To what range of frequency of disturbing torques is the control responsive?"

The anticipatory control does not utilize angular acceleration and higher derivatives. (Filters to eliminate high frequency impulses can accordingly be dispensed with, apparently).

(o) "Are the fins hollow or filled?"

The fins are hollow.

(p) "How much is performance improved by accepting the complication of tail flaps on the fins?"

The use of tail flaps allows reducing the size of fins by about one-half.

(q) "How many men need be added to the complement on account of the stabilizer?"

No additional crew members are needed. Maintenance of the gear is the only demand on time. Operation of the gear is automatic. The switches placing the gear in or out of operation are located on the bridge. The best location of fins from the standpoint of attention is the engine room.
By the time the March 1949 meeting took place, Lidgerwood Industries, Inc. of New York had been appointed by Denny-Brown to have exclusive U.S. license to manufacture the Denny-Brown stabilizer. Lidgerwood was also designated as the point of contact for all Denny-Brown correspondence with the U.S. Navy.

The original Denny-Brown design studies for the three types of ships called for retractable fins, but the results revealed such large weight and space requirements for the installations that additional design studies were authorized. Those additional studies called for the use of nonretractable fins with the fin outreach limited to keep the fins within the extreme dimensions of the ship.

The activated fins designed previously for the British cruiser CUMBERLAND had an outreach of 3 feet, a chord of 4.5 feet, and were designed for a ship speed of 20 knots. The original nonretractable fin design for the DD 692 class (long hull) destroyer called for this identical fin but with 1 foot more outreach. This fin developed a righting moment of 452 ton-feet per ship at 20 knots (lift coefficient = 1.14). The effective wave slope required to produce an upsetting moment of this same amount was 1.9 degrees.

Growing dissatisfaction with the amount of righting moment developed by this fin design led to design studies to increase capacity of fins without an increase of outreach and without an increase in the number of fins per side. The search for a fin of greater capacity
resulted in various alternative designs by Denny-Brown which were evaluated by the Bureau in late 1949 and 1950.

Independent of the Bureau of Ships effort to get roll stabilization into the Fleet in the late forties, the Office of Naval Research (ONR) sponsored Stanford University to continue research on roll stabilization. Naturally, since both Prof. Durand and Dr. Minorsky were at the University, most of the work there centered around active tanks as opposed to fins.

In the technical memorandum [5-46] which defined for ONR the content of the proposed work for the period of October 1950 through September 1951, Durand and Minorsky stated,

"Our job in the next year, as we see it, is essentially 'system evaluation' research. We propose to provide the Navy with a body of organized and digested information on ship stabilization in about one year's time. This calls for an extension of the previous work of the project, which has been concerned principally with stabilization using tanks, to more general and also to more special questions. All ship stabilization systems will be studied but systems using fins will be studied especially intensively to bring our knowledge up to the level of knowledge of tank systems."

In March 1951, two years after the meeting between Denny-Brown, Ltd. and the Bureau, ONR had become aware of what must have been a very low-keyed effort at the Bureau, i.e., to introduce fin stabilizers into the U.S. Navy. The Stanford comment was one that may be termed a typical University response to a "real world" program [5-47].
"The schedule for future BUSHIPS work is somewhat more advanced than we had anticipated. In view of this, we'll modify and adjust our own schedule insofar as possible, so that questions of the most immediate importance to BUSHIPS will be treated first. There is, of course, a limit to such modification beyond which the basic aims of the program will suffer. The shortness of time makes it very important that information be exchanged rapidly, say almost on a week by week basis."

This exchange may have taken place between the ONR, San Francisco Office, and Stanford or between these two organizations and ONR, Washington, and perhaps even the David Taylor Model Basin (DTMB), but certainly not between these organizations and the Bureau. It appears that DTMB was picking up information about the Bureau of Ship's work from correspondence that they received on route sheets, but the feedback communications and round table discussions didn't take place. This is clearly evident from the record. Specifically, some fairly unfriendly correspondence between the Bureau and DTMB and from minutes of meetings of a new committee which was tasked later to investigate the situation and come up with recommended solutions. But we are getting somewhat ahead of ourselves.

In the meantime, another report became available from Stanford [5-48] in which fin stabilization was discussed and which specifically addressed the issue of controls. Interestingly, they adopted the basic theory developed for the study of stabilization by active tanks which they had worked on for a number of years. At this time, a new player began his involvement with roll stabilization. T. H. Chadwick was a student working on his Ph.D. thesis at Stanford. He was a controls engineer
and prepared a report on controls for activated tanks. Summarizing
in his first fin stabilizer report [5-48], Chadwick stated that:

"We found that roll velocity was perhaps the
ideal principal control for fin angle."

He also disagreed quite strongly with some of the features of
the Denny-Brown control system saying:

"The author is a firm disbeliever in the idea of
'energy balance' proposed by Allan [5-41] and some others.
A system neutralizing only 60 percent of the disturbing
torque would be practically ineffective and certainly
uneconomic since the degradation of performance is all
out of proportion to the power saved."

It is apparent that at Stanford at that time the controlled
tank stabilizer concept was favored as opposed to fins, and there
was disagreement as well with the Denny-Brown concept for fin con-
trol. In discussing the power requirements for both tanks and fins,
Chadwick stated [5-48]:

"Now in general, power may be of two types: (1)
true 'dissipative' power which is expended, never to
return; and (2) 'reactive' power which flows out from
the power source, is stored, and later is returned to
the power source. We would naturally prefer that all
the power involved be of this latter type. However,
for fins, the stabilizing power is completely dissipa-
tive, that is to say the act of applying a torque to
the ship by means of fins, never tends in practice to
propel the ship forward. When U-tube tanks are used,
the stabilizing power has a large 'reactive' component,
hence it is apparent that the power cost of stabilizing
"by fins will be reduced when it is stabilized. This is an entry on the credit side of the power balance, but it is not yet clear just how this will compare with the power required for fin stabilization. The tentative figures of Allan [5-42] are believed optimistic for a number of reasons."

By 1952, no anti-roll fins were seriously considered for a specific U.S. Navy ship; however, the endless studying and experimenting went on.
5.4. Prelude to the Adoption Decision

It is hard to tell what specific reason led to the establishment of a Hull and Hydromechanics Panel in April 1952, but from the nature of the problems which were given to the Panel to tackle, specifically roll stabilization, along with the particular membership of the Panel, i.e., both Bureau of Ships and David Taylor Model Basin (DTMB) senior personnel, it appears that the impetus might have come from recognition of problems of apparent lack of communication between the research and development and design establishments.

The Chief of the Bureau appointed an Admiral who was the Commander, Mare Island Naval Shipyard to chair the panel. Membership was from the Engineering Duty Officer community, not limited to the Washington area; the only civilian was the Technical Director for Preliminary Ship Design in the Bureau.

At the first meeting of the Panel in May 1952, one of the first items presented for immediate action was a recommendation on how to proceed in the field of roll stabilization. The minutes of the first meeting hit hard on the roll stabilization issue [5-49].

"The Bureau has a history of unsuccessful attempts to apply roll stabilization systems to ships. The difficulties appear to have stemmed from incomplete scientific analysis of this complex problem, inadequate engineering application of the scientific requirements and lack of enthusiastic, informed leadership of the projects with determination to carry through to a successful result.
"It is understood the British have made in the order of a hundred ship applications of the Denny-Brown roll stabilizing system. The relative sea roughness about the British Isles undoubtedly gives their need for such a system greater emphasis than we have been subjected to.

"The effectiveness of ship crews to perform their tasks, especially in small ships, could, without doubt, be improved were they less physically tired by the violence of ship motions. Behavior of devices such as guns, radar and fire control instruments requiring their own stabilization and the precision and speed of manual weight handling associated with serving weapons should be improved by roll suppression.

"The Bureau may be confronted at any time with an urgent demand for a proven roll stabilizing system for ships to meet the need of requirements for new types of armament.

"It is understood that the scientific work on roll stabilization control being performed under an ONR contract at Stanford University has reached the stage where a thorough check on the work is in order. If this work proves to be adequate for the purpose, it may then be in order to proceed with the essential engineering preparatory to an actual ship installation."

The Hull and Hydromechanics Panel therefore recommended that a program be instituted and vigorously executed to develop roll stabilization systems for naval ships in general and that the program to install fins into the destroyer TIMMERMAN be continued, (a low-keyed project started at the Bureau as a result of the Denny-Brown design studies in 1948). In order to avoid the pitfalls which defeated the project in prior attempts, the Panel felt the program should include [5-49]:

"A. Establishment of quantitative requirements for roll quenching on various types of naval vessels.

"B. The assignment of a project manager who will assure strong and enthusiastic leadership and persistence throughout the phases of analysis, development, installation and trial."
"C. Thorough check by acknowledged experts of any system proposed for use.

"D. Careful selection of the vessel to which the application is first to be made to insure the best promise of acceptance in trial and in service.

"E. Deliberate and careful surveillance of the development engineering, installation and trial phases of the design to insure that the scientific requirements are fulfilled."

The second meeting of the Panel was held in July 1952 and ships' roll stabilization was again discussed. Captain Morgan of the Bureau indicated that: "Activated fins using the DTMB control system will be installed on the TIMMERMAN." This statement appears strange since DTMB did not have a control system developed; however, he may have meant Stanford.

Morgan also reported that the Bureau of Ships had solicited a proposal from the Intercontinental Engineering Corporation in order to be able to conduct parallel stabilization development with Lidgerwood Ind. Company.

During this meeting, the DTMB representative summarized a British paper [5-50] titled "Multi-fin Stabilizer on H.M.S. CUMBERLAND." The CUMBERLAND was reported to have had four fins on each side of the ship. This installation was a refit into a ship built 25 years earlier.

The trials report [5-51] indicated that, for forced rolling in the stabilized condition, all motion was dissipated in about two cycles.
In the open ocean, the maximum roll due to the seas was 6.2 degrees out-to-out without stabilization which was reduced to 2.5 degrees by using the fins.

Prior to the third meeting of the Panel, Albert Morris of ONR, San Francisco, who worked with Dr. Chadwick of Stanford sent a paper to the Panel at the request of the Chairman of the Panel [5-52]. The Chairman wanted this paper discussed by the Panel at its next meeting. The paper was to be presented by Chadwick and Morris at SNAME's Northern California section in September 1952. The "Comments on the Future" section of the paper [5-52] stated that:

"There is every reason to believe that ship stabilization systems can now be built with performance markedly superior to the performance of any system constructed to date. The performance to be expected of such systems should make them attractive for wide commercial and Naval use. Both the knowledge and the equipment are available to do the job. It simply remains to get on with the doing."

The Hull and Hydromechanics Panel was one of several panels which reported periodically to the Ship Design Coordinating Committee, composed of the most senior management of the Bureau of Ships. The Chairman was a member of this committee and he reported the findings of the Panel after its second meeting.

The reaction of the Committee was that they wanted a general discussion on roll stabilization at their next meeting after the Panel
had a chance to study the problem in further detail. The Committee also
wanted to know why tanks were not being considered with at least the same
priority as fins. One of the members of the Panel agreed to write up a
brief paper giving a resume of the whole subject as a basis for further
discussion within the Committee [5-53].

The Committee recommended, with the approval of the Chief of
the Bureau, that two members of the British Joint Services Mission (Navy
Staff) in Washington should be allowed to attend the Hull Hydromechanics
Panel's meetings. The Committee also agreed that the Director of DTMB
should attend the next meeting of the Panel to discuss the possibility
of the Panel acting in another role, i.e., as an Advisory Committee for
DTMB.

The third meeting of the Panel took place on 23 September 1952.
A senior engineer of the Hull Design Division of the Bureau was present
and was asked to summarize the Bureau's program for roll stabilization at
that time. He stated that there was only one project with money actually
appropriated and that was for the investigative work at Stanford University.
The results there, he felt, indicated the need for getting into the actual
engineering phase.

The TIMMERMAN, a small destroyer, had been assigned for the trial
installation of the fin-type stabilizing system and money for this project
had been requested from the CNO. One of the advantages of the TIMMERMAN,
especially after the HAMILTON case, was that it was going to stay under
the control of the Bureau of Ships for a large number of ship subsystem tests.

Negotiations for a fin-type stabilizer had been initiated with Lidgerwood; however, Lidgerwood apparently did not care to do much development work but wanted to sell the Bureau an off-the-shelf unit, including the controls. It should be noted that, while Lidgerwood manufactured the stabilizers, the design work was done in Scotland by Denny-Brown.

The legal status of the Intercontinental Engineering Corporation was still being investigated prior to awarding a concurrent contract for fin development.

The Senior Bureau of Ships Engineer stated that there was no report or written data available to show that the Denny-Brown system installed on the British vessels was actually satisfactory or to what degree it had reduced rolling. This appears somewhat strange since Allan's paper had been available since 1945 and the CUMBERLAND paper discussed earlier by the Panel gave results of the British installations.

The fin proposed by the Bureau for the TIMMERMAN was to be located in the bilge keel area. It had a span of 12 feet and a trailing edge flap. Evidently, this scheme was adopted because of span limitations for a nonretractable fin. It gave an effective stabilizing fin without loss of much bilge keel area.
No development work was being done on the activated-tank type system in the Bureau.

This report from the Hull Design Division Engineer triggered a detailed discussion in the Panel meeting. One of the members criticized the compound-fin arrangement proposed by the Bureau for the TIMMERMAN and supported the use of two pairs of nonflapped fins.

Another member thought that the Bureau should proceed with its own developmental work and should even pay patent infringements, if necessary, rather than let the project bog down with lengthy, written negotiations with Lidgerwood or other companies.

It was agreed that success was necessary in this program and that no compromise should be made on the basic scientific principles. Proper selection of a vessel was judged to be extremely important, and it was agreed that the program should be kept active even if it meant more development work by the Bureau of Ships.

The Panel agreed that roll stabilization had a real military value, especially in smaller ships, and that its installation would mean more alert and efficient personnel, easier ammunition handling, better performance of equipment, and smaller auxiliary power requirements.

The Director of DTMB requested the Panel's advice on the desirability of using one of the presently-organized hydromechanics groups as the
previously agreed upon Advisory Committee to the David Taylor Model Basin. After much discussion in the Panel meeting, it was agreed that neither the mission nor the organization of any of the present committees on hydro-mechanics or hydrodynamics suited them for this function. Therefore, the Panel recommended to the Director that he appoint a group of three civilians to act in a review and advisory capacity on the hydromechanics program at the David Taylor Model Basin. The sponsors of the various projects being conducted at the Model Basin and those doing research and experimental work under those projects could appear before this group to explain or justify their programs as necessary.

It was also the opinion of the Panel that, as the review and advisory board recommended, membership from the Bureau of Ships and the Office of Naval Research was not necessary because those offices had frequent occasion to give the Director their ideas about the hydromechanics research program at the David Taylor Model Basin.

In view of the previously elaborated communications disconnect between ONR, NSRDC and the Bureau, this recommendation, in my opinion, can be seriously questioned.

Development programs which are not sensitive to the "user's needs" are of questionable value and, as shown by research on this question, the successful innovations are those which reflect those needs [1-1], [1-2], [1-3]. In this case, the user was the Bureau and the researcher was DTMB.
The fourth meeting of the Panel convened on Monday 4 December 1952. In addition to the regular members, the Head of the Design Department of the Bureau, the Head of the Contract/Hull Design Division and Dr. K. S. M. Davidson, Director of the Stevens Institute of Technology towing tank, and a respected hydrodynamicist were present.

The Head of Contract/Hull Design Division, who had just returned from a visit to Denny-Brown, Ltd. in England, was asked to open the discussion. He first enumerated why Denny-Brown favored retractable fins [5-54]:

"A. They permit use of a higher aspect ratio with higher efficiencies than is possible with non-retractable fins. This allows a greater outreach with more of the fins in the high-velocity flow outside the boundary layer.

"B. Retractable fins permit reduction in number of fins per side, with easier maintenance.

"C. By retraction, appendage resistance is reduced when the fins are not in use."

Denny-Brown had tested numerous schemes by then. A biplane type fin was used on the BATTLE class destroyers, which required 6,000 cubic feet of space for the whole installation. In the early 1950's Denny-Brown preferred a flap-type fin since it gave the maximum restoring force for a given torque and drag. In controls, they favored a compromise between efficiency and simplicity. In their opinion, acceleration control was not worth the added complications for the slight improvement gained. The philosophy of the Denny-Brown engineers stemmed from the fact that
stabilization was secondary to other vital components on the ship, and that it would never become a primary consideration. Therefore they felt that overloading stabilization with cost would cause its death. A philosophy which in retrospect appears to have been quite correct as we shall see.

It was Denny-Brown's belief that good stabilization required good mechanical design as much as basic theoretical work. This is a very important factor in innovation adoption in general but, as we shall observe, even more so in the case of roll stabilization.

The Head of Contract/Hull Design Division also had discussed ship stabilization with British Admiralty representatives. From his discussions, he concluded that the Bureau of Ship's approach to the problem was sound. At the meeting, the Panel asked questions such as: What is the desirability of the third (acceleration) component in the control system? Have the British worked out a three-component control system or have they just thought it would be too complicated?

The Head of Contract/Hull Design Division felt that three components added a slight improvement in a realistic seaway. It also meant a more complicated control system. He felt that the Bureau should look into both two and three components-systems in order to get a proper evaluation.

Captain Forrest from the Portsmouth Naval Shipyard felt that any study of controls should consider acceleration. Thus, the Navy should
develop a control system using three components so it could determine what could be done and then, if desired, remove the components which they determined unnecessary.

The general conclusions of the Panel after the fourth meeting appear to have been as follows:

A. Any roll-quenching device built by the Bureau should be designed to give complete stabilization.

B. If a ship could be made to stay upright, there would probably be many advantages not previously foreseen. With an upright ship, one could use a smaller safety factor in structures such as towers and masts, and could save power in operating gun mounts, machinery, and electrical units. Also, the propulsive power of an upright ship may be much less in rough seas.

C. With the knowledge of servo-mechanisms and hydraulics available at that time, a stabilizing system should be as reliable as the steering equipment.

As will be seen later reliability received little attention and this had an impact on eventual adoption.

D. For design purposes, the maximum effective wave slope conceivably could be as high as 9 degrees for a small ship; 6 degrees to 7 degrees is about the maximum for ships of DE size or larger.

E. There was little space in a destroyer-type hull for installation of roll-stabilization equipment, except in locations devoted to fuel-oil storage. Loss of 20 to 30 percent in fuel oil capacity would menace the project from the start.
F. Choice of ship for installation was thought to be very important since:

1. The required restoring moment varies directly as the product of the displacement and GM.

2. A destroyer has a high GM and large speed range.

3. Installation in one of the DE conversions would just point up the loss of endurance when operating with other ships of the class.

As a result of this reasoning, the Panel changed its mind with respect to the TIMMERMANN. The TIMMERMANN was designed to test equipments having high ratios of performance to weight and space. The ratios were so high, in fact, that those equipments were frequently breaking down. The ship already had a poor reputation among operating personnel. Furthermore, it had all the disadvantages of a destroyer type and it would probably be available only a small fraction of the time for stabilization tests.

As a part of the final discussion, lists were prepared itemizing the immediate benefits and the long-range improvements to be expected from complete roll quenching. Similar lists embodied the advantages and disadvantages of the active-tank and active-fin stabilizer types, with recommendations for the Bureau's action.

A jet system of roll quenching, which might have had promise, was noted as being developed in Norway, but no other information was available and it was dropped from consideration.
One British report which was discussed earlier in the meeting gave the following effects of active-fin roll stabilization on sonar operation [5-54]:

"When operating in a heavy sea, interference due to heavy rolling is greatly reduced on all forward bearings. Background noise level is increased and ranging reduced. Interference due to pitch is not changed."

This was the first time that discussion of the effect of roll stabilization on sonar performance was recorded. It is important to note this fact, because later, in the final adoption decision, this fairly obscure mention became the specific reason for the first new ship design installation.

As a result of this fourth meeting, a final paper was drafted that gave the background, the advantages of roll stabilization, a comparative evaluation of active-fin and active-tank roll stabilization systems, and conclusions and recommendations. For some unknown reason, the TIMMERMAN was not mentioned at all.

This paper, in a draft form, was reviewed by all members of the Panel, and the final draft was ready for the Chairman of the Panel to sign and send to the Chief of the Bureau via the Ship Coordinating Committee just before the next meeting of the Panel.

The fifth meeting of the Panel was held on 24 February 1953. Mr. Morris of ONR, San Francisco who was working closely with Dr. Chadwick was invited to participate and, in fact, was the first speaker that day.
Morris and Chadwick had reviewed the Panel's draft paper on roll stabilization and, while they considered it very good, they had a few comments.

Morris' first point was that the U.S. Navy's PÉREGRINE tests had achieved less than 30 percent roll reduction, in contrast to major British and German achievements with roll stabilization devices they had developed (both fin and tank type). Both the British and the Germans had achieved 70 percent to 80 percent roll reduction, 20 to 30 years earlier. Therefore, he felt that any future U.S. Navy attempt, had to be more than just successful; it had to be highly successful and show significant improvement over all previous systems.

In my opinion, this was a clear pitch for "let us not just buy Denny-Brown's fins but let us develop a new, better one at Stanford."

Continuing his pitch in the same direction, he said that the dynamics of a ship in roll are simpler than in yaw, yet Sperry already had developed an excellent automatic steering system. At that point, Mr. Morris, tainted both by his many years exposure to the activated tank work at Stanford and by the "blue-sky" approach of some researches, defined what he called "a simple active-tank system" and "a diversified active-tank system." He defined a "simple system" as one in which the set or sets of tanks are all of like design and each is tuned to the same frequency. In a diversified system, each set of tanks is of different design and geometry, and each is tuned to a different frequency. After explaining
why, in his view, the response of a diversified-tank stabilizer can be just as rapid as that of active-fins and why simple-tank systems necessarily respond more slowly, he went on to conclude,

"The controls for any of the active-tank systems, whether simple or diversified, should be no more complicated than for the fins."

In view of the data presented thus far in this study, Morris' statement appears outrageously naive.

In reply to a question, Mr. Morris said that he and Dr. Chadwick had never analyzed a diversified-tank system for space and weight requirements. He went on to say that, in a simple-tank system, one pays a big price in pump size and power requirements for stabilization at higher frequencies (above resonance), which could be greatly reduced in a diversified system. Morris stated further that stabilization at the higher frequencies was necessary because the accelerations are high and these cause trouble. In order to obtain a high-frequency response, controls which incorporate acceleration were felt to be necessary. Mr. Morris believed that the greatest improvement in the performance of a modern ship-stabilization system could be made in the design of the control system.

Some of Morris' statements, specifically that the controls of such a contraption, i.e., many tanks tuned to different frequencies, "should be no more complicated than for the fins," appear almost insulting
when the concept had never been model tested, but fins had been installed in real ships for years.

Mr. Morris also commented on the price to be paid for fin resistance at high speeds.

"The tare drag (drag at zero lift) of fins increases as the square of the speed, assuming no surface wavemaking from this cause. This drag can be reduced by the use of retractable fins. Non-retractable fins, however, require 30 percent less weight and 70 percent less space."

Mr. Morris then discussed, what he believed, were defects of the Denny-Brown fin system and made frequent references to Allan's paper on ship stabilization. The major part of his criticism was directed at the control system design. Mr. Morris believed, that as long as the British had such complete faith in Mr. Bell, chief engineer of Admiralty Research Laboratory (ARL) at that time [5-55]*, [5-56]*, it was doubtful that they would physically or psychologically be able to complete the necessary control system redesign. Mr. Bell's ARL control system was, in Mr. Morris' opinion, below modern standards regarding the application of servo-mechanism theory.

Briefly, Mr. Morris considered that the following elements of control needed improvement in the Denny-Brown system, assuming that position and velocity control already existed:

* Papers presented in the open literature a few years later.
A. Need for high-frequency-response positioning motors

B. Fin motion throughout the cycle should be smooth in order to avoid high-frequency shocks

C. Acceleration control.

In a later discussion, it came to light that Chadwick and Morris had designed an anti-roll fin stabilization system for the TIMMERMAN, consisting of five fins per side if no flaps were used, each fin of 4 feet span and 5.4 feet chord, while if flaps were used, three pairs of fins of 4 feet span and chord were necessary. The small fin outreach allowed caused the requirement for the large number of non-flapped fins. Theoretically this might have been the optimum system, but it appears that it would have been a maintenance nightmare, as we will see later.

The Panel again turned to the TIMMERMAN issue which after the previous meeting appeared to have been dropped. It was felt that if the limitations imposed by the TIMMERMAN prevented the use of an optimized stabilization system that had the best chance of success, then the TIMMERMAN should be dropped. It was also felt that, if the TIMMERMAN was getting a black mark for engineering deficiencies, it would reflect negatively on the stabilization project.

A contract had been awarded to Lidgerwood to complete design study of both retractable and nonretractable active-fin stabilizers for the TIMMERMAN. The Bureau emphasized that it was in no way committed to
purchase a Denny-Brown stabilizer, since the contract called simply for a design study for preliminary planning purposes.

Some members of the Panel were worried about questioning the suitability of the TIMMERMAN since the selection of another ship would have caused a delay. Others pointed out that the Lidgerwood design study would be applicable to any long-hulled 692 class destroyer.

The Panel kept returning to the issue of controls and the need to retain Chadwick and Morris to develop an improved control system over that offered by Lidgerwood, i.e., the Denny-Brown system. The discussion was divided along expected lines: the conservative engineers of the Bureau, those who instantly wanted the best and latest system, and those who wished to study the matter to death.

The senior engineer from the Bureau said that the Bureau wanted to procure the equipment from a contractor who would guarantee performance. Lidgerwood (Denny-Brown) would provide such assurance.

The Panel then had a long discussion about performance guarantees, and it was the general opinion that they could not be enforced. The Panel thought that the Bureau should not insist on performance guarantees if the success of the program would be jeopardized.

A second group wanted to explore the possibility of getting Chadwick and Morris, Sperry, or M.I.T., or other prominent groups in the
field of control system design to work with Lidgerwood in developing new controls for the Denny-Brown fins.

Research proponents proposed to go on experimenting. Specifically, the DTMB representative proposed that the Model Basin would like to experiment with stabilizing a 40-foot model in the Chesapeake Bay before a full-scale installation was made. He felt that the following advantages would accrue from such an approach [5-54]:

"A. Could easily change fins.
B. Could try various controls.
C. It would be possible to measure the seas in shallow water to check performance.
D. Could easily take motion records.
E. Could take speed and thrust records to determine power cost of stabilization.
F. Could determine course keeping.
G. Could relocate fins forward and aft for pitch-quenching experiments.
H. The same model and controls could be used for active-tank experiments."

The model proposed would carry two men, strapped in and would weigh about 2,000 pounds. About 1,000 pounds of ballast would be incorporated so that the model's CM could be varied. The model would be self-propelled with a 30 hp motor and made of fiberglass and plastic. DTMB provided no estimate on time requirements. The direct cost estimate was
$115,000 plus $65,000 overhead. This proposal had been submitted informally to the Bureau two months earlier. No funds had been available at the Bureau.

The Panel was not sure of the reliability of the data for design purposes because of scale effects. Thus this approach was defeated at the fifth meeting of the Panel. On 27 February 1953, having obtained an unanimous endorsement from the Ship Design Coordinating Committee, the Chairman of the Panel sent the findings and recommendations of the Panel to the Chief of the Bureau.

Interestingly, Mr. Morris flew back to San Francisco with the Chairman, allowing considerable time for Mr. Morris to explain his viewpoint. This trip resulted in a letter from the Chairman to the Panel in March 1956 [5-57] in which he emphasized the need to avoid using the Denny-Brown stabilizer without the complete new control system proposed by Stanford. He further weakened the Denny-Brown case by indicating that, even with the new control system, it was questionable whether the heavy hardware of Lidgerwood, whether in single or multiple pairs of fins, could be used properly with a fast action control system such as the Stanford group would have devised. The Chairman felt that this was so because the hydraulic controls, the drive motor, and the equivalent inertia of the fin were as much elements of the control system as the sensitive electronics elements themselves.

The recommendations were not changed by the Chairman's letter. Having developed a set of recommendations, the Panel had to put them
into a form which would endorse specific actions. The vehicle selected was a memorandum from the Deputy for Design to the Chief of the Bureau, issued in 1953. This memorandum listed the most significant recommendations and iterated the necessary Bureau action in that area. For example, it was pointed out that 15 months earlier the CNO had approved the use of the TIMMERMAN for roll stabilization experiments and that the Design Department was not recommending any change. It is interesting that it appeared from the phrasing of the memorandum that stabilization was not very important if it meant sacrificing endurance fuel. Rather than assigning a project manager which was so strongly emphasized in all discussions of the Panel, the memorandum clearly stated that not only was the Design Department not going to immediately assign a qualified man but also the project was going to be thrown back to DTMB with its "less than perfect past record on this matter." The wordings of that part of the memorandum was quite blunt [5-58]:

"Panel Recommendation. The assignment of a project manager selected to insure keen interest, strong and enthusiastic leadership, and dogged persistence throughout the phases of analysis, development, installation and trial. The Panel is convinced that, without this, the project cannot succeed.

"Comment. The multiplicity of design projects since Korea, all under varying degrees and directions of pressure from within and without the Bureau, have so over-obligated our design capacity that it has not been possible to emphasize ship stabilization at the expense of contract designs in current shipbuilding programs. Despite this condition appreciable progress has been made. As soon as design studies now underway have been received by acknowledged experts under Bureau coordination, the development will be assigned to the David Taylor Model Basin, as was done for
"PEREGRINE. The TMB organization provides for project managers and it is expected that one with the qualifications described will be assigned."

The Chief of the Bureau approved this memorandum on 26 March 1953, and thus ended a full year of intensive Panel investigations. Neither this decision paper nor the decision of the Panel earlier stopped DTMB from continuing its effort to "sell" a model test program, as part of the effort to introduce roll stabilization to U.S. Naval ships.

In April 1953, the Commanding Officer of DTMB sent a proposal to the Design Department of the BUSHIPS proposing essentially what had been already turned down by the Panel [5-59]:

"The subject of roll stabilization has been discussed at great length at recent meetings of the Hull and Hydromechanics Panel and the Ship Design Coordinating Committee of the Bureau of Ships. These discussions have placed great emphasis on complete roll quenching and on the paramount need to make the next installation on a ship a successful one. The use of a large model was discussed at the meetings of both Panel and Committee, but was not endorsed by either group, leaving the question for direct action between the Model Basin and the Bureau of Ships. The tests herein proposed could well be accomplished as a preliminary to full scale tests or concurrently with them. ....... It is therefore suggested that very serious consideration should be given to preliminary work on large-scale self propelled dynamic models, which could be operated in an actual seaway."

Not enough that this approach was going to delay the adoption of the innovation, the proposal also suggested that the model be used to study every other conceivable topic, while studying roll stabilization [5-59]:
"The model could be used to investigate pitch stabilization by fitting suitably designed activated fins. This could be done with or without roll stabilization.

"The same equipment installed in the same or a different model could be used to investigate the performance of activated tanks or other devices independent of ship speed.

"The model could be used for turning tests which, in association with similar tests on smaller models, would give much needed information on scale effect.

"Resistance and propulsion tests, in the same way, would give equally valuable data regarding the effect of scale on resistance, propeller efficiency, wake and thrust deduction."

One paragraph of the proposal showed clearly that little appreciation existed, at times, in organizations dealing with development and research for the purpose of a full-scale experiment [5-59]:

"It is submitted that the use of such a model would enable the complete answer to be found to problems in stabilization more quickly and cheaply than by full-scale trials. Changes in the fins could be accomplished quickly, easily and without the use of dry docks. The work would be supplemented by mathematical and analytical studies."

This proposal was rejected, fortunately because its acceptance would have delayed the adoption of fins for several years.

Late in 1954, the Naval Attache of the Netherlands wrote to the U.S. Navy [5-60] complaining about the poor rolling performance of six U.S. destroyers given to the Dutch under the mutual Defense Assistance Program
in 1950. He said that these ships had been reported to be rolling in heavy seas to a degree impeding their usefulness as gun platforms.

He explained that, as a result of the poor motion performance of these vessels, the Dutch had conducted experiments in their model basin and were ready to share their results with the U.S. Navy. The Naval Attache was also interested in knowing whether any attempts for improving roll characteristics in new U.S. destroyers were being made.

While reviewing this letter, the Preliminary Design Division of the Bureau stated that the problems the Dutch were having with the DE's were similar to those of the CAPTAIN class of destroyers given to the British at the beginning of WW II. Those problems, discussed previously in this study, were attributed to the fact that the CAPTAIN class carried less topside weight than those DE's in service in the U.S. and therefore had shorter periods of roll. These short periods, in conjunction with high amplitudes of roll, caused uncomfortably large accelerations.

The reply to the Dutch made note of the widening of the CAPTAIN class bilge keels by the British and of the fact that new U.S. destroyers were being designed with deeper drafts and reduced beam-to-draft ratio in order to counteract the trend over the preceding decades towards higher vertical centers of gravity. This trend was attributable to heavier topside weights and lighter machinery. Remedies being considered to offset this phenomenon were also described [5-61]:

391
"High centers of gravity, shallow draft and broad beam in conjunction with one another, doubtlessly lead to quick rolling and uncomfortable ships in a seaway. In order to attain deeper draft and decreased beam, consideration is even being given to fitting fuel tanks with salt water ballast compensating system. Such a system would prevent the center of gravity from rising as fuel was consumed and would therefore permit a reduction in beam as compared to a ship without compensating fuel tanks."

What stands out in this reply is that it never once mentioned any intent to provide active roll stabilization devices in future warship designs. This evidence, as well as the next incidents described, indicate that the Panel's recommendations weren't pursued very vigorously.

A second indication that things were not moving well came as the Main Propulsion Panel's 13th Report concerning the future application of nuclear power issued on 23 December 1953. The following recommendation was made [5-62]:

"Roll stabilization, at least of medium-sized ships may be necessary so that the endurance of the crew may equal that of the hull during possible long periods of high speed in heavy weather."

The third indication came from the Hull and Hydrodynamics Panel which only discussed roll stabilization once more before it was abolished in April 1954 [5-63]. The discussion came up in reference to nuclear propulsion in March 1954, and it appears that the Panel attempted to ride on the coat tails of nuclear propulsion in endorsing once more roll stabilization [5-64]:

392
"The Hull and Hydromechanics Panel agrees that roll stabilization has increased in importance as result of development of nuclear power with possible increased operating time at high speeds. However, the Panel feels that of equal and probably greater importance is the need to extend our knowledge of seakeeping qualities of ships in order to take full advantage of these power developments. In most circumstances, the ship speed under unfavorable sea conditions will be limited by the ability of the ship to withstand the effects of the rough seas rather than by the endurance of the crew."

The Panel during its two-year existence recognized the roll stabilization quite clearly and did a thorough analysis. Unfortunately, its recommendation regarding roll stabilization was not put to action. Consequently, the prospects of introducing anti-roll fins into U.S. warships didn't move much closer to reality as a result of these two years of fine work by the Panel.
5.5 The Last Experiment Before Adoption

While the U.S. Navy was studying and experimenting on small scale and generally contemplating which way to go, both the commercial world and the British Navy shifted into high gear and adopted fin stabilizers in a number of new designs.

The British adopted the Denny-Brown stabilizers for a number of destroyers (see Table 5-3) and, in 1954, the QUEEN ELIZABETH received two pairs of Denny-Brown stabilizers [5-5]. The only U.S. adoption was also a Denny-Brown stabilizer in a commercial ship, in 1955, (a banana boat being built in England for the United Fruit Company of the u.s.) [5-5].

Dr. Chadwick of Stanford, who had worked for 5 years on roll stabilizer controls primarily sponsored by the Office of Naval Research, joined the Sperry Gyroscope Company in 1953 and, by 1955 [5-65, 5-66], had developed a practical fin control system. Fins with this control system were first installed in two Mariner-type ships which were converted for passenger use in 1956 by the Oceanic Steamship Company for the West Coast - Hawaiian trade route.

Two papers, one in 1956 [5-67] and one in 1957 [5-68], were delivered, describing in detail the fin development program which took only one year from the time of contract signature to delivery.
<table>
<thead>
<tr>
<th>BRITISH ADMIRALTY</th>
<th>NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>H.M. Battle Class Destroyers</td>
<td>2 ships</td>
</tr>
<tr>
<td>H.M. Destroyer &quot;Wolfhound&quot;</td>
<td>1 ship</td>
</tr>
<tr>
<td>H.M. Hunt Class Destroyers</td>
<td>62 ships</td>
</tr>
<tr>
<td>H.M. Sloops</td>
<td>31 ships</td>
</tr>
<tr>
<td>H.M. Cruiser &quot;Cumberland&quot;</td>
<td>1 ship</td>
</tr>
<tr>
<td>A.A. Frigates</td>
<td>4 ships</td>
</tr>
<tr>
<td>A.S. Frigates</td>
<td>1 ship</td>
</tr>
</tbody>
</table>
The first roll stabilized commercial vessels of American registry were the MARIPOSA and MONTEREY which were designed and built at the Newport News Shipbuilding and Drydock Company in cooperation with Sperry Gyroscope Company.

In the mid and late 1950's, the two primary competitors in the roll stabilizer business were Denny-Brown and Sperry Gyroscope. The Denny-Brown and Sperry Gyroscope systems were different in a number of ways. In the Denny-Brown system, the fin was designed to be stowed during calm weather or when the ship was in port by retracting the fins directly into the hull. During "heavy" weather, the fins were designed to extend and the stabilizer was put into operation (see Figure 5-7). As the fins were extended, a small "vertical keeping" gyro was designed to be activated and if the ship was heeled, the fins were given a static angle of attack to correct it. As the ship rolled, a small, angular-velocity gyro took over the major part of the control. As soon as the angular velocity exceeded 2 degrees per second, the fins were set to their full angle to reduce the roll. As the end of the roll was reached, the fins returned to neutral and, thereafter, reversed their positions at the start of the return swing. All this was accomplished by the reactions from the gyros being combined electrically and amplified electrically and hydraulically through a series of servomechanisms which, in turn, controlled the main variable delivery, hydraulic pumps.

In the Sperry system, the fin was arranged to fold back into the hull until the time came when it was put to work (see Figure 5-8).
Figure 5-7  Denny-Brown Fin Stabilizer System

- No. 1: Fin retracted
- No. 2: Fin extended and not angled
- No. 3: Fin extended and fully angled "up"
This system positioned the fins in accordance with the lift, rather than with the tilt, or angle of attack, of the fins, as was done in the Denny-Brown system. The sea's action on the ship resulted in a roll motion which was sensed by a linear accelerometer, a roll-rate gyroscope, and a roll accelerometer. These signals were combined in an amplifier and fed into a computer which ordered a certain lift force, depending on the magnitude of the ship motion. The ordered lift was limited so that the fins would not be positioned to produce more than the maximum safe load on the fins. The resultant signal, transmitted from the bridge control station through a servoamplifier to a stroke-control mechanism, placed the variable-delivery pump on a stroke which, in turn, positioned the tilt-cylinder piston. As the fin tilted, lift was developed proportional to the angle of attack of the fin on the water at the instant the lift was ordered. Identical forces of opposite sense were produced on both the port and starboard fins, thereby creating a stabilizing moment which counteracted the sea's input and reduced the net roll of the ship. The operational experience with this system received good reports from Sperry's project manager on the maiden voyage of MARIPOSA [5-68]:

"Effects of stabilization onboard ship are seen everywhere -- waitresses carrying trays with dishes stacked in triple tiers, the back of the bar set up as ashore, passenger's dressers and tables neatly arrayed with perfume bottles, flowers in vases and so on, only fore and aft ripples in the swimming pool, extravagant dips and whirls on the dance floor, and an absolute absence of staggering or lurching while walking. Water levels in the boilers and evaporators remain steady, tools and parts of a disassembled machine stood neatly on the floor plates, pencils and pens lay on the log desk -- the engineering department is also enjoying stabilization. On deck, tradition is still an
important factor with lashings still very much in evidence. However, the mate on watch strolls easily from bridge wing to bridge wing without the typical seaman's stiff legged gait. And, if the stabilizer is secured, the phone switchboard lights up immediately as all hands demand to know why."

What appears very interesting is that both Sperry Gyroscope and the ship operators had considerable foresight with respect to psychological problems which could have influenced the acceptance of roll stabilization by both crew and passengers. This foresight appears lacking in the case of the Navy as we shall see later. Sperry held lengthy conferences with the Steamship Company and the ship designers, Gibbs and Cox, as well as with psychologists and psychiatrists. They instituted a very specific training program to train the operators of the fin system. For the passengers, a brief memorandum on the purposes and operation of the stabilizers was distributed on the maiden voyage.

There were some equipment problems on these commercial vessels, but, after a year's operation, the problems were found traceable to quality assurance problems during the assembly of the equipment.

Adoption of fin stabilization in the commercial field was picking up to such an extent that, by 1954, Vosper Ltd. of Canada entered the roll stabilization field by introducing a nonretractable type fin with a control system sensitive to roll velocity (see Figure 5-9).
In the U.S. Navy, a retractable type fin ship stabilizer was developed by the Bureau of Ships in cooperation with the Lidgerwood Company for the TIMMERMAN (AG 152). The specification for the control system read as follows [5-69]:

"The Contractor shall furnish an ARL control of the latest tested and proven type available. The Contractor shall design the stabilizer so that an alternate stabilizer control can be used."

The specification was issued on February 22, 1954 but the TIMMERMAN never received the equipment. Dissatisfaction with the TIMMERMAN discussed earlier eventually prevailed and the first U.S. Navy fin installation was on another destroyer, GYATT.

The GYATT, originally of the GEARING class, a long hull DD 692, and had been built in 1945. Its conversion to a guided missile destroyer (DDG), provided under the Fiscal 1956 Appropriations and reclassified as DDG 1 on 1 December 1955, was completed at the Boston Naval Shipyard, where it was fitted with the complete TERRIER missile installation. The GYATT was recommissioned in December 1956 and reclassified as DDG 712. In May 1957, the ship was again reclassified, this time as DDG 1.

Thus, the GYATT was the world's first guided missile destroyer. It was also the U.S. Navy's first warship to have a fin roll stabilization system.
The fins on the GYATT had an outreach of 10 feet, and a chord of 4-1/2 feet, making the total area of each fin 45 square feet. The main part of the fin was fixed to a 19-1/2 inch diameter shaft and could tilt about 23 degrees up or down. Hinged to the trailing edge of the main fin was the tail flap. Its relative motion was 38-1/2 degrees up or down. The flap was linked so that its angular movement was always greater than that of the main shaft. The flapped fin produced a greater lift than would a solid or unarticulated fin of the same proportions.

Pumps were provided to extend and retract the fins. The weight of the entire stabilization gear for the GYATT was 68 tons. Since 11 tons of buoyancy were lost through flooding of the retraction compartments, the total net weight of the stabilizer was 79 tons. This represented 2.3 percent of the ship's displacement.

The stabilizer on GYATT was housed in a compartment below the first platform, running across the ship. It was bounded by transverse bulkheads 14 feet apart. Since this compartment had been used previously for the storage of 155 tons of fuel oil, GYATT's cruising radius was somewhat reduced. Although it is important to remember that, in the case of a new design where roll stabilization is a specified military characteristic, stabilization can be incorporated in such a way that the endurance range is not compromised. Of course, stabilization does have its price in terms of weight and space.
The GYATT had a third gyroscope installed, in addition to one responsive to roll angle and one responsive to roll velocity, i.e., in addition to the traditional Denny-Brown System. The modified system was designed by another British firm, the Muirehead Co., which at that time had been working with Denny-Brown providing the control system designs. As discussed earlier, previous analogue computer studies had indicated that stabilization which included acceleration sensing would be more effective than when only the angle and velocity sensors were used. This is shown by the curves of Figure 5-10. Curve 1 of this figure represents the response of the unstabilized ship with fins extended. Curve 2 shows how the motion is reduced, in beam seas and following seas, using angle and velocity inputs. (A manually operated selector switch was located on the bridge and could be used to change the stabilizer control system to suit sea conditions.) Curve 3 shows the more effective stabilization which is theoretically possible when the third sensing element, i.e., acceleration, is added. In a physical sense, the roll angle control had the effect of increasing the restoring constant of the ship, velocity control increased the apparent damping, and acceleration control increased the apparent inertia. With acceleration sensing, the system was more fully automatic since the need for the selector switch could be eliminated. Whether or not the theoretical predictions were realizable in practice was to be tested during rough sea trials.

The preliminary trials were run on the GYATT in calm seas. These consisted of rolling the ship artificially by means of fins, then measuring the roll decay with fins activated and with fins extended at a
FIGURE 5-10 FREQUENCY RESPONSE CURVES
fixed angle. The ship was forced to roll to angles of 22 degrees from the vertical at its natural period of 9 seconds. The effectiveness of the fins in quenching the induced roll was clearly shown by the tests. After the fins were activated, the ship became virtually upright after only one swing. The GYATT stabilizer was designed to have a capacity capable of counteracting a sea torque corresponding to an effective wave slope of 5.5 degrees associated with a ship's speed of 20 knots. This capacity appeared adequate to reduce rolls of 20 degrees from the vertical to about 1-1/2 degree.

Motion measurements were made in a State 4 sea to determine the effectiveness of the fins at various headings relative to the sea for various fin control settings and fin extensions. The trials were conducted on 30 and 31 March 1957.

The trip report of the Bureau's engineers was issued first. The items recorded during the test were fin angle, two ram pressures, roll acceleration, roll angle, two heave accelerations, surge acceleration and pitch angle. The sea and weather were observed and noted. Excerpts from that report [5-70] indicate a very favorable impression:

"Full evaluation of the records must wait for DTMB, but the following items were noted:

(1) At 20 knots in a quartering sea unstabilized, maximum roll ranged from 15 to 18 degrees from the vertical."
"(2) With the fins working as designed, the maximum roll ranged from 1-1/2 to 2 degrees.

(3) The stabilizers have given very little trouble since builder's trials. There have been no breakdowns or malfunctions with the exception of a transfer of hydraulic fluid from one pump to another when rigging the fins. This is probably due to a faulty transfer valve and the ship will try to remedy it.

(4) It was the practice of the ship to have the stabilizers operating during meal times, even at low speeds, since this made eating much more convenient. The general opinion of the ship's force seemed to be favorable to the stabilizer."

In January 1958, the DTMB report [5-71] was issued and presented quantitative data. Figure 5-11 shows that the reduction in the average roll amplitudes was approximately 70 percent for 100 percent fin extension and 55 percent for 75 percent fin extension, except for seas from stern quartering where the reduction was somewhat less: 60 percent and 40 percent, respectively. The ship experienced her highest roll motions in quarter head seas. The corresponding reduction in roll acceleration was approximately 60 percent with 100 percent fin extension and 50 percent with 75 percent fin extension.

By December 1957, the Operational Test and Evaluation Force (OPTEVFOR) completed its tests on the GYATT and among other points, its report concluded the following [5-72]:

"The Denny-Brown ship stabilization system increased the effectiveness of GYATT by improving personnel performance."
FIGURE 5-11 REDUCTION IN AVERAGE ROLL AMPLITUDES
"Fuel oil capacity of GYATT has been reduced approximately 33,000 gallons from a capacity of 213,000 gallons, a reduction of 15 percent.

"Operation of the stabilizer did not affect significantly the fuel consumption and speed of the ship.

"Crew's comfort, safety, morale and efficiency under heavy weather were improved by the operation of the stabilization system.

"All units were easily accessible for routine maintenance and repair.

"The instruction manual supplied with the equipment was adequate."

The report recommended that:

"A. The Denny-Brown stabilization system be retained in GYATT.

B. Further sea trials be conducted to gather additional data for detailed analysis of ship's motion by the Bureau of Ships.

C. That the concept of fin stabilization for certain naval ships be accepted provided that important operational characteristics, such as cruising range, were not unduly sacrificed."

Thus the first installation of fin stabilizers in a U.S. warship was a complete success. The year was 1957.
5.6 The Decision to Adopt

As a result of the success of the GIATT tests, two more ships, not destroyers, were fitted with fin roll stabilizers by 1958. These two ships, the COMPASS ISLAND and OBSERVATION ISLAND, were converted Mariner-type cargo ships for the purpose of assisting in Polaris missile test firings. One of the ships received a Sperry fin and the other a Denny-Brown unit.

In February 1958, the Chairman of the Ship Characteristic Board (SCB) issued the first tentative characteristics for a new destroyer, the FY 60 DE. This class of destroyer escorts was intended to provide a balance between the optimum escort ship of good ASW detection and kill capability and the need for minimum size, complexity, and cost required for a large shipbuilding program. The DE 1006 class, a previous class, was considered as the point of departure for the new design which had several new Anti-Submarine Warfare (ASW) combat capabilities.

First, it was to incorporate the first SQS-26 sonar, for which a prototype contract had just been let in the spring of 1958. This sonar was envisioned as an ultimate escort sonar and was the first sonar to employ a technique (bottom bounce) that was to overcome the tremendous problem of detection in bad thermal gradients of the ocean.
An ASROC launcher was also incorporated. It was designed to launch a torpedo weapon from a ship with rocket assistance to exploit the ranges which were expected of the new sonar.

Another important first was the introduction of facilities for a helicopter drone which was to fly off the ship and extend the ship's ASW capability even further than ASROC could, as well as to serve as an alternate ASW weapon delivery.

The tentative set of characteristics specified a 1,450 ton light ship displacement, a fairly low speed, a 3"/50 gun, torpedoes and other sensors and electronics required, in addition to those previously enumerated. No mention was made of any stabilization system.

In March 1958, the chairman of the SCB wrote to the Chief of the Bureau of Ships requesting feasibility and cost studies in connection with the new DE's and reminded the Bureau that OPLAN Instruction 4700.12A prescribed that, by 15 May 1958, the SCB had to submit the ship's characteristics to the CNO for the FY 1960 Shipbuilding Program.

On 9 April 1958 a working level meeting of the SCB was held to discuss the FY 1960 DE. In this meeting, numerous changes were agreed upon and the SCB recommended incorporating them. The need to incorporate a roll stabilizer was stated for the first time.
On 14 April 1958, the second set of preliminary characteristics for the FY 1960 DE was issued and roll stabilization was included as a requirement [5-73]. Comments were requested by 23 April from all concerned parties, which were to be adjudicated in a meeting on 24 April 1958.

The meeting on 24 April produced the final proposed characteristics for the FY 1960 DE, which was designated SCB Project No. 199. Roll stabilization was a topic of discussion at this meeting [5-74].

Recognition was given to the fact that roll stabilization was not a cure-all, since motions of pitching, heaving and yawing, as well as slamming of destroyer type ships in heavy seas, were not going to be necessarily reduced. Concern was also expressed that additional stresses would be introduced into the ship by installing the fins which might require heavier scantlings, hence would increase displacement. In spite of these considerations, it was agreed that roll stabilization would improve significantly certain aspects of the overall problem [5-74]:

"A. Personnel Performance.

(1) Operator efficiency, especially for operators of sonar, communications, and fire control equipment.

(2) Efficiency of maintenance, administrative, and other support personnel.

B. Performance, Reliability and Life."
In rough weather, sonar, radar, communication, fire control and ordnance equipments do not realize their smooth weather potentials. In addition to this immediate effect, there is the long term effect upon the life of equipment subjected to severe stress and strain due to whip, shock, and gyroscope precessive forces, especially in vertical and athwartship mounted high speed machinery. These long term effects become apparent in increased requirements for replacement and maintenance and in physical damage.

The discussion in the SCB working level meeting also highlighted the fact that COMOPTEVFOR, which is the command which performs all the operational test and evaluation for naval ships, had given endorsement to roll stabilization in the report mentioned earlier concerning the performance of the GYATT. The British experience was brought up, specifically the fact that the then-new British Type 81 General Purpose Frigate, as well as their guided missile destroyers, under construction had roll stabilization. The same discussion also mentioned that roll stabilization was included in five HMS LEOPARD class ASW frigates built since 1950.

In May 1958, the SCB requested the Bureau of Ships to conduct studies to determine the influence of fins on hull-mounted sonar effectiveness, on additional stresses induced by the fins on the hull, on the comparative effectiveness of the Sperry Gyrofin and the Denny-Brown fins, and on the comparative cost, space and maintenance of these two systems [5-75].
In the Bureau's opinion [5-76], fin stabilizers did not have any significant effect on hull stress, and discussions with officers of the British Navy, who had had considerable service experience with fin stabilizers, reinforced the feeling that there had been no such problems in their Denny-Brown installations.

With regard to the effect of fin stabilizers on sonar performance, the Bureau had requested the availability of GYATT to test in this area [5-76]. The major purpose of that test was to determine the effectiveness of the fin stabilizers in reducing quenching of the SQS-4 sonar (installed on the GYATT). It was thought that qualitative results of the proposed test would be applicable to the AN/SQS-23 sonar and to the much larger sonar which was being installed at that time on most new destroyers. The Bureau was waiting for test approval by the Chief of Naval Operations, which never came. Thus, the SCB never did receive an answer to this question.

With regard to the last question, both the Sperry and Denny-Brown fin stabilizers were considered highly effective in reducing roll. There were some differences in the control mechanisms of the two, as discussed earlier, and considerable differences in structural modification and in space required in the ship. The Bureau noted [5-76] that there was a healthy competition between the two firms and that there was a tendency for each to copy the best points of its competitor in spite of conflicting advertising claims. Thus, the Bureau suggested if fin stabilization was specified, the SCB should leave the choice to the
The Bureau felt that it was in the best position to specify the best servo system and best overall fin arrangement (whether fins should retract by sliding inboard axially or rotating horizontally, or whether fins should retract at all). In this way, the Bureau felt it would be in position to take advantage of competitive bidding to the economic advantage of the Navy and would, at the same time, obtain the best system for the particular ship under construction.

In June 1958, the Chief of the Bureau of Ships responded to the Chairman of the SCB in reference to the final proposed characteristics of the SCB Project No. 199 [5-77]. In that letter, he dismissed the notion that the roll stabilizers would increase the hull girder stresses to such an extent that the scantlings of the hull would have to be increased as suggested in the working level discussion of the SCB.

He also pointed out that the SCB discussion appeared to have made the sonar the primary beneficiary of roll stabilization and he took issue with those conclusions:

"While it is evident that reduction of ship motion in the way of the sonar will tend toward improvement, the effect on the actual detection capability of the sonar has not been established."

He went on to quote the COMOPTEVFOR report "Evaluation of the Denny-Brown Ship Stabilization System" [5-72]:

415
"The stabilizer had no noticeable effect upon the capability of the ship's sonar to detect a submarine."

He also indicated that further tests were scheduled for the GYATT which were expected to yield more valuable data on roll stabilization.

Concurrently, studies were being performed in the Bureau dealing with the impact of roll stabilization on ship size. A 17-foot increase in ship length was attributed to the accommodation of the roll stabilizer in the hold. Also, an increase of 70 tons and 80 kW of electric power were attributed to the stabilizer. The light ship displacement of the ship had thus increased to 1620 tons and the full load displacement was 2,450 tons.

The estimated ship cost, at that time, was $21 million for the lead ship and $17 million for the follow ships.

The usual concern with preserving maximum ship speed was very much alive in the Navy and, as a result, the Chief of the Bureau ordered a study to see what could be done to increase ship speed by one knot. A summary of a study on another topic [5-78] revealed the prevailing Navy mood,
"Since the SCB has indicated a willingness to reduce armament somewhat in order to obtain speed, and since BUSHIPS does not seem to favor activated fin stabilization...."

It is no wonder that, in response to a formal request by the SCB [5-79] to study the increase of ship speed, the Bureau offered the elimination of roll stabilization as the sacrificial lamb, stating in September 1958 [5-80]:

"The elimination of dynamic roll stabilization without otherwise changing the design would result in a speed increase of approximately two tenths of a knot, a decrease in full load displacement of 70 tons and a reduction of about $500,000 in estimated cost."

Fortunately, the offer was not accepted and, in spite of numerous other studies on a variety of issues, the Approved Characteristics for the DE, issued on 31 October 1958, did contain the roll stabilizers.

On 21 October 1958, just ten days before the Approved Characteristics were issued, and evidently in response to a request for comments, both Commander Destroyer Force, U.S. Atlantic Fleet and Commander Cruiser-Destroyer Force, U.S. Pacific Fleet, jointly recommended that the adoption of destroyer stabilization should proceed as quickly as possible.

In forwarding these comments to the CNO, the Commander in Chief, U.S. Pacific Fleet (CINCPACFLT), listed the advantages and disadvantages of fin stabilization as determined from the evaluation of the GYATT, but
recommended that ship stabilization not be authorized in destroyers until proven necessary. The Commander in Chief, U.S. Atlantic Fleet (CINCLANTFLT) concurred with CINCPACFLT. The CNO, in response to their comments [5-8] stated:

"The Chief of Naval Operations appreciates the advantages to be gained through stabilization of destroyers. It is intended that stabilization be provided in new construction destroyers when such installation can be considered acceptable within the parameters of weight, space, and cost and without penalty to endurance, speed or other military characteristics. To date, the Ocean Escort is the only class for which roll stabilization has been approved. Continued study is being made on further application of stabilization. Future decision will be largely influenced by results of heavy weather tests recently conducted on the GYATT."

It is quite clear that roll stabilization, unlike speed, armament, or endurance, did not have an advocate in a decisive organizational location. The user, i.e., the commanders of the specific ships and their immediate leaders, were obviously all for stabilization. Unfortunately, as individuals in the organizational structure became further removed from having to live with the results of their decisions, i.e., CINCPACFLT or CINCLANTFLT or CNO or the Chief of the Bureau of Ships, they became increasingly influenced by factors more political in nature. Introducing roll stabilizers was costly and with a fixed cost goal per ship it meant some other equipment would not be installed, therefore it became a highly charged political issue.
The CNO's statement made it clear that he put every factor ahead of stabilization. In fact, the only way that stabilization could have been adopted, given that it could not be at the expense of the factors listed, was if the cost ceiling on the ship was increased.

In the meantime, discussion and correspondence between the Bureau and Sperry and Denny-Brown continuing through the early part of 1958.

At the request of the Bureau in April, Sperry quoted a price of $400,000 for a destroyer installation. This installation had a weight of 40 tons with a compartment for housing the equipment of about 11 feet wide, 13 feet high and 12 feet long.

The engineering group responsible for fins at the Bureau requested that Lidgerwood Industries, Inc. work up a conceptual design for a non-retractable fin stabilizer for destroyers.

A conference was held on 1 May 1958 [5-82] and the Lidgerwood people presented several alternatives for folding fins, a non-retractable fin, and methods for the installation of the conventional Denny-Brown stabilizer with weight and space savings. Of the different methods presented, the non-retractable fin type appeared to have the most possibilities.
It was estimated that one set of non-retractable fins of the same capacity as those installed on the GYATT would cost approximately $150,000, or less than one-half of the cost of retractable fins. These non-retractable fins would extend considerably below the baseline of the subject ships. They would save approximately 60 percent of the space required for the GYATT installation and about 50 percent of the weight, with no loss of buoyancy.

In May 1958, two letters were sent from the Bureau [5-83], [5-84], requesting that each manufacturer submit quotes on non-retractable fins and provide weight and space data. Since the new destroyer requirements were still undefined, this exploratory correspondence continued for two whole years, eventually leading to bids for the new destroyer - the first to adopt a roll stabilization system.

The Bureau of Ship's evaluation of the two manufacturers' systems prior to awarding the contract, as well as the implications of DOD procurement policies on the buying practices of the Navy, come to light in the last of a series of letters between the U.S. and Italian Navies which went back and forth over a 10-month period, starting in September 1958. The Italians had become aware of the U.S. Navy's full scale experiments with fin stabilizers and they wanted to know the results [5-85], [5-86].
The last letter in this series was written by the Bureau to the U.S. Naval Attache in Rome on 8 July 1959, about 14 months prior to the award of the contract to Lidgerwood. The decision had been made to have roll stabilizers on the DE 1037 [5-87]:

"The principal differences between the two designs are:

(a) Sperry uses lift control; Denny-Brown uses angle control.

(b) Sperry fins are housed by rotating inboard, in the plane of the fin at zero angle; Denny-Brown fins are housed by translating inboard.

"Both systems use controls that are based on instantaneous readings of roll angle, roll velocity, and roll acceleration. In connection with paragraph (a), the Sperry system provides a lift transducer which brings the fin to an angle which in turn develops a desired measured lift. If wave orbital motion changes the effective angle of attack, the fin angle responds so as to still produce the desired lift. In the Denny-Brown system, this feature is not considered necessary, since the fins are constantly rotating in response to new sea conditions. We understand that Denny-Brown can now offer lift control as an optional feature on some designs. In our opinion, lift control is a marginal improvement, and we would make the choice between Sperry and Denny-Brown based on lower cost.

"In connection with retraction and housing features, per paragraph (b), there are no significant differences. For the COMPASS ISLAND (EAG153) and the OBSERVATION ISLAND (EAG154), both systems have proved satisfactory. The awards to Sperry for the former and to Denny-Brown for the latter were made on basis of lower bid price. In our new design DE 1037 class, the desired fins are non-retractable, and lift control is not required. We expect that, in addition to Sperry and Denny-Brown, a bid will be submitted by Western Gear Corporation.
"In summary, we have no technical preference between Sperry and Denny-Brown. Our policy is to specify the system requirements, and then invite competitive bids."

This approach to procurement has contributed to a maintenance nightmare which, in part, has been responsible for the 1975 decision to remove the roll stabilizers from the DE 1037 and DE 1038, the first ships in which they were installed.

As we shall see later, the policy of going to the lowest bidder had many negative aspects to it. In the case of roll stabilizers, it resulted in the eventual use of six different systems manufactured by three different manufacturers, even though fins were adopted in only two major classes of destroyers.

In April 1959, during the contract design phase of the DE, the Director of Ship Design Department in the Bureau of Ships, wrote to the U.S. Naval Attache in London and requested that he obtain information from the British with respect to their experience with the Denny-Brown stabilizers installed in the LEOPARD class anti-aircraft frigates. The Director wanted to know the size of the fins and the angle of mounting of the fins with the horizontal. He also requested the design calculations for the capacity of the fins in degrees of effective wave slope and any available full scale performance data. [5-88]
The reason that the Bureau was interested in knowing about the angle of mounting with the horizontal stemmed from the fact that non-retractable fins were chosen for the DE in order to save space and cost. This meant that the fins had to be mounted at a fairly large angle to the horizontal in order to keep the extremities within the beam of the ship. Several problems were created by this decision which obviously was dictated by the desire to make stabilizers inexpensive since it was quite clear that low cost was a condition for acceptance. Two major problems were:

A. The installation was radically different from the GYATT which was supposed to have been the prototype test installation. By changing the DE design so radically, a lot of the debugging from the GYATT tests could not be taken advantage of.

B. The angle of mounting introduced alternating transverse forces on the ship, tending possibly to yaw the ship which in turn could give it a bad reputation with the users in the fleet.

The reply came from London in August 1959 [5-89]. First, the stabilizer on the LEOPARD class was an old design, retractable type, and very heavy. It was not being considered for use on future ships. The newest stabilization device was being incorporated in their guided missile destroyer. No model tests had been run or planned by the Admiralty because they felt that only full scale trials had any value. It was estimated that the stabilizers could combat a wave slope of 8-1/2 degrees
but this figure varied among different ships. Table 5-4 shows that the British were proceeding rapidly in adopting fin stabilizers.

The letter also pointed out that the Admiralty did not possess any of the Denny-Brown calculations which appears to indicate a lot less "cooks in the kitchen" than in the case of the U.S. Navy, where the laboratory and other research organizations rather than only the design division wanted to determine the detailed characteristics of the control system.

In August 1959, the Bureau of Ships issued a request for proposals (RFP) for non-retractable fin stabilizers for the DE 1037 and DE 1038 [5-90]. The RFP, requesting design, and weight and cost estimates for two ship sets, was sent to Lidgerwood Industries, Sperry Piedmont Company, and Western Gear Corporation.

Lidgerwood quoted $284,000 for two ship sets; Sperry quoted $575,000; Western Gear did not respond. This was the initial inquiry. It took another year before the Bureau went out for bids on the hardware.

The pressure continued to forfeit roll stabilization on the two DE's to save money. This was the only characteristic not specifically barred from alteration by the CNO.

A conference was held in the late summer of 1959 between the DE Ship Design Manager and the group responsible for sonars in the Bureau
<table>
<thead>
<tr>
<th>Date</th>
<th>Fin Type</th>
<th>Fin Area</th>
<th>Displ. (Tons)</th>
<th>Speed (Knots)</th>
<th>GM (Feet)</th>
<th>Wave Slope (Degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.2.56</td>
<td>Retract.</td>
<td>50</td>
<td>6000</td>
<td>30</td>
<td>3</td>
<td>6-1/2</td>
</tr>
<tr>
<td></td>
<td>Retract.</td>
<td>78</td>
<td>6000</td>
<td>30</td>
<td>5</td>
<td>6-1/2</td>
</tr>
<tr>
<td>28.5.56</td>
<td>Multifins</td>
<td>4 at 16.5=66</td>
<td>5900</td>
<td>30</td>
<td>3</td>
<td>10-1/4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 at 24 =120</td>
<td>5900</td>
<td>20</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20</td>
<td>5</td>
<td>10-1/2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>5</td>
<td>10-1/2</td>
</tr>
<tr>
<td>6.9.56</td>
<td>Multifins</td>
<td>4 at 24 = 96</td>
<td>5900</td>
<td>30</td>
<td>4</td>
<td>10-1/2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20</td>
<td>4</td>
<td>5-1/4</td>
</tr>
<tr>
<td>27.9.56</td>
<td>Multifins</td>
<td>4 at 24 = 96</td>
<td>6000</td>
<td>30</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(Broader Vessel)</td>
</tr>
<tr>
<td>30.1.57</td>
<td>Multifins</td>
<td>4 at 32 =128</td>
<td>6000</td>
<td>20</td>
<td>4</td>
<td>6-1/2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>22-1/2</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>25</td>
<td>4</td>
<td>9-3/4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>27-1/2</td>
<td>4</td>
<td>10-1/2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>30</td>
<td>4</td>
<td>10-1/4</td>
</tr>
<tr>
<td>If Now</td>
<td>4 at 32 =128</td>
<td></td>
<td>6000</td>
<td>20</td>
<td>5</td>
<td>5-1/2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>25</td>
<td>5</td>
<td>8-1/4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>30</td>
<td>5</td>
<td>8-1/2</td>
</tr>
</tbody>
</table>
of Ships. The sonar group was advised of the possibility of eliminating the stabilization fins from the new DE 1037. The suggestion was made that the adverse effects on the sonar performance by eliminating the roll be presented if retention of the fins was desired. A table sent by the sonar group to the Design Division as a reply, showed the cumulative effect on the AN/SQS-26 sonar of removing the fin stabilization. It was noted that there was an effect on operator efficiency and it applied to other electronic equipments as well. Only minimum electronic stabilization on the sonar was required if the fins were installed and an additional $75,000 would be required for each sonar to provide full electronic stabilization if the fins were eliminated. Strictly from the sonar standpoint the $75,000 against the $500,000 for fin installation was quite a bargain. Nevertheless, roll stabilization was retained in the DE 1037, but for a reason that in my opinion, is not the primary reason for its usefulness.

Earlier in July 1959, the Bureau of Ships had requested DTMB to test the DE 1037 configuration to determine the effect of the installation angle on the maneuvering of the ship. The DTMB test showed that, when the ship was operated at its top speed with the maximum fin setting for that speed, the rate of change of heading of the full-scale ship would be 0.025 degree per second, a yaw rate so small that it was negligible. Thus, it appeared that the concern with fin installation relative to its effect on maneuvering was not a real problem.
Since two different design organizations were included in the Bureau of Ships, i.e., one for Preliminary and one for Contract Design, it was quite common that once a design left the Preliminary Design organization, many changes were made to it, especially since there was no mechanism by which the Preliminary Design organization controlled the design evolution downstream. This situation was further aggravated by the fact that a third design organization usually took over after the completion of the Contract Design for the Detail Design of the ship. There was no such thing as rigorous configuration control, and the roll stabilization was no exception. In February 1960, not long after the completion of the DE 1037 Contract Design, a discussion was held at the Bureau among the various design organizations, including Gibbs and Cox, the Detail Design organization, regarding a proposal to relocate the fin stabilizers.

An examination of the DE 1037 machinery arrangement revealed that, while the propulsion units were essentially the same as for the DE 1006, the modification of the Fire Room to accommodate the fin installation combined with the location of the fresh water tanks at the forward end of the Engine Room made it almost impossible to run the ballast drainage and fuel oil piping through one of the bulkheads at the lower levels. It was also noted that the outboard edge of the condenser scoop was immediately aft of the inboard edge of the port stabilizer fin. Thus, the scoop would be operating in a turbulent and low pressure area which
could have seriously affected its performance. It was agreed that, moving the fins forward of the Fire Room, would only result in a slight adjustment of the fin angle and that the new location was not going to have an adverse effect on the fins' performance.

This incident does not appear to have major significance regarding the process of innovation except that it reveals that the reason for moving the fins was the concern about other functions in the ship, and the roll stabilizer having no advocate was placed in a possibly inferior location. From recent events which relate to maintenance problems of the stabilizer, it will be even more clear (see Section 5.9 of this chapter) that not much attention was paid to the selection of a beneficial location for the roll stabilizer.

As far back as 1956, the Bureau had been concerned that the new control system for the Denny-Brown stabilizers was being manufactured abroad and not in the U.S. The Bureau was concerned that the Muirhead controls might be difficult to duplicate, that they did not provide readily available spare parts, that they did not provide readily available engineering services for installation, and that test and maintenance or reasonably fast service on factory repairs would be difficult. The Bureau wrote to Lidgerwood Industries [5-93] and asked that they submit a proposal for an American manufactured stabilizer control system similar to that furnished by Muirhead. This proposal was to have included roll angle, velocity and acceleration data.
This study did not produce any tangible results until much later. In fact, in August 1960, about two weeks prior to the opening of bids on the fin hardware for the DE 1037 and the DE 1038, the Chief of the Bureau, received a letter from the Managing Director of Brown Brothers & Co., Ltd. stating that they had just concluded an agreement with the McKiernan-Terry Corporation for a licensing agreement for the Denny-Brown stabilizers. In effect, they dropped the Lidgerwood Company, which had had that exclusive license for the 12 previous years. It is not clear what happened subsequently but in spite of the letter from Denny-Brown and another to the Chief of the Bureau from McKiernan-Terry the deal fell through. Lidgerwood, with its own design, became the winner of the DE 1037 and DE 1038 fin stabilizer contract as well as the supplier of many of the DE 1040 and DE 1052 class fin stabilizers. Denny-Brown completed a licensing agreement with Canadian Vickers Company to represent them in the U.S.

Another interesting twist, with respect to the suppliers of stabilization equipment, occurred in 1961 when representatives from both Lidgerwood and Sperry approached the Bureau in order to ascertain whether the Bureau would have any contractual or legal objections to a joint effort with respect to procurement of fin stabilizers. Lidgerwood and Sperry were contemplating an arrangement for supplying fin stabilizers. Sperry would have provided the controls and Lidgerwood the heavy machinery work. One of them would submit the proposals and bids and, if successful, would be the prime contractor taking full responsibility vis-a-vis the Bureau but subcontracting to the other.
Lidgerwood and Sperry had asked for the Bureau's views since they were cautious as a result of the collusive bidding and price fixing convictions in the heavy electrical industry at that time, even though the firms involved had said that counsel for each of the firms had approved the legality of the proposed arrangement. However, under the circumstances, the Assistant Counsel of the Bureau did not see any antitrust implications in the proposed arrangement between Lidgerwood and Sperry and said so.

This cooperative venture never materialized. If it had, the per-unit cost to the Navy might have increased because of reduced competition, but, at the same time, this arrangement would have prevented the different designs of the same hardware item which exists today in the Fleet. Procurement policies forcing competition each time a new shipbuilder bid for the construction of a new DE 1040 and DE 1052 class ship, and, the fact that the Navy opted not to provide the stabilization hardware as Government Furnished Equipment (GFE), created the situation shown on Table 5-5.

In designing the fins for the DE 1037, the design and performance characteristics of the GYATT fins were used as a guide. The GYATT fins were designed to have rated capacity at 20 knots and 5.5 degrees effective wave slope. This meant that, for rated throw of the fins, the static heel of the ship in calm water would be 5.5 degrees for an assumed zero coupling between heel and yaw. This same criterion was chosen for the design of the DE fins.
<table>
<thead>
<tr>
<th>HULL NO.</th>
<th>SHIPYARD</th>
<th>STABILIZER VENDOR</th>
<th>HULL NO.</th>
<th>SHIPYARD</th>
<th>STABILIZER VENDOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE 1037</td>
<td>Avondale</td>
<td>Lidgerwood</td>
<td>DE 1064</td>
<td>Todd-Seattle</td>
<td>Lidgerwood</td>
</tr>
<tr>
<td>DE 1038</td>
<td>Avondale</td>
<td>Lidgerwood</td>
<td>DE 1065</td>
<td>Lockheed</td>
<td>Lidgerwood</td>
</tr>
<tr>
<td>DE 1040</td>
<td>Bethlehem</td>
<td>Lidgerwood</td>
<td>DE 1066</td>
<td>Todd-Seattle</td>
<td>Lidgerwood</td>
</tr>
<tr>
<td>DE 1041</td>
<td>Bethlehem</td>
<td>Lidgerwood</td>
<td>DE 1067</td>
<td>Todd-San Pedro</td>
<td>Lidgerwood</td>
</tr>
<tr>
<td>DE 1043</td>
<td>Avondale</td>
<td>Lidgerwood</td>
<td>DE 1068</td>
<td>Avondale</td>
<td>Sperry</td>
</tr>
<tr>
<td>DE 1044</td>
<td>Avondale</td>
<td>Lidgerwood</td>
<td>DE 1069</td>
<td>Lockheed</td>
<td>Lidgerwood</td>
</tr>
<tr>
<td>DE 1045</td>
<td>Avondale</td>
<td>Lidgerwood</td>
<td>DE 1070</td>
<td>Todd-Seattle</td>
<td>Lidgerwood</td>
</tr>
<tr>
<td>DE 1047</td>
<td>Defoe</td>
<td>Canadian Vickers</td>
<td>DE 1071</td>
<td>Todd-San Pedro</td>
<td>Lidgerwood</td>
</tr>
<tr>
<td>DE 1048</td>
<td>Lockheed</td>
<td>Sperry</td>
<td>DE 1072</td>
<td>Avondale</td>
<td>Sperry</td>
</tr>
<tr>
<td>DE 1049</td>
<td>Defoe</td>
<td>Canadian Vickers</td>
<td>DE 1073</td>
<td>Lockheed</td>
<td>Lidgerwood</td>
</tr>
<tr>
<td>DE 1050</td>
<td>Lockheed</td>
<td>Sperry</td>
<td>DE 1074</td>
<td>Todd-San Pedro</td>
<td>Lidgerwood</td>
</tr>
<tr>
<td>DE 1051</td>
<td>Defoe</td>
<td>Canadian Vickers</td>
<td>DE 1075</td>
<td>Avondale</td>
<td>Sperry</td>
</tr>
<tr>
<td>DE 1052</td>
<td>Todd-Seattle</td>
<td>Lidgerwood</td>
<td>DE 1076</td>
<td>Todd-San Pedro</td>
<td>Lidgerwood</td>
</tr>
<tr>
<td>DE 1053</td>
<td>Todd-Seattle</td>
<td>Lidgerwood</td>
<td>DE 1077</td>
<td>Avondale</td>
<td>Sperry</td>
</tr>
<tr>
<td>DE 1054</td>
<td>Todd-Seattle</td>
<td>Lidgerwood</td>
<td>DE 1078</td>
<td>thru Avondale</td>
<td>Sperry</td>
</tr>
<tr>
<td>DE 1055</td>
<td>Todd-San Pedro</td>
<td>Lidgerwood</td>
<td>DE 1079</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DE 1056</td>
<td>Avondale</td>
<td>Sperry</td>
<td>DE 1080</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DE 1057</td>
<td>Lockheed</td>
<td>Lidgerwood</td>
<td>DE 1081</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DE 1058</td>
<td>Todd-San Pedro</td>
<td>Lidgerwood</td>
<td>DE 1082</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DE 1059</td>
<td>Avondale</td>
<td>Sperry</td>
<td>DE 1083</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DE 1060</td>
<td>Todd-San Pedro</td>
<td>Lidgerwood</td>
<td>DE 1084</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DE 1061</td>
<td>Avondale</td>
<td>Sperry</td>
<td>DE 1085</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DE 1062</td>
<td>Todd-Seattle</td>
<td>Lidgerwood</td>
<td>DE 1086</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DE 1063</td>
<td>Lockheed</td>
<td>Lidgerwood</td>
<td>AGDE-1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The coefficient of lift chosen for design of the GYATT fins for operation at 20 knots was 1.30, and the geometric aspect ratio of the fins (ratio of outreach to chord) was 2.22 (10/4.5). The corresponding values for the DE fins were 1.29 and 2.00 (8/4).

The estimated breakdown of cost, weight and space savings compared with the GYATT retractable fin installation is shown in Table 5-6. The procurement contract of the non-retractable fin was awarded on 19 October 1960 to the Lidgerwood Company, marking the first adoption of fin stabilizers for a new destroyer class.

Roll trials of the DE 1037 (USS BRONSTEIN) were conducted in mid-March 1964 off the San Diego coast to evaluate the performance of the active fin stabilizers installed. The results of the trials were reported in October 1964 [5-91].

Data providing a measure of fin effectiveness are presented in Table 5-7 and Figures 5-12 and 5-13. The criteria used to determine the indicated average time of damping for the stabilized and unstabilized conditions were as follows: For the stabilized condition, the time was the seconds required for the roll angle to reach five percent of the maximum value $\theta_o$ occurring immediately after activation of the stabilizers. For the unstabilized condition, the time was the seconds required for the roll angle to reach a peak value which was approximately five percent of the maximum value $\theta_o$ immediately after the fins were returned to zero at
<table>
<thead>
<tr>
<th></th>
<th>Equipment Cost</th>
<th>Installation Cost</th>
<th>Weight (Pounds)</th>
<th>Space (Cu.Ft.)</th>
<th>Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retractable</td>
<td>$300,000</td>
<td>$62,177</td>
<td>158,000</td>
<td>6144</td>
<td></td>
</tr>
<tr>
<td>USS GYATT (DDG-1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-retractable</td>
<td>59,359</td>
<td>15,000</td>
<td>30,000</td>
<td>1700</td>
<td></td>
</tr>
<tr>
<td>DE 1037</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Savings per ship</td>
<td>240,641</td>
<td>47,177</td>
<td>128,000</td>
<td>4444</td>
<td>25%</td>
</tr>
</tbody>
</table>

* The total cost savings for the DE 1037 and DE 1038 of $575,636 is more than the cost of 9 ships worth of stabilizer equipment.
TABLE 5-7 MERIT VALUES INDICATING FIN EFFECTIVENESS

Average Time to Damp to 5% $\theta_o$* or less,

<table>
<thead>
<tr>
<th>Speed, Kts</th>
<th>Stabilized</th>
<th>Unstabilized</th>
<th>BRONSTEIN</th>
<th>GYATT</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>10.8</td>
<td>35.1</td>
<td>3.27</td>
<td>3.03</td>
</tr>
<tr>
<td>25</td>
<td>11.6</td>
<td>32.9</td>
<td>2.84</td>
<td></td>
</tr>
</tbody>
</table>

* $\theta_o$ is initial roll amplitude serving as zero time reference.
FIGURE 5-12 QUALITATIVE COMPARISON OF ROLL ANGLE ENVELOPES FOR STABILIZED AND UNSTABILIZED CONDITIONS FOR SHIPS EQUIPPED WITH ACTIVE ANTIROLL FINS

NOTE: STABILIZED AND UNSTABILIZED CURVES WERE COMPUTED ASSUMING DAMPED FREE RESPONSE OF A SECOND ORDER SYSTEM

$$T_N = \frac{2\pi}{\omega_N}$$

SOURCE: REF [5-911]
FIGURE 5-13 COMPARISON OF STABILIZED AND UNSTABILIZED ROLL
the end of the run. The ratio of the unstabilized time to the stabilized time indicates the amount by which stabilization effectively increases the damping coefficient of the ship. Since variable initial roll amplitudes serving as time references are small, they do not significantly affect these ratios.

Figure 5-12 gives a qualitative comparison of roll angle decay envelopes with and without stabilization. Similar curves for the COMPASS ISLAND and GYATT, also equipped with roll fins, are included for comparison.

The tests showed that the fins worked as expected. Thus, the successful installation of the first fin stabilization system into a new class of U.S. destroyers finally became a reality.
Three More Adoptions Between 1961-1963 - But Only For DE's

In early 1961, a new class of DE's (the DE 1040 class) was being developed, as well as the AGDE, a single special purpose test ship. The Design Department of the Bureau of Ships decided to adopt the DE 1037 fin stabilizer system for both the DE 1040 and the AGDE.

Stabilization capacity is inversely proportional to the GM displacement product and directly proportional to the fin outreaches from the ship's center of gravity, as discussed earlier. Since the DE 1040 had a large GM displacement product and an almost proportionally larger outreach, the stabilization provided by an identical system was within one-tenth degree of being the same as that of the DE 1037. The AGDE had the same outreach as the DE 1040 but a slightly higher displacement so that the stabilization with identical fins was slightly reduced. The design condition, 20 knots and 70 percent maximum fin angle, was selected to provide reserve capacity for stabilization at lower speeds.

Even before the DE 1037 roll trials in mid-March 1964, the reports to the Bureau's roll stabilization equipment organization were glowing. One trip report led to a memorandum from the stabilization equipment group to the Hull Design Division which not only expressed joy over preliminary results, but also suggested policy decisions [5-92]:

"It is recognized that many classes of Destroyers and Destroyer Escort types are weight and moment critical. In some ships, i.e., DDG
and DLG, there is adequate weight margin remaining in CNO's future growth margin and in the service life margin to absorb the weight of small fixed stabilizers. Installation of these stabilizers well below the center of gravity offers an advantage of improving GM.

"A cursory examination of the machinery arrangements on DDG's indicates that space is available in the forward engine room for a stabilizer installation.

"In view of the above it is recommended that roll stabilization be included as a requirement in the specifications of all future destroyer new construction. In addition, it is requested that Code 440 conduct a study to determine the feasibility of backfitting non-retractable roll stabilization into post-World War II Destroyer and Destroyer Escort Types."

No such policy resulted but there was no problem in having roll stabilization spelled out in the ship's characteristics of the DEG class as well as the DE 1052 class which were issued [5-93] in 1962. The DE 1052 design had smooth sailing through the decision making obstacles with its roll stabilization requirements. This smooth sailing relative to the incorporation of roll stabilization in the DEG 1 and the DE 1052 classes stemmed from the fact that both of these ships were merely minor modifications of the DE 1040 class. The DEG class was exactly the same as the DE 1040, but while the DE 1040 class was equipped with a 5"/54 gun, the DEG 1 was equipped instead of the gun with a guided missile battery. The DE 1052 had some weapons suite changes relative to the DE 1040 and the Bureau went back to an unloaded 1200 psi power plant from the pressure fired boiler power plant introduced into the DE 1040; nevertheless it was still a close evolution of the DE 1040 class. The AGDE was of the DE 1040
class, modified to a test ship. All ships of these classes were designated as SCB Project No. 199. The DE 1037, DE 1040, AGDE, and DEG 1 had identical fins while the DE 1052 received a slightly larger set because of the increase in ship size.

In November 1962, when the specifications were being written for the DE 1052, the Bureau of Ships wrote to the U.S. Naval Attache in London to request that the British Admiralty explain how they specify stabilizers in their specifications. The Royal Navy stated that, in the design of other ship equipments, the fact that stabilization was provided was not taken into account. They stated that the equipment was designed for use in the unstabilized ship because the fin stabilizers were not effective at low speeds and, for a number of reasons, they might be out of action at times.

The Royal Navy pointed out that the control systems had been supplied, for the most part, by Muirhead who had developed them for merchant ships. Vosper, mentioned earlier in this study as a newcomer to the field, was supplying fin stabilizers to two of the LEANDER class frigates. The Royal Navy further stated [5-94]:

"The amount of stabilization to be provided is based on experience and is usually specified as either reducing roll, e.g. from +10° to +3° at a certain speed or correcting completely an effective wave slope of 8° with ship steaming at a certain speed. Stabilizers are being considered for the new aircraft carrier to reduce roll from +6° to +2°. For the TRIBAL class frigates it was specified that the installation should:
"(1) consist of a single retractable fin each side capable of reducing a roll of +10° to +3° with the ship steaming at a speed of 22 knots; 

"(2) be capable of being operated while the ship is moving at a speed of 25 knots; 

"(3) have the best possible performance at speeds below 20 knots; and 

"(4) operate the fin from hard-over to hard-over in about one second. 

"Compensated control systems are now being fitted and control functions used are: 

"(1) roll angle; 

"(2) roll velocity; 

"(3) roll acceleration; 

"(4) natural list; and 

"(5) feed back (necessary to maintain fin in deflected position after acceleration is reduced to zero). 

The U.S. Navy, for some reason, relaxed these specifications requiring only:  

a. Hard-over to hard-over in 1-1/2 seconds  
b. Wave slope of only 5 degrees. 

An examination of various types of roll stabilization was conducted for the DE 1052. The conclusion was that a single pair of stabilizer fins designed for 5 degrees heel at 20 knots using 70 percent
of stall angle would provide adequate stabilization with the least dis-
ruption to other ship systems.

The design conditions for the fins were:

Static heel 5 degrees
Ship displacement 3670 tons
GM 5.1 feet

An examination of flapped versus non-flapped fins was conducted
to compare the trade-offs of total weight and complexity for each type
fin for the same conditions. It was concluded that non-flapped fins
showed an overall weight advantage provided that non-retractable fins
were used. No serious consideration was given to retraction because the
fin size was not seriously restricted by draft considerations in shallow
water or side clearance when alongside. This was because of the deep
sonar and deep propeller draft, which permitted large span fins to be
permanently mounted to advantage as enumerated earlier.

Several studies for various fin, sweep angles, and aspect
ratios were made, resulting in the selection of a 30 degree sweep of the
leading edge and a geometric aspect ratio of one. This combination was
a fair resolution of the conflicting requirements of hydrodynamic effi-
ciency, outreach and strength. The maximum non-cavitating lift coeffi-
cient was 1.5 at about a 31 degree angle. The design value for lift
coefficient was 1.05 at a 21 degree fin angle at 20 knots.
Several potential fin locations along the hull girth were examined at the same time, to establish the trade-offs of span and effective fin lever arm in roll. The fin stock was located normal to the shell between frames 72 and 73 and at the 14 foot 6 inch buttock. The tip was 5 feet below the baseline and inboard far enough so that the ship could list 5 degrees alongside a vertical wall without interference.

The fin was designed to withstand full angle at full speed, although the correct operation of the control system limited the angle at speeds of about 20 knots so that the fin load did not exceed the maximum 20 knot load.

Fin torques were calculated for the dynamic cases of full 30 degrees angle at 17.2 knots and a limited angle (11.6 degrees) at 30 knots. Thirty degrees at 17.2 knots develops the design value of lift for 70 percent of stall angle at 20 knots. These conditions resulted in approximately the same fin load. The torque included hydrodynamic, friction, and inertia torque based on accelerating the fin from "stop" to a rate of 34 degrees per second in one quarter second. Total torque was calculated for each two degrees for a cycle of hard-over to hard-over at each of the two speeds. The balance selected provided for about the same maximum torque at each condition.

The Bureau actually designed the fins; however, it converted the design into a set of performance requirements for the ship specification
which required that the Shipbuilder, during the detail design phase, actually designed and procured the fins and associated machinery and controls.

During detail design performed by Gibbs and Cox, the issue of stabilization was discussed between Denny-Brown and Gibbs and Cox. In fact, Gibbs and Cox asked Denny-Brown to design the fins. By that time the old firm of Denny-Brown was in liquidation and the Brown Brothers of Edinburgh were carrying on the stabilizer business. The Managing Director of Brown Brothers visited Gibbs and Cox in February 1965. Brown Brothers designed a fin for a 3460 ton ship with a GM of 4.5 feet which had grown to a 4280 ton ship with a GM of 5.2 feet. In their opinion, this dictated an extremely large single pair of fins or a design using twin pairs of fins which they were considering.

Canadian Vickers Industries had entered into an agreement with Brown Brothers to be the U.S. representative. In 1965, they joined Sperry and Lidgerwood in bidding on the fins for the DE 1052.

In a letter written to Todd Shipyards [5-95], Canadian Vickers brought up the issue of the design changes and stated that, in order to achieve the performance requirements, the size of the fins had to be increased from 75 square feet to 100 square feet. They further stated that such a large fin would be unattractive from a hydrodynamic viewpoint. They also felt that operating such a large fin would present unforeseen
problems. Therefore, they proposed two sets of fins of equivalent area but cautioned that [5-95]:

"Either proposal to meet the specified performance with the latest ship characteristics will inevitably cost more than the price submitted for a 75 square foot set of fins."

Several other advantages were cited by Canadian Vickers for the twin fin arrangement [5-95]:

"These twin fins would meet the required performance of 5 degrees wave slope at 20 knots and 90 percent full fin angle.

"The twin fin installation would allow greater flexibility in the use of the stabilizers - one set only being used in moderate weather with a saving in power - and in the event of damage to any unit some stabilizing power would still be available.

"From lift and drag data available to us the combined drag of the small fins for equivalent lift would be less than that for the large single fin.

"From a preliminary review the weights of the single and twin fin installations would be very similar.

"Finally, if in the long term standardization of fin units is ever contemplated as in the case of the LEANDER class frigates and guided missile destroyers in the United Kingdom, where only the number of fin units is varied from class to class, then this could be anticipated with the smaller units, but not the large fin."

The other alternative i.e., a reduced performance requirement from the 5-degree wave slope at 20 knots, was not recommended.
The suggestion to use a twin fin installation was not accepted and the DE 1052 was completed with only one fin on each side.

The first four ships of the class were built by Todd Shipyards and incorporated Lidgerwood designed fins. This was the last U.S. destroyer class to have roll stabilization incorporated in it. Effectively, this means that the last decision to incorporate fin stabilizers occurred about 12 years ago.
5.8 Studies, Tests and More Studies - But No More Adoptions

Roll stabilization was considered for most of the destroyers and destroyer types which were designed after the DE 1037, but it was not adopted, in most cases, because of the reasons already enumerated.

In fact, fins were only adopted in those destroyer escorts that were evolutions of the DE 1037 class, i.e., DE 1040, AGDE, DE 1052 and DEG. Once the fins had been adopted in the DE 1037, it would have required an elaborate justification to take them out of follow-on ships, and the decision-making bureaucracy has high inertia. Also, it is a fact that once an innovation is adopted, the documentation for the rationale for the adoption generally is not well preserved. When new decision makers appear on the scene, they tend to follow what has been done in the past, since to put the issue under the microscope again is costly in both time and money.

In cases of new destroyer type designs which were not DE's, the battle for adoption had to be fought over and again. The guided missile destroyer, which was in the design stage in early 1961 and was to carry the TYPHON weapon system, is a good example of this fact.

The subject of roll stabilization came up in the fifth Bureau of Ships - Bureau of Weapons, TYPHON Coordinating Committee meeting which was held on 7 March 1961. In this meeting, it was stated that installing roll stabilization equipment in the TYPHON ships would permit reducing
the number of elements in the antenna system with a corresponding reduction
in topside weight and some reduction in cost.

However, the Committee concluded [5-96]:

"The saving in topside weight would result in
increased righting arm, but the total ship weight
would increase, and the loss in fuel storage space
would result in decreased cruising radius unless
compensated for by making the ship larger. From an
operation standpoint, it does not appear wise to
make the operation of the weapon system against
low altitude or surface targets dependent on the
operation of the roll stabilization system."

The British would have strongly disagreed with this statement
since their primary postwar impetus for incorporating roll stabilization
in destroyers was the need for a steady platform for missile firing.

On 10 March 1961, a working level, SCB meeting was held con-
cerning the CG TYPHON. The cost of stabilization and its effect on the
ship was discussed [5-97]:

"a. Assuming 10 degrees residual roll after
stabilization, the number of elements in the radar
can be reduced by about 7 percent, the weight
reduced by 33 tons and the cost by $450,000. Power
requirements remain unchanged.

b. A residual roll of this magnitude could
be obtained with two pairs of fixed stabilizers
weighing about 50 tons per pair and costing about
$300,000 per pair for installation.

Thus, the working level committee considers
stabilization a poor bargain for a cruiser."
This view clearly shows a somewhat distorted perspective, i.e., that roll stabilization would be incorporated only if it showed a cost advantage.

Rough estimates of the antenna plus fin system impact are shown in Table 5-8.

### TABLE 5-8

**ANTENNA AND FIN SYSTEM IMPACTS**

<table>
<thead>
<tr>
<th>MAXIMUM ROLL</th>
<th>WEIGHT REDUCTION</th>
<th>COST REDUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>DESTROYER</td>
<td>CRUISER</td>
<td>DESTROYER</td>
</tr>
<tr>
<td>Δ = 3,400 tons</td>
<td>Δ = 10,000 tons</td>
<td>Δ = 3,400 tons</td>
</tr>
<tr>
<td>10°</td>
<td>11 tons</td>
<td>33 tons</td>
</tr>
<tr>
<td>5°</td>
<td>16 tons</td>
<td>48 tons</td>
</tr>
</tbody>
</table>

The $150,000 saving for a destroyer-size system was an estimate based on using retractable fins. For nonretractable fins, the cost saving was estimated at $300,000. Both the Bureau of Weapons and the Bureau of Ships were going to take a closer look and refine these rough estimates of cost savings.

The situation regarding roll stabilization two months subsequent to the working level meeting of the SCB mentioned earlier is documented in a memorandum for the file of the Preliminary Design Division of the Bureau of Ships [5-98]:

449
"From the standpoint of sonar performance, there is a difference of opinion as to the magnitude of gain by using roll stabilizers. There is a feeling, however, that a small ship such as the DE 1037 will benefit. At the present time, it is difficult to determine what the upper limit on ship size should be for roll stabilization. If other benefits from stabilization occur, the decision becomes more apparent. Reference [5-104] cites the advantages of roll stabilization for TYPHON ships; namely a reduction in the number of antenna elements with a consequent reduction in weight and cost. While reference [5-105] considers the advantages offset by disadvantages and does not recommend roll stabilization solely for TYPHON, a ship equipped with both TYPHON and the SQS-26 sonar would present a different picture since stabilization would benefit to some degree.

"In view of the lack of sufficient quantitative data on roll stabilization, a policy decision is not considered desirable at the present time. It is recommended that a policy decision be delayed until the DE 1037 has been evaluated full scale and a comparision between fin and tank systems fully analyzed."

These discussions and memoranda closed the issue of roll stabilization consideration for other ships than DE's for about 5 years.

In 1964, model tests were performed on the DE 1052 with a pair of 75 square foot fins sized for the ship and an alternate pair of 136 square foot fins. The control system was only sensitive to roll angle and velocity and not to acceleration. Nevertheless, very good results were obtained as summarized in the DTMB report [5-99] which was issued a few years later:
"The size of the fins designed for the DE 1052 appears to be adequate. The amount of stabilization realized during the model tests was about the same as that measured on full-scale installations, for example, on the GFATT (DDG 712); in certain heading conditions, the larger fins tested on the model increased the roll stabilization slightly, but the improvement is probably not sufficient to justify the greater cost of equipping the ship with larger fins."

In April 1965, the Bureau requested DTMB to participate in the DE 1044 anti-roll stabilizer performance evaluation. The fin's projected area was 32 square feet with a span of 8 feet, a chord of 4 feet, and an aspect ratio of two. The roll trials were conducted in January 1967.

The fin stabilizer effectiveness for various ship speeds was determined by forced rolling the ship near its natural roll period. After a steady roll oscillation was obtained, the fins first were returned to their zero angle and the time that it took for the roll amplitude to subside to 5 percent of its initial value was measured. The same experiment was performed again except that the fins were kept activated to hasten the roll damping. The time required to reduce the roll amplitude to 5 percent of the initial value was measured. The ratio of the times which it took to reduce the roll to 5 percent of the initial roll angle with and without stabilizers, when compared with similar results for the DE 1037, showed satisfactory performance, but not as good as that of the DE 1037.

This does not appear to have been a very conclusive test since the ability of the stabilizer's control system to phase the response was
not tested, and the capability of performing functions like landing helicopters or moving large objects on deck or general crew effectiveness was not tested.

The AGDE 1 (USS CLOVER) was chosen to perform those tests. This ship had identical fins to the DE 1040 class. The request to perform these studies came from the fin stabilizer equipment organization in the Naval Ship Engineering Center and was accomplished by the Annapolis Division of the David Taylor Naval Ship Research and Development Center.

The focal point of that study was: Is human performance significantly affected by ship roll?

The results of the study show that motivation to perform tasks goes down and roll caused accidents go up substantially as a function of roll (see Figure 5-14 [5-100]).

The data recorded was: falls, stumbling, mistakes in judgment, spilling or dropping materials, difficulty in handling tools which resulted in damage or injury, and mechanical mishaps which resulted from failure to anticipate the effects of roll. The motivational measures were based on an arbitrary scale developed by social scientists, but not developed especially for the study. The report concluded that human performance is clearly affected by roll and recommended that roll stabilization equipment be installed on any ship which is expected to roll above 10 degrees.
FIGURE 5-14 ROLL-CAUSED INCIDENTS AND MOTIVATION INDEX AS A FUNCTION OF SHIP'S ROLL

SOURCE: REF [5-100]
In 1967, a new DDG design was initiated. This destroyer (designated FY 67 DDG) was envisioned as displacing about 6700 tons. The new ship would be larger than the DE 1052. During the establishment of early ship characteristics, the issue of roll stabilization was raised, and accepted as a candidate for the eventual Approved Ship Characteristics. This initiated the design of alternative fin configurations. In May of that year, NAVSEC requested that the Model Basin conduct tests with a 20 foot model on two alternative stabilizer configurations. One configuration had two pairs of fins each with 75 square feet. The second configuration had twice the area but only one pair of fins.

The results of the experiments summarized in Table 5-9 show that there is no significant difference in performance between the two configurations tested. Therefore, the selection decision would have to be made on considerations such as cost, space, weight and anticipated operational problems. The FY 67 DDG never materialized because Congress never authorized the SCN funds, and instead authorized the building of a nuclear design. The next non-nuclear destroyer design was procured under the Total Package Procurement approach, a new DOD policy of the mid-1960's.

Using this approach, three contractors in competition for the design and production contracts were given Contract Definition performance requirements for the requested design. Because of the competition, the contractors were not allowed direct access to the vast data base of the Bureau of Ships (renamed the Naval Sea Systems Command) other than by the direct knowledge of the facts by those individuals who manned the three
<table>
<thead>
<tr>
<th>Ship Speed In Knots</th>
<th>Unstabilized Roll In Degrees</th>
<th>Stabilized Roll In Degrees</th>
<th>Percent Reduction In Significant Roll Obtained Using Stabilization</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Two Pairs of Small Fins</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>8.0</td>
<td>5.8</td>
<td>27.8</td>
</tr>
<tr>
<td>20</td>
<td>10.3</td>
<td>3.2</td>
<td>69.3</td>
</tr>
<tr>
<td></td>
<td>One Pair of Large Fins</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>8.8</td>
<td>5.7</td>
<td>35.1</td>
</tr>
<tr>
<td>20</td>
<td>9.9</td>
<td>2.6</td>
<td>73.4</td>
</tr>
</tbody>
</table>

* Significant Single Amplitude (Vertical to One Side) Motion. Sea State 6, Beam Seas.
competing teams. Certain documents were provided by the Navy in support of the design trade-offs and specific documents were available upon request from the Navy's project office. However, much of the facts described in this case study were only available in the historical files of the Navy and in a fragmented fashion in the minds of individuals who were with the Bureau for many years. Thus, for all practical purposes most of the facts were not readily available for the contractors. Thus, each contractor was forced to develop its own rationale without the benefit of much of the past experience of the Navy in roll stabilization. Litton Industries, the successful contractor for the DD 963 decided that the ship did require a roll stabilization system, based on the wording of the requirements given to each contractor, i.e., that the ship should be able to perform continuous efficient operations in Sea State 6. Litton chose passive tanks. It is doubtful that Litton would have made that particular choice had the information presented in this study been available to the contractors.

Litton initiated a roll stabilization study during the early design phase in 1968 to determine:

A. The degree of stabilization necessary to meet the performance requirements.

B. The type of system which would best provide the required degree of stabilization.
C. The parameters of the selected system.

D. The roll response of the ship with the selected stabilization system installed.

By examining the sensitivity of the critical ship subsystems, relations between each subsystem effectiveness and roll angle were developed. A summary of the findings is given in Figure 5-15.

To form a basis for selection of the optimum type and size roll stabilization system, a study was conducted to examine the roll response of the DD 963 class design with seven types of stabilizing systems in a range of sizes. Gyroscopic and moving weight stabilizers were considered but not included in the study because they were determined to be inapplicable on the basis of their essential features. The seven stabilizer types considered were:

A. Passive anti-roll tanks of various configurations
B. Bilge keels
C. Combination system bilge keels and passive tanks
D. Active fins
E. Controlled passive tank
F. Combination system of active fin and passive tank
G. Active tanks.
*A, B, C, D, E, F, G, H, I, J, K, L, M are different subsystems on the ship which are influenced in their effectiveness by roll. They are left unspecified here to avoid classification.

Source: REF 5-101

Figure 5-15 Subsystem effectiveness as a function of roll amplitude
It was determined that helicopter landing in a high sea state required a landing assist system because none of the stabilizing schemes would reduce roll to the degree required for an unassisted landing in the high sea state. Therefore, the selection of the stabilizer was made on the basis of which of the critical subsystems would benefit from it. These subsystems were F, I and H of Figure 5-15.

Table 5-10 shows some of the subsystems effectiveness as a function of the stabilization options which were examined along with a ranking of each candidate stabilization system's reliability, vulnerability and noise. The evaluation of these latter aspects was qualitative since data on such features as noise and reliability were not available. A typical statement indicating the very poor data base is the discussion relating to the importance of noise in the selection of the appropriate roll stabilizer [5-101]:

"Noise characteristics of internal stabilization systems are less critical than are those of the external stabilizers. However, noise emissions from all types of stabilizers are minor and should have little effect upon the choice of roll stabilization system."

The Navy imposed life-cycle cost as a criterion for subsystem trade-offs during the DD 963 design and the Navy could only give so called negative guidance. This meant that if the Navy saw something it didn't like during one of the periodic reviews of the contractors or if it felt the contractor could use more data or guidance, the Navy could not provide it unless it was requested.
TABLE 5-10  COST-EFFECTIVENESS STUDY OF THE SHIP WITH A BEARTRAP HELICOPTER LANDING ASSIST SYSTEM AND VARIOUS ROLL STABILIZATION SYSTEMS

I. EFFECTIVENESS

<table>
<thead>
<tr>
<th>Effectiveness Indices</th>
<th>Rank Index (1 is best)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F Subsystem</td>
</tr>
<tr>
<td>Bilge Keels</td>
<td>0.83</td>
</tr>
<tr>
<td>Passive Tank</td>
<td>0.90</td>
</tr>
<tr>
<td>Passive Tank + Bilge Keels</td>
<td>0.95</td>
</tr>
<tr>
<td>Controlled Tank</td>
<td>0.98</td>
</tr>
<tr>
<td>Small Fins + Passive Tank</td>
<td>0.96</td>
</tr>
<tr>
<td>Medium Fins</td>
<td>0.95</td>
</tr>
<tr>
<td>Medium Fins + Passive Tank</td>
<td>0.98</td>
</tr>
<tr>
<td>Large Fins</td>
<td>0.98</td>
</tr>
</tbody>
</table>

II. COST

<table>
<thead>
<tr>
<th>Added Weight</th>
<th>Intern. Vol. Required</th>
<th>Added Required</th>
<th>Development Cost - $</th>
<th>Purchasing Cost - $</th>
<th>Installation Cost - $</th>
<th>Maintenance/Yr. Cost - $</th>
<th>Helicopter Houldown Cost - $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bilge Keels</td>
<td>50</td>
<td>0</td>
<td>60-700</td>
<td>Neglig.</td>
<td>-</td>
<td>5,000</td>
<td>1,000</td>
</tr>
<tr>
<td>Passive Tank</td>
<td>200</td>
<td>18,600</td>
<td>0</td>
<td>40,000</td>
<td>-</td>
<td>4,000</td>
<td>Neglig.</td>
</tr>
<tr>
<td>Passive Tank + Bilge Keels</td>
<td>250</td>
<td>18,600</td>
<td>60-700</td>
<td>40,000</td>
<td>-</td>
<td>9,000</td>
<td>1,000</td>
</tr>
<tr>
<td>Controlled Tank</td>
<td>200</td>
<td>26,900</td>
<td>15</td>
<td>90,000</td>
<td>45,000</td>
<td>Un</td>
<td>Un</td>
</tr>
<tr>
<td>Small Fins - Passive Tank</td>
<td>230</td>
<td>18,000</td>
<td>30 + Fin Drag</td>
<td>60,000</td>
<td>100,000</td>
<td>Un</td>
<td>Un</td>
</tr>
<tr>
<td>Medium Fins</td>
<td>65</td>
<td>1,100</td>
<td>65 + Fin Drag</td>
<td>210,000</td>
<td>Un</td>
<td>Un</td>
<td>Un</td>
</tr>
<tr>
<td>Medium Fins + Passive Tank</td>
<td>265</td>
<td>20,000</td>
<td>65 + Fin Drag</td>
<td>270,000</td>
<td>Un</td>
<td>Un</td>
<td>Un</td>
</tr>
<tr>
<td>Large Fins</td>
<td>150</td>
<td>2,800</td>
<td>150 + Fin Drag</td>
<td>350,000</td>
<td>Un</td>
<td>Un</td>
<td>Un</td>
</tr>
</tbody>
</table>

UN = Unknown

NOTE: Beartrap effectiveness assumed to be 100 percent for all stabilizer systems.

SOURCE REF (5-101)
The naivete' with which Litton selected the most suitable stabilization system is indicated by reasons given for the choice [5-109]:

"A. Bilge keels are included because of their low cost-effectiveness ratio and attendant safety factor offered in case of internal passive system failure.

B. Internal stabilizers are less vulnerable to damage.

C. Passive stabilizers have superior reliability.

D. Life-cycle costs of passive stabilizers are considerably less than the cost of an active or controlled stabilizer.

E. The pure passive tank is more fully developed than the controlled passive tank, in addition to having a lower acquisition cost.

F. The small passive tank meets all given and derived requirements for reducing roll amplitude."

One fact is certain: The contractor was not aware of the almost 100-year history of roll stabilization system development which preceded the DD 963 design and is summarized here. The blame can not be put on Litton alone since much of this history has only been available in the heads of a few people who lived with the decisions the Navy made within the preceding 20-30 years. Even within the Navy, most people outside a very small number of people whose specialty is roll stabilization are not aware of the history relating to the pertinent facts of roll stabilization. The Navy instructed Litton to take out the passive tank after the contract award, but, economic and political considerations prevented the Navy from dictating the use of fin stabilizers which the NAVSEC engineers felt were desirable for the DD 963 [5-102].
5.9 Revival of Interest But Instead of Adoption — Regression

During 1972, a number of complaints came in from the Fleet criticizing the poor seakeeping performance of U.S. destroyers compared with their Soviet counterparts. These observations generated a great deal of interest at the Naval Material Command in Washington. An explanation was requested from the Naval Ship Engineering Center (NAVSEC).

As a result of this inquiry, a task was initiated to study comparative seakeeping features of U.S. and USSR destroyers. Among other features, the study disclosed that roll stabilization fins are a standard design practice in USSR destroyers. The study created considerable stir among those groups whose specialty is seakeeping, culminating in a workshop on seakeeping, mentioned at the outset of this study. Endorsements of a comprehensive seakeeping R&D program were quick to come from the design as well as the laboratory communities. Typical of the endorsements was a recent letter from COMNAVSEC to the Engineering Directorate in the Naval Sea Systems Command [5-103]:

"It becomes apparent after reviewing the requirement documents that the extent to which seakeeping performance is considered in the ship design process is still in its infancy. The ship design community is becoming more knowledgable in dealing with ship/sea interactions but is far from fully utilizing the existing seakeeping technology. Therefore, the primary objective of the program, identified in reference [5-3], is to provide the ship designer with analytical techniques, experimental methods and design criteria performance in the ship design process."
While the preceding is true, what should be patently clear from this case study is that being able to improve the roll prediction capability, by model test or computer programs, by 5, 10, or 20 percent is completely divorced from the fact of whether U.S. Navy destroyers will have fin stabilizers.

In order to substantiate the latter point, let us look briefly at what happened to the two destroyers which were designed during this era of concern about U.S. destroyer's poor performance vis-à-vis the Soviets.

The early stage feasibility studies were initiated for a new destroyer, the PF 109 (later FFG-7), in early 1971. This destroyer design was started in 1971 when the new administration had reached the point of making substantive changes to DOD procedures and policies. As part of the new policy, the concept of "Design to Cost" was born and the PF was the first warship design to have to abide by the new rules.

During the preliminary and contract design phases of the PF, a very detailed roll stabilization study was performed. These studies cost a great deal and unnecessarily went back to ground zero and examined all possible stabilization means even though it is quite obvious (or at least it should be from this case study) that only fins ought to be considered seriously for a 3,500 ton destroyer. According to the initial study report [5-104]:

463
"Based on the preliminary examination of the roll performance of the PF with various roll stabilization system installed, four most promising systems were selected for more detailed study. These systems were:

Bilge Keels
U-tanks low in the ship, plus Bilge Keels
Free surface tank low in the ship, plus Bilge Keels
Active Fins, plus Bilge Keels."

To determine the critical roll angles, a study similar to that for the DD 963 was made of the effect of rolling motions on mission-essential equipment and shipboard operations. From that study, it was deduced that certain operations would suffer degradation when roll angles exceeded 15 degrees. In addition, it was evident that roll angles as small as 5 or 6 degrees could be troublesome for handling of missiles and torpedoes on deck.

It was decided to evaluate roll stabilization system effectiveness in terms of the probability of not exceeding specified roll angles. For the cases where a 15-degree roll was considered to be critical, system effectiveness was evaluated in terms of the probability of not exceeding significant and maximum roll angles of 15 degrees. This was done using random headings at speeds distributed in accordance with an assumed speed/time profile for a destroyer. For the cases where 5-degree roll angles were critical, it was assumed that the ship would normally be free to choose an optimum heading.
The comparative performance of the several roll stabilization systems were shown as plots of effectiveness versus system type (for some of the conditions examined). These plots are shown in Figure 5-16. The probability of not exceeding 10 degrees significant roll, averaged over all headings and in a North Atlantic distribution of sea states, was viewed as a crew comfort or "crew operability" index. The two curves of the probability of not exceeding a 5-degree maximum roll angle are pertinent to the PF operational requirements for replenishment at sea and helicopter operational capability.

Cost estimates were also obtained. The passive anti-roll and total follow ship acquisition cost was delta $70,000. Active fins of 49 square feet per fin cost $300,000 on the same basis. Based on this data, the engineers at NAVSEC concluded [5-105]:

"A. The relatively small increase in ship performance in S.S. 5 of fins over tanks and bilge keels does not appear to justify the high cost of a fin stabilization system.

"B. The increase in performance of the tanks over the bilge keels at the optimum heading in a Sea State 5 does not appear to justify the cost in space and dollars."

Accordingly, it was recommended that bilge keels be selected for the PF roll stabilization system.
**Figure 5-16** COMPARATIVE EFFECTIVENESS OF PF STABILIZATION SYSTEMS
These conclusions were reached on 25 April 1972. At that time, the official requirements issued by OPNAV stated that the ship had to be able to perform its functions without degradation at a relatively low Sea State. The SHAPM's decision was that fins were not required.

The Sea State requirement subsequently was modified to a higher Sea State. As a result, further studies were made and a number of different types of fins were evaluated for the destroyer. In this higher Sea State, roll was shown to be reduced significantly even by the smallest set of fins analyzed, as shown on Figure 5-17. By the time the Approved Characteristics of OPNAV were issued in October 1972, they called for "a space only" reservation for fins. Dedicated space was not provided, but "convertible" space was provided in the form of tanks which, whenever necessary, could be converted into the required compartment. That is the way the contract design left NAVSEC in April 1973. Shortly thereafter, Captain Kehoe began to publicize the benefits of fins within the Navy community. Also in the spring of 1974, the Australians decided to purchase three PF's and stated that they wanted fins in their ships. One of the members of Captain Kehoe's party visiting the Fleet, discussed at the outset of this case study, was a close friend of the Chairman of the Ship Characteristic's Board and he strongly suggested that the Chairman consider fin stabilization for the PF. Shortly thereafter, the SHAPM got indications from the OPNAV Characteristics Board Chairman that the follow ships would probably get fins and that the Board intended to change the "space only" requirement to a space and weight reservation for fins. NAVSEC was tasked to do
FIGURE 5-17  ROLL RESPONSE AS A FUNCTION OF ROLL STABILIZED FIN SIZE
IN SEA STATE 6 FOR THE PF 109

SOURCE: REF [5-111]
a study for this change. The study was used by the SHAPM to task Bath Iron Works (the shipbuilder) to include a space and weight reservation for fins in the PF design. The study was also used to initiate the incorporation of fins into the Australian PF's.

The study indicated that, with fins, varying in aspect ratio from 1.1 to 2.3, a 16 to 25 percent reduction in roll would be achieved even at the low speed of 5 knots in comparison with the roll amplitude of the ship fitted with bilge keels only. It was estimated that a 55 to 70 percent reduction in roll could be realized near the ship's top speed.

Based on that study, it was estimated that, for the PF, one pair of activated fin stabilizers with 65 square feet of projected area per side would provide adequate stabilization over a range of sea conditions and ship speeds. It was noted that the selection of stabilizer size took into account performance, cost, weight, space, and power requirements.

A specific fin geometry was to be selected from the aspect ratio range of 1.1 to 2.3 and fin area range of 50 to 65 square feet whenever the fins were to be installed.

More than a year later, in November 1975, operational problems were experienced by the Fleet during an exercise in a higher Sea State off the Eastern Coast of Canada, which prompted the CNO to request, that the
Naval Sea System Command again investigate the effectiveness of fin stabilizers for the FFG-7 [5-106]. In January 1976, the NAVSEC recommendation to the SHAPM was to install fin stabilizers [5-107]:

"It is emphasized that in addition to extending helo operations, fin stabilizers provide continuous benefits by significantly increasing the mission effectiveness in other important areas, such as UNREP, refueling at sea, missile/ammunition handling, equipment maintenance and personnel performance. Therefore, it is reiterated that fin stabilizers should be installed on FFG-7 regardless of the decision concerning the RAST System (a helo hauldown and traversing system)."

No decision was made.

In the summer of 1976, the SHAPM became interested in investigating the procurement of fin stabilizers for the FY 78 shipbuilding buy of FFG-7's. The Naval Ship Engineering Center developed several alternative procurement options by late 1976. As the budget submission exercises for FY 78 reached a mature stage, the stabilizers were deleted again. This pushed the first opportunity for a FFG-7 with stabilizers to the FY 79 buy, by which time almost half of the planned class would be procured.

In 1973, another destroyer (the DG) entered the early stage design phase. This destroyer design also constrained by the "Design to Cost" concept was to carry the Navy's newest surface warship weapon system, the AEGIS. The size of the ship was limited to 6,000 tons at the outset and was budgeted at 100 million dollars.
The Chairman of the Ship Characteristics Board was so intent on developing the ship within the cost constraint that he demanded that every feasible dollar be squeezed out of the design. The studies listed in Table 5-11 are indicative of the cost conscious environment at the time. For example, Table 5-11 shows, the level of detail of the very early stages of design, e.g., worrying whether there would be a barber shop or even a barber onboard. Under these circumstances, it is quite obvious that active roll stabilizer equipment would be highly scrutinized.

NAVSEC completed a study [5-108] on roll stabilization of the ship and evaluated single pairs of fins with areas of 40, 50, 60, and 70 square feet as well as two pair of fins with areas of 50, 60, and 70 square feet.

Fortunately, by the time of the DG study, the recent experiences of the engineering group indicated that only fins ought to be considered. Thus, the study was limited to the fin configurations mentioned.

The general approach taken to the study was similar to that taken in the DD 963 and PF roll stabilization studies previously described. NSRDC (old David Taylor Model Basin) was tasked to predict rolling motions of the unstabilized and the stabilized ship. Hydronautics Incorporated was tasked to investigate roll stabilization effectiveness. As part of the task, the various NAVSEC engineers cognizant over specific critical subsystems were interviewed. NSRDC concluded, on the basis of this analysis, [5-109]:

"A stabilization system is believed necessary for the DG AEGIS to carry out helicopter operations in higher Sea States."
<table>
<thead>
<tr>
<th>SHIPS</th>
<th>CONFIGURATION = 93</th>
<th>AUSTERE LITTLE OR NO RISK</th>
<th>EXTREMELY AUSTERE LITTLE OR NO RISK</th>
<th>EXTREMELY AUSTERE LOW RISK</th>
<th>EXTREMELY AUSTERE MEDIUM RISK</th>
<th>EXTREMELY AUSTERE HIGH RISK</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NONE OF THESE FEATURES INCLUDED IN THE BASELINE CONFIGURATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Hydronautics Inc. completed its analysis and reported in two separate reports in March 1974 [5-110] and July 1974 [5-111].

A comparison of the effectiveness of the three different sizes of fins considered is shown in Figure 5-18 of [5-111].

The report drew the obvious conclusions from Figure 5-18, i.e., that there is a lot to be gained by installing a 50 square foot set of fins and that it pays to go even as high as 70 square foot fins.

Figure 5-19 of [5-111] showing one of the figures from Capt. Kehoe's paper, indicates the relative standing of the DG AEGIS stabilized and unstabilized. NAVSEC, using the results of the Hydronautics studies, assessed the impact of adding fins to the ship with respect to weight, space, and cost [5-110]:

"The following information is based on the installation of the DE 1052 (75 square feet) type fins in the engine room at Station 11. Approximately 2,400 cubed feet of volume for a working envelope would be required. This appears feasible within the existing engine room envelope if the machinery arrangements were tightened up further. The 150 kW connected load could be absorbed by the current electric plant but would cut into the electric load margin. The estimated weight effects would be 30 tons for the light ship increase and 14 tons of fuel oil for the increased resistance in calm water. It should be emphasized that in calm water conditions (which is how endurance fuel is calculated), there is an increase in drag but in reality the decrease of ship motion in waves with the installation of fins would actually
Figure 5-18 Comparison of Stabilized Ship and Unstabilized Ship Effectiveness during a Lengthy North Atlantic Mission

Note: Effectiveness is defined as one (1) minus the probability of exceedence of a limiting roll angle.

Limiting Roll Angle, Degrees (expressed as the average of the 1/3 highest vertical-to-out roll angle)

Source: Ref (5-112)
FIGURE 5-19 COMPARATIVE ANNUAL AVERAGE MAXIMUM SPEED FOR DESTROYER-TYPE SHIPS
decrease the ship resistance and allow a slight increase in overall speed profile. In calm seas and at sustained speed, however, the ship speed would be reduced about 0.1 knot. A rough estimate of the cost for the DE type fins would be $225K acquisition cost plus $75K for installation."

The ship design manager received the following recommendation from the Hull Division [5-108]:

"Based on the valuation of the improvements in ship performance with the fin stabilizers, it is highly desirable to include fin stabilizers in the DG design.

"The SHAPM should be requested to change the design-to-requirements and incorporate the fin stabilization system into the DG. The analysis and rationale used in this report are sufficiently quantifiable to show very tangible improvements in the operational flexibility of the DG. During Contract Design, additional studies could be made to determine the exact size of fins which are required."

Being well aware of the "Design to Cost" concept which prevailed, the recommendations were structured to anticipate the reaction of the OPNAV sponsor [5-112]:

"If current cost and weight constraints preclude installation during new construction, a space, weight and power reservation should be included so that the addition of a fin stabilization system during modernization would be a minimum impact."
The Ship Design Manager decided that the weight and cost impact was too high and that, if the ship were allowed to choose the optimum heading in Sea State 5, the roll stabilizer would not reduce roll that significantly and helo operations could take place without stabilization. In the summary of the meeting the Design Manager held to review the Hull Division recommendations, he concluded as follows [5-112]:

"The DG project office concurred that an active fin system would be highly beneficial to the DG but believed that it should not be considered essential to the ship's primary mission. ASW is a secondary mission of the DG and one that can be accomplished, albeit with limited flexibility, without a roll stabilization system. The recommendation that an active fin system be specified for the DG was therefore not accepted for implementation because of the adverse weight and cost impacts on the ship. However, the DG project office has made a recommendation to PMS 378 that the present weight and cost constraints on the design be relaxed to permit the addition of an active fin system and thereby obtain the benefits referred to above."

Of course, these conclusions side step the many other reasons for which roll stabilization is useful and also minimize the extent to which, in a real tactical situation, the ship can choose an optimum heading with respect to the waves when helo operations dictate it.

Before the issue could be settled by the SHAPM one way or another, Congress passed House Bill No. 14572 which became law in August 1974 and which killed the DG AEGIS ship. Section 801 of the bill reads as follows [5-113]:
"It is the policy of the United States of America to modernize the strike forces of the U.S. Navy by the construction of nuclear powered major combatant vessels and to provide for an adequate industrial base for the research, development design construction operation and maintenance of such vessels. New construction of major combatant vessels for the strike forces of the United States Navy authorized subsequent to the date this act becomes law, shall be nuclear powered, except as provided hereafter."

Thus the design of a non-nuclear ship intended to be part of the strike forces was stopped.

The ship which was born as a result of the restriction of the above law, was a much larger ship (approximately 18,000 tons) for which preliminary design was started in early 1976. Therefore, even though there are plans to initiate a study for roll stabilization, the study is not yet underway. Of course, the whole issue of whether such a large ship would require roll stabilization in view of the fact that much smaller ones do not have any, will most likely work against adoption of roll stabilization on the strike cruiser (CSGN).

The pessimistic predicted outcome is offered in spite of the fact, that for example, the British believe in installing roll stabilizer fins not only on their destroyers but also on their larger ships. The CUMBERLAND in the early fifties received fin stabilizers (10,000 tons displacement) and their newest so-called Thru-Deck-Cruiser of about 19,000 tons displacement, currently under construction, has fin roll stabilizers.
Early in November 1975, the Hull Division in NAVSEC was tasked by the DD 963 project office at NAVSEA to review a report submitted by Litton Industries titled "Performance in a Seaway Verification Report for the DD 963". During the review process, the Hull Division expressed its concern about the capability of the DD 963 to meet the new 5-degree roll criterion, (set by NAVSEC as a result of joint studies among NAVSEC, NAVAIR and NSRDC, and influenced by the Royal Navy's criterion), even though the ship met its contractual specifications in this area which was that the ship be able to execute continuous, efficient operations in a certain high Sea State.

The 5-degree roll criterion was based on:

A. Helo handling
B. Helo operations
C. Personnel effectiveness

As a culmination of the review, NAVSEC made a presentation to the SHAPM in which it was proposed that a pair of 90 square foot fins be backfitted into the DD 963.

A table which was a part of the presentation, showed a significant predicted reduction of roll resulting from the proposed fin installation. It was estimated that the penalty for installing the fins would be:

A. 0.1 knot at endurance speed
B. 135 KW power required
C. $250 - $300K acquisition cost
D. $100 - $500K installation cost (backfit)
E. 120 miles endurance loss
F. Minimal impact on other systems if fitted in existing tank space.

The presentation was received with interest and significant discussion took place after the presentation, addressing the areas of acquisition and installation cost rationale for the installation of fins in previous U.S. Navy ship [5-114]. The SHAPM said that, in his opinion the DD 963 rolled more like a CG and could not be compared in motions to a destroyer. He also said that since the rolling criterion, which had been set early in the DD 963 design, had been met, there is no need to apply a more rigid criterion, since the criterion could change every few years and that, if a ship were stabilized to meet the new criterion, perhaps in five years or so, a more strict criterion would be set which the ship would not meet.

The cost figures quoted during the presentation were challenged. The cost estimate for the acquisition and installation into the ship of one pair of fins (about 60 square feet in area) for two FFG-7's was $700,000 (or $350,000 per pair). A maximum figure of $350,000 was quoted, per pair of fins, for the DD 963. NAVSEC stated that the lead stabilizer costs would be spread over about 30 ship sets, which accounted for the lower figure. It was agreed that the costs quoted during the presentation
were estimates, based on FF 1052 costs and would have to be treated as such. It was pointed out that monies required for backfitting fins on the DD 963 class would be about $15,000,000.

The SHAPM vetoed the proposal to backfit the DD 963 class ships with fin stabilizers. Support to additional studies was not indicated. This ended the issue of roll stabilizers for the DD 963.

Early in 1976, a new destroyer design, the DDG 47 (approximately 9,000 tons displacement) was in the preliminary design stage. This ship was to carry the AEGIS weapon system, and a study for roll stabilization was conducted for the ship [5-115].

This study also addressed the issue of noise generated by the fins that could impact operation of the sonar as well as affect the radiated noise signature of the ship. Several fin sizes were evaluated. Some findings of the report were [5-115]:

"DDG 47 stabilized against roll only by bilge keels will not meet the TLR roll requirement of [a] significant roll angle [in a high Sea State], at worst heading based on helicopter operations.

"The above TLR criterion would be satisfied for DDG 47 by installation of one pair of fins approximately 60 square feet in platform areas per fin. One pair of 90 square foot active fins would stabilize the ship for helicopter operations through [an even higher Sea State].

"The arrangement impact on DDG 47 of the active fin installation is insignificant.
"The speed impact of active fins due to the resistance increase is negligible.

"Ship with active fins will be capable of developing higher speeds in Sea State 4 and above.

"The weight impact of the 90 square foot fin installation is:

Light ship .......... +40 tons
Full load .......... +57 tons

(depending on whether the lost tank volume will be compensated for or not).

"Electric power impact ........ +150 KW.

"The cost impact by fins is:

$250-300K Acquisition
$100-150K Installation

"Endurance impact 0 or -180 nautical miles
(depending on whether the lost tank volume will be compensated for or not)."

As a result of the study, the Hull Division recommended that one pair of 90 square foot active fins be installed on DDG 47 and that the bilge keels aft of the active fins be eliminated.

The Ship Acquisition Manager turned down the recommendation of the Hull Division on the basis that the DDG 47 was a derivative of the DD 963 and, as such, the same reasons that applied to the refusal to backfit the DD 963 applied to the DDG 47 as well.

These events present the current (1977) status of the adoption of roll stabilization in destroyers in the U.S. Navy.
Unfortunately, the proliferation of the many different manufacturers who supplied the fins for those ships which have the fins installed, see Table 5-12, together with the inability to dedicate one ship to test, evaluate and completely "debug" one standard nonretractable fin with its controls, has created a maintenance problem in the Fleet.

The stabilizer fins in the Fleet have experienced continuing operational problems in all the ships in which they are installed. The problems stem from a number of factors such as:

A. Bad location relative to access for maintenance
B. Insufficient attention to protecting vital parts of the system against damage caused by other equipments which are in the vicinity, such as dripping water from a distilling plant
C. Proliferation of three different manufacturer's equipments with variations even within one manufacturer's equipment, negating the experience of a sailor who learns to maintain one type of stabilizer and, when he joins another ship of the same class, finds a different type stabilizer
D. Poor maintenance practices
E. Lack of adequate monetary allocation for maintenance
F. Lack of extended Operational Test and Evaluation in order to discover the bugs in the system and its environment and to correct them once and for all.
<table>
<thead>
<tr>
<th>STABILIZER*</th>
<th>CLASS</th>
<th>SUBTOTAL</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>DE-1037</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>L2</td>
<td>DE-1040</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>DEG-1</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AGDE-1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>DE-1040</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>DEG-1</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>DE-1040</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>L3</td>
<td>DE-1052</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>S2</td>
<td>DE-1052</td>
<td>7</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>DE-1078</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>

* L: Lidgerwood
CV: Canadian Vickers (Licensee of Brown Bros.)
S: Sperry Marine Systems
1,2,3 - Different sizes and/or control systems
These fundamental problems have caused major breakdowns such as that reported, for example, on the DE 1038 in January 1970 [5-116].

"The stabilizer system was inspected and the following conditions noted:

"(1) The shafts, cylinders, cross heads, rods, piping and all the lower portions of the port and starboard units were in poor material condition due to rusting and flaking caused by excessive seawater leakage at the shaft glands.

"(2) The port unit pump, motor, hydraulic relay unit (HRU), control linkage and electrical cables were also in a state of deterioration due to rust and corrosion. This condition was caused by salt water leaking directly above the port unit. A drip pan presently installed to prevent this from occurring does not adequately protect the unit.

"(3) The starboard drain and fill pump had been removed because of a motor failure. The fill and drain piping and valving are also in very poor material condition.

"(4) There was no visual evidence of water content in the hydraulic fluid and the system fluid did not appear to have a high particulate content.

"(5) The gyro unit had accumulations of rust on internal components: magneties, gear trains and connecting linkages. It was apparent that the gyro cover gasket had allowed moisture to enter the gyro unit.

"(6) The port and starboard HRU access covers were removed and some internal corrosion was present."
The conclusions of the engineers making the DE 1038 inspection were that:

"A. The extreme rusting conditions were caused by the excessive sea water leakage at the shaft gland and the failure of the distilling plant drip pan to collect the drains.

"B. The fill and drain pumps and their associated piping had also been exposed to sea water spraying from the shaft gland.

"C. The pink color of the moisture indicators in the gyro unit is a positive indication of the presence of moisture."

Therefore, the engineers recommended that, in order to insure operational reliability between regular overhauls, a complete system overhaul be accomplished during the next overhaul of the ship which was supposed to be imminent at that time.

In May of that year, engineers from NAVSEC Philadelphia Division visited the DE 1038 and assisted in some repairs of the starboard stabilizer. To improve the performance of the hydraulic relay units, new filter elements were provided and the dirt which had accumulated between a valve spool and its sleeve was cleaned, thus eliminating the problem of the low pressure reducing valve sticking.

In February 1971, the results of another inspection yielded the following findings [5-117]:

486
"Both stabilizer fin shafts have deteriorated to the point where the packing no longer is effective in controlling shaft leakage. Salt water spraying into the ship has damaged adjacent areas including fin shafts, hydraulic rams and the fill and drain pumps and motors. In addition, the port unit machinery package has suffered considerable damage from the evaporator located directly overhead. On this unit the hydraulic lines, linkages and other exposed surfaces are heavily corroded."

Among the many recommendations for repair and replacement of parts, made at that time, the following stands out:

"Repair or replace hydraulic rams. Because of the much more hostile atmosphere in the Fire Room where the stabilizers on DE 1037 and DE 1038 are located, consideration should be given to use of a corrosion resistant material for the rams on these ships."

Three years later, in May 1974, another trip was made by NAVSEC Philadelphia Division personnel to the DE 1038 in order to define work to be done on the stabilizers during the ship's upcoming overhaul. The survey reported that additional deterioration of the stabilization system was evident [5-118].

As a result, the report's recommendation was not a surprise:

"Because of the poor material condition of the stabilizer units and the amount of work required to restore them, it is recommended that the cost of repair be evaluated against the cost of new stabilizer units. If complete replacement is undertaken,
the feasibility of relocating the stabilizer units from the fire room to the engine room should be investigated."

This deteriorated situation on DE 1038 existed in spite of the fact that, in 1968, a complete new unit was installed to replace the original 1962 installation, which had corroded and was beyond economical repair. The NAVSEA Ships Logistic Manager who is allocated an amount to maintain his ships, found that an excessive portion was being used for the stabilizer. In February 1975, he turned again to NAVSEC to evaluate the DE 1038 fin stabilizer.

NAVSEC evaluated the condition of the fin units along with the spare parts and repair parts availability in depots. An excerpt from the memo sent back to the Ship Logistic Manager says it all [5-119]:

"The fin stabilizers on the McCLOY (DE 1038) are located in the fire room and are subjected to severe environmental conditions. The humidity level is excessively high, and salt water from the distilling plant drips onto the port stabilizer. A drip pan presently installed to protect the stabilizer from the distilling plant is ineffective.

"It is recommended that NAVSEC be tasked to coordinate and direct a shipyard effort to improve the stabilizer environment on McCLOY. Either one of the following two approaches could be considered:

"A. Provide ventilated drip-proof enclosures for both the port and starboard units and locate the Gyro Unit, the Master Hydraulic Relay Unit and the Transmitter Box in one of these stabilizer compartments."
"B. Relocate the stabilizer units in the Engine Room and relocate interfering equipment as required. Provide foundations, electrical power, control wiring and cooling water connections.

"If funds are not available to adequately improve the stabilizer environment on McCLOY, then it is recommended that the stabilizers be removed, the hull openings blanked off, and the entire stabilizer system shipped to SPCC for cannibalization. The units cannot be adequately maintained in the present environment."

The decision was to remove the fins and the work was completed in 1975.

The situation in the DE 1038's sister ship (DE 1037), the first U.S. Navy ship to receive nonretractable fin stabilizers as a new ship at the time of its design, was as bad as that described for the DE 1038.

In view of the badly deteriorated condition of the fin stabilizer machinery and controls in the DE 1037, the Commander, Naval Sea Systems Command suggested the complete removal of the DE 1037 roll stabilization system also.

A year earlier, in February 1975, NAVSEC had proposed a complete fin stabilizer improvement program. This program consisted of the items listed on Table 5-13.
<table>
<thead>
<tr>
<th>Upgrade and Standardize Hardware</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comprehensive ShipAlts</td>
</tr>
<tr>
<td>Preliminary or Interim ShipAlts</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Improve Stabilizer Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relocate Drains</td>
</tr>
<tr>
<td>Control Humidity</td>
</tr>
<tr>
<td>Compartment Cleaning</td>
</tr>
<tr>
<td>Relocate Stabilizers (L1)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Improve Parts Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muirhead Controls (L1, L2, L3, CV)</td>
</tr>
<tr>
<td>Sperry Controls (S1, S2)</td>
</tr>
<tr>
<td>Special Long Lead Items</td>
</tr>
<tr>
<td>Monitor Parts Support</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Improve Preventive Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muirhead Controls (L1, L2, L3, CV)</td>
</tr>
<tr>
<td>Sperry Controls (S1, S2)</td>
</tr>
<tr>
<td>Hydraulic System</td>
</tr>
<tr>
<td>Fin Shaft Seals (S1, S2)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Improve Documentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obtain Detail Drawings</td>
</tr>
<tr>
<td>Revise Technical Manuals</td>
</tr>
<tr>
<td>(L1, L2, L3, CV, S1)</td>
</tr>
<tr>
<td>Technical Repair Standards</td>
</tr>
<tr>
<td>NAVSEC Technical Notes</td>
</tr>
<tr>
<td>Revise PMS Cards (S1, S2)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Improve Training</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vendor Furnished Training</td>
</tr>
<tr>
<td>NAVSEC Field Divisions</td>
</tr>
<tr>
<td>Naval Training Center, Great Lakes</td>
</tr>
</tbody>
</table>
The reason for the proposed program stemmed from the fact that the Navy had spent large amounts of money on piecemeal repairs and procurements but had not had the benefits of fin stabilizers for a large part of the time. Therefore, it was felt that it was uneconomical on a continuing basis to overhaul unreliable obsolete components.

The objectives of the fin stabilizer improvement program were to minimize down time and repair costs. It was felt that these objectives could be met by upgrading and standardizing the fin hardware and by improving the fin environment, parts support, preventive maintenance, documentation, and training.

As shown in Table 5-14, the cost of the proposed program was certainly not small but it was felt that the problems had been identified and that solutions were available for the problems.

The theme of the presentation to the SLM regarding the proposed program was that the standardization would solve most stabilizer problems.

As shown on Table 5-5, there were three shipyards that had produced the DE 1052 class of ship during the late sixties and early seventies. Because of Navy/DOD procurement policies, only performance specifications were possible for the stabilizers. If the Government had bought the stabilizers and provided them as GFE to each shipyard, it would have created interface problems and raised the question of who is
<table>
<thead>
<tr>
<th>PRIORITY</th>
<th>SHIPALT DESCRIPTION</th>
<th>START. COST (1,000's)</th>
<th>RUN COST (1,000's)</th>
<th>NO. OF KITS</th>
<th>TOTAL COST (1,000's)</th>
<th>UNIT COST (1,000's)</th>
<th>INSTL. COST (1,000's)</th>
<th>TOTAL COST PER KIT (1,000's)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Upgrade &amp; Standardize Controls</td>
<td>300</td>
<td>10</td>
<td>65</td>
<td>950</td>
<td>15</td>
<td>25</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>Upgrade &amp; Standardize Hydraulics</td>
<td>250</td>
<td>30</td>
<td>65</td>
<td>2,200</td>
<td>34</td>
<td>40</td>
<td>74</td>
</tr>
<tr>
<td>3</td>
<td>Upgrade Mechanical System (S2)</td>
<td>50</td>
<td>5</td>
<td>27</td>
<td>185</td>
<td>7</td>
<td>20</td>
<td>27</td>
</tr>
<tr>
<td>4</td>
<td>Upgrade Mechanical System (L3)</td>
<td>10</td>
<td>1</td>
<td>19</td>
<td>29</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Replace Denison 30 Pumps (L1, L2, CV, S1)</td>
<td>40</td>
<td>4</td>
<td>38</td>
<td>192</td>
<td>5</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>6</td>
<td>Remove Desurgers</td>
<td>10</td>
<td>0</td>
<td>65</td>
<td>10</td>
<td>0</td>
<td>(1)</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>Install Hydraulic Filters</td>
<td>20</td>
<td>2</td>
<td>65</td>
<td>150</td>
<td>2</td>
<td>(1)</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>Mod Controls to Ease Removal (L1, L2, L3, CV)</td>
<td>20</td>
<td>1</td>
<td>36</td>
<td>56</td>
<td>2</td>
<td>(2)</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>Mod Controls to Ease Removal (S1, S2)</td>
<td>10</td>
<td>1</td>
<td>29</td>
<td>39</td>
<td>1</td>
<td>(2)</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>Standardize Ram Seals (S2)</td>
<td>10</td>
<td>1</td>
<td>27</td>
<td>37</td>
<td>1</td>
<td>(2)</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>Improve Replenishing Oil Circuit (S2)</td>
<td>10</td>
<td>1</td>
<td>27</td>
<td>37</td>
<td>1</td>
<td>(1)</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>Improve Fin Shaft Seal Arrangement (S2)</td>
<td>10</td>
<td>1</td>
<td>27</td>
<td>37</td>
<td>1</td>
<td>(1)</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>Install Protective Shields (S2)</td>
<td>20</td>
<td>1</td>
<td>27</td>
<td>47</td>
<td>2</td>
<td>(1)</td>
<td>2</td>
</tr>
<tr>
<td>14</td>
<td>Relocate Drains</td>
<td>50</td>
<td>1</td>
<td>65</td>
<td>115</td>
<td>2</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>15</td>
<td>Control Humidity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Compartment Cleaning</td>
<td>10</td>
<td>1</td>
<td>65</td>
<td>75</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>17</td>
<td>Relocate Stabilizers (T1)</td>
<td>50</td>
<td>5</td>
<td>2</td>
<td>60</td>
<td>30</td>
<td>60</td>
<td>90</td>
</tr>
<tr>
<td>18</td>
<td>Upgrade Mechanical System (S1)</td>
<td>80</td>
<td>10</td>
<td>2</td>
<td>100</td>
<td>50</td>
<td>60</td>
<td>110</td>
</tr>
</tbody>
</table>
responsible for what, if the equipment did not perform as specified and yet it probably would have been the lesser of two evils.

It is interesting to note that the idea occurred to at least one naval architectural firm, J. J. Henry Company that problems could arise from the arrangement in which each shipbuilder would provide its own stabilizer equipment, not necessarily identical to the rest of the class. J. J. Henry Company sent an unsolicited proposal to the Bureau of Ships in October 1963 [5-120] suggesting centralizing the design and procurement of stabilizers. The Contract Design Division replied that [5-121]:

"Your proposal on centralizing design and procurement control surfaces would involve the Bureau in additional detail design and procurement scheduling, plus also complicating responsibility for performance of external hydraulic systems. Over the years, we have found it far better to centralize responsibility for performance in the shipbuilder, and let him do the detailed design and procurement.

"If you are interested in applying your control surface design ability to new construction, it is suggested that you discuss your proposal with Gibbs and Cox, Inc. They are prime design agents for the new DE 1052 class which will have shipbuilder furnished fin stabilizers."

The argument of competition, of course, has validity, and it is the other side of the coin, i.e., once standardization is introduced, the one manufacturer, selected to supply all destroyers, especially if protected by patent or other proprietary rights, may drive prices up.
In an informal handwritten memorandum back in 1963, one of the Bureau of Ships engineers stated [5-122]:

"I believe Mr. Blake's, of Lidgerwood (now with McKierman-Terry), estimate was $325,000 for a stabilizer like the GYATT (45 square foot fin). Sperry's estimate for a 32 square foot gyrofin was $335,000. It is possible that the cost of a GYATT retractable fin stabilizer would be somewhat reduced under the competition that now exists. For example, the Lidgerwood quoted price for the DE 1037 nonretractable stabilizer, before Mr. Blake left Lidgerwood to work for a newly established competitor was $104,620 each for two ship sets. However, we got the DE 1037-1038 fins for $59,359 from Lidgerwood later."

It is extremely interesting to note, that, throughout the years, during the numerous discussions about adopting or not adopting fins, the Navy's enormous maintenance problem was never explicitly mentioned as a deterrent to further adoption of fins to destroyers.

However, a variety of more elegant studies are being pursued vigorously. Researchers in the field have identified numerous pitfalls in the current bag of tools which is used to predict performance of both fin and tank stabilizers.

For example, in a just completed comprehensive review of the state-of-the-art of roll stabilization [5-123], the following recommendations are made for further work:
"Predictions of Lateral Motions, the following are identified:

"Evaluation of the existing quasi-linear one-degree-of-freedom roll motion prediction procedure;

........development and evaluation of a quasi-linear three-degree-of-freedom lateral motion prediction procedure.

"Sea State Specification. Investigations are necessary to:

"Explore the sensitivity of roll stabilization device sizing and design to the use of specific design Sea State spectra. This should include the analysis of existing installations whose 'at sea' performance has been established;

........explore and improve the suitability of Sea State data bases for performance assessment purposes.

"It is necessary to keep the problem of Sea State specification under continual review, so as to take advantage of new data bases and improved spectral formulations.

"Bilge Keels. It is necessary to:

........evaluate the general applicability of equation 55 of Appendix B for the bilge keel drag coefficient, and hence the derivation of the nonlinear contribution of bilge keels to the roll decay coefficient. This is accomplished by computing values of the bilge keel drag coefficient, from an analysis of all available experimental roll decay coefficients for ship models with and without bilge keels.

"It is also recommended that:

........subject to the successful outcome of the previous item, investigations be carried out to replace the overly complex method of Kato (used to predict bilge keel roll damping moment in many lateral motion prediction procedures)......
........a thorough review be carried out on the subject of the scale effect problem for the experimental determination of ship hull damping moment, without and with bilge keels, using ship models.

"Anti-roll fins

"It is recommended that research and development be undertaken to improve the theoretical prediction of fin lift effectiveness, and the selection of fin platforms and thickness to delay inception of cavitation....

"Anti-roll tanks

"Theoretical prediction procedures (even when supplemented by experimentally determined regular wave tank moment and phase data) are considered very inadequate as design or performance assessment tools. Also, irregular wave experiments with a "small" tank installed in a ship model, are severely limited in their useful application to design and performance due to:

"A. the inability to generate short crested waves;

"B. possible scale effect problems;

"C. a severe limitation on the number of conditions that can be evaluated due to reasons of time, cost and facility limitations. It is recommended that major reliance be placed upon simulation procedures using large models of anti-roll tanks, for design and performance assessment purposes. This appears to be the only satisfactory way to ensure a proper representation of the complex nonlinear hydrodynamic action of a passive tank...."

In just the last two months, in addition to the report just mentioned, two additional technical papers [5-124], [5-125] were presented by the naval research and engineering community on various aspects of roll stabilization. Under the heading of "Areas Needing Additional Work" [5-124], it is suggested that:
"While it might appear from preceding sections that means for designing roll stabilization systems and for predicting the roll motions of ships with and without stabilizers are fairly well in hand, additional work is needed, if not required, in a number of areas. These include roll motions predictions in quartering seas, minimum acceptable model size and correlation of ship data, model data and theoretical predictions.

"Observed discrepancies between model data and predictions may be due to a number of causes including:

"(1) Inadequate model size

"(2) Unrealistic model constraint during tests

"(3) Failure to hold model on desired oblique heading or unrealistic model rudder action

"(4) Failure to properly account for non-linear ship roll damping or viscous contributions to sway damping in calculations

"(5) Failure to account for rudder action and heading changes in calculations."

While these suggestions are well thought out and are worthwhile, in general, I question whether they should command top priority in view of this case study, if the ultimate objective is to have U.S. destroyers adopt reliable and maintainable anti-roll stabilizers. It seems that VADM Adamson (Commander, Naval Surface Force U.S. Atlantic Fleet) had grasped the problem well when he wrote to Deputy Chief of Naval Operations (DCNO) (Surface Warfare) in the Pentagon, subsequent to the Seakeeping Workshop held in Annapolis in the summer of 1975 [5-3], encouraging the establishment of policy regarding roll stabilization [5-126]. Excerpts from his letter are quite to the point:
"Based on the results of that meeting NAVSEA and NAVSEC have embarked on establishment of an organized approach to future R&D efforts to help forestall some of the operational limitations and self-imposed restrictions faced by our commanding officers in order to prevent or lessen damage during heavy weather. We have also seen evidence from both our allies and our adversaries that they do not appear to experience these problems with the same severity that we do. The evidence appears to point to their successful use of active fin stabilizers for smoother rides and drier decks.

Furthermore, it appears evident to me that, in order to improve the seakeeping performance of ongoing and future warship designs, we will have to place high priority in the characteristics selection process on those features that will ensure such performance. Policy statements to this end may be necessary to assure that such priorities are maintained. The policy of installing anti-roll fin stabilizers, for example, appears to have proven effective for the Soviet, British, French, Italian, Canadian, and other major foreign navies. We should buy in on their experience in this area and proceed to harness our available talent and technology to do better. Proving that we need fins at this stage in the state-of-the-art seems redundant, and we should stipulate it as a requirement in our ships."

The reply from DCNO (Surface Ships) [5-127] indicated that, in general, improved seakeeping was an important goal in all new designs and indicated that NAVSEC was studying the issue of roll stabilizers. It did not indicate the resolve to formulate policy such as incorporating fin stabilizers in all destroyers.

Thus, after at least 60 years of attempts to incorporate effective roll stabilization in small and medium size warships in the U.S.
Navy, the adoption is, at best, incomplete. While researchers are eagerly proposing ways to gain new knowledge, overcoming some of the practical engineering and procurement problems for those ships which already have the devices is not in sight. Most importantly, the requirement decision makers are still skirting the issue of policy.
CHAPTER 6
SYNTHESIS & ANALYSIS

6.1 Introduction

The objective of this thesis is to examine the process by which innovation is adopted in the Navy. Innovation, as distinct from invention, refers to the first actual application of a new device, system or method of operation. The application of innovations (innovation adoption) and the process by which it is achieved within the Navy is the subject of this thesis.

In the innovation literature ([6-1] and [6-2]), this process has been described as occurring in the following phases: generation of an idea, its development, its implementation and, finally, its diffusion. At each stage of the adoption of an innovation, the responsible organization must make decisions. Social scientists have been intrigued by the sources of the influences on this process.

In terms of importance and visibility, there are at least two categories of innovations; first, the kind which is of national importance and, consequently, leaves a highly visible trail of debate leading to the adoption decision, such as Polaris [6-3] and nuclear propulsion [6-4]. The second category includes innovations which are potentially of equal importance, but occur over long periods of time, and mostly within the depths of an organization, obscuring the path leading to the adoption decision. The latter type of innovation is more evasive than the former and is more
typical of the innovation process. The process of innovation sometimes spans several decades during which substantial changes in organizational structure and environmental factors take place. To understand it, a historical survey appears to be required. Such a survey was conducted in the two case studies of this thesis. These two case studies reveal decades of experimentation leading to the adoption of an innovation. In the case of roll stabilization, the diffusion phase of the adoption process has not yet been reached.

Because of security classification, access to information pertaining to military innovation is quite difficult, compounded by: (1) the neglect of DOD to develop good archival records for the project histories [6-5], (2) the strong biases of the participants in innovation [6-6], and (3) the difficulty to assess, through unobtrusive measurement [6-7], the status and worth of innovations. It is for these reasons that the historical survey approach was taken in this thesis.

For comparison, it is fortuitous that the innovation studied in both cases were adopted by the two other most significant navies, an ally, the Royal Navy, and our primary adversary on the sea, the Soviet Navy, over a decade prior to adoption by the U.S. Navy and, as such, have provided a benchmark. This evidence establishes the status and worth of these two innovations. Though the fact that these two navies have adopted these innovations hardly provides full proof that they are worthwhile for the U.S. Navy (because of such differences as size, composition
resources, and missions of these three navies), it does, nevertheless, strongly suggests their importance in modern naval ship design.

The arguments of Kehoe [6-8] and VADM Adamson [6-9] substantiate the worthwhile impact of roll stabilization while, in the case of gas turbines, the findings of the National Academy of Sciences in 1971 [6-10] and the Navy Research Advisory Council in 1970 [6-11] provide similar supporting evidence.

This chapter is intended to synthesize evidence in support of the hypotheses established in Chapter 3. The technologies of roll stabilization and gas turbines are quite different, not only in the functions they perform for a ship, but also in their importance to mission accomplishment, the relevant capital investment they represent in U.S. industry (both for the product to be introduced as well as what it displaces), and in the organizational rivalry within the Navy for the two products.

These and other factors tend to differentiate substantially between the two cases of innovation adoption. Nevertheless, the conclusions will take the form of an analysis of every hypothesis as supported by each of the two case studies.

The discussion in the "Literature Review" chapter pointed out the different factions among social scientists studying the innovation process. The literature search indicates that research done on the
innovation process has produced widely divergent views of the process: economists looking at R&D expenditures as a surrogate for innovation [2-39,2-40], organizational psychologists seeing the enhancement of innovation adoption in effective communication within R&D organizations [2-29, 2-25], and political scientists attributing success of innovation to "innovation champions" [2-20, 2-49], appropriate organizational structure [2-41, 2-44], or the political "clout" of highly visible leaders associated with a particular innovation [6-3, 6-4]. As the hypotheses in this thesis suggest and as the two case studies demonstrate, the innovation process is influenced by all of these factors.

The remainder of this chapter provides a comprehensive analysis of each case study as it supports or disproves the various hypothesis postulated at the beginning of this thesis.
6.2 Nature of the Process of Innovation Adoption

6.2.1 Hypotheses A-1. The process of innovation adoption is a political process.

Complex organizations cannot be viewed either from the "bureaucratic" viewpoint, i.e., organizations exist without regard to the people who man them, Weber [6-12], Taylor [6-13], nor from the "human relations" viewpoint, i.e. people without organization as "happy anarchies" [6-14, 6-15]. Complex organizations are political systems. By necessity, large complex organizations require differentiation, resulting in a system with multiple goals involving multiple interest areas among differentially powerful units such as R&D, design, production, finance.

Organization studies by Dahl [6-16], Sapolsky [2-34], Allison [6-17], Baldridge [6-18], Pfeffer and Salanak [6-6], Hickson et al. [6-20], Patchen [6-21], and others, all suggest that organizations should be viewed as political systems. During the past 20 years, the study of organizational behavior has developed from an internally-oriented structure to an externally-dominated system-oriented view. In the 1940's and 1950's, most organizational research was internally oriented. Organizations were seen as internally integrated, rationally coordinated, hierarchical and goal-oriented in nature, Parsons [6-22]. The 1960's brought the systems theory and the notion that social systems could not be viewed in isolation. Organizational input, throughput and output processes as they impacted and were affected by the environment became important
research considerations e.g., March and Simon [6-23], Katz and Kahn [6-24], Thompson [6-25], Lawrence and Lorsch [2-23].

Differentiation, as defined by Lawrence and Lorsch, is "the difference in cognitive and emotional orientation among managers in different functional departments [2-33]." This concept suggests that manager's attitudes become differentiated to the degree that the tasks they manage differ in uncertainty and feedback time span. The fact that several departments prefer different alternatives as a solution to the same problem is a basic source of conflict. As the variety of tasks to be performed by the organization increase in uncertainty, differences in other dimensions become causes of conflict.

The resolution of such conflicts takes many forms. Lawrence and Lorsch [2-33] talk about integrating roles and matrix organizations, but structure alone is not sufficient for resolving conflict.

No existing studies were found supporting what Lindbloom and Braybrooke [6-26] have termed synoptic (i.e., rational) decision making. Lindbloom and Braybrooke [6-26] and Wildavsky [6-27] claim that synoptic decision making is possible only in simple organizations. Stagner [6-28], Allison [6-29], and Hage and Dewar [6-30] have presented both case and empirical studies directly supporting a political approach to decision making in complex organizations.
Since a significant innovation is more than a routine change, it requires marshalling organizational resources and decision support in a complex organization, a process which, by its nature, requires bargaining, negotiation and deception—in short, a political process.

Studies of industrial organizations by Norman [6-31] and of the Navy by Davis [2-49] illustrate the political approach to innovation. The work of Davis [2-49] as well as findings of the SAPPHO project [1-1] demonstrate the required political skills for innovation adoption in complex organizations. Political skills are necessary to resolve conflicts arising both from the internal organization mentioned earlier and from the environment. The evidence provided by the two case studies overwhelmingly supports this hypothesis.

Seidman [6-32] points out the special value of committees, panels and task forces as political tools in a bureaucracy. The Navy’s request (in 1939) that the National Academy of Sciences establish a committee to aid in its decision concerning gas turbines can be seen as a political approach. Having the respected National Academy of Sciences form a committee assured obtaining the country’s key experts to make recommendations, thereby protecting the Navy from being criticized that it was not progressive enough [6-33]. A political strategy which Sapolsky [2-52] terms "cooptation".

Another instance of bureaucratic politics was the establishment in 1952 of the Ship Design Coordinating Committee (SDCC) of the Bureau of Ships with its various panels [6-35], composed partially of in-house
Bureau of Ships members and partly of senior engineering duty officers (EDO's) from naval shipyards. The Chief of the Bureau, by providing such a forum, was attempting to diffuse criticism that the Bureau's capacity to be innovative might have diminished. Judging from the significant amount of time spent by the propulsion panel of the committee debating the issue of nuclear power, at the height of the power struggle between then Captain Rickover and the rest of the Bureau, it would not be surprising if one of the motivations behind the establishment of the propulsion panel was part of the Bureau's last attempt to contain Rickover. As we know now, that attempt failed; Rickover out-maneuvered the Bureau and his part of the Bureau's organization was put in a special status, a luxury rarely afforded to one part of a large bureaucracy like the Bureau of Ships [6-4](also see Appendix A).

The care with which the Chief of the Bureau meticulously defined the Ship Design Coordination Committee's functions indicated the thorough understanding the Chief and his immediate staff had of Bureau politics. This explicit format was intended to insure orderly decision-making procedures by the Committee.

In spite of these precautions, organizations which intend to retard innovations can resort to slow-down tactics. This type of political maneuver has been well demonstrated by a Bureau department. In December 1952, the organization responsible for managing naval
shipyards responded to a propulsion panel request for overdue comments on a panel report by claiming its comments would require a year's worth of study. [6-35]

A similar incident occurred on 20 March 1952, about a year after the establishment of the SDCC and its panels. By this time, the panels had issued a number of reports with findings which were unacceptable to the Bureau's design organization. In response, the Ship Design Division requested a procedural change for handling the panel's reports. This change would require that all official reports and recommendations go through the SDCC. Politically, this requirement to pass every study and every recommendation through a committee meant a slowing down of the process, enhancing the opportunity for the bureaucracy to defeat innovative proposals.

Further insight into the process of innovation in a large bureaucracy is provided by the decision regarding the steam turbine configuration (1200 psi, 950°F) which was to have been selected for the DD 931, the second ship class to have 1,200 psi, 950°F steam conditions. The case in point was the two-casing series-parallel turbine design as opposed to the conventional cruise turbine system.

The Chief of the Bureau decided to proceed with the two-casing series-parallel turbines. His rationale for this decision reveals the importance of consensus on the decision to adopt an innovation of
significant magnitude in a large government organization [6-35]: "I find such preponderance of opinion in favor of proceeding as we are, that I can find no adequate justification whatever to discontinue the proposed new design and revert to the old design."

The Chief's further emphasis on "the unanimous opinion of the Bureau's experts that the new design has every promise of being successful" indicates that chances of approval for an innovation without "a preponderance of opinion in its favor" are slim [6-35]. The implication of this fact is that the successful innovator has to be a shrewd politician so as to manage to bring about a unanimous opinion in regard to the innovation prior to its presentation to the decision maker.

Another demonstration of the political nature of innovation decisions is provided by the CNO's decision in the early fifties to invest in nuclear power. The Bureau proposed an elaborate five-year program aimed at providing five nuclear power plants, from 3,000 shp per reactor to about 70,000 shp per reactor. Though the cost was to be shared by the Atomic Energy Commission (AEC), the Navy's share of the proposed investment was still phenomenal compared with the usual Bureau appropriations for systems developments. [6-35]

The Chief of the Bureau defended the high costs by claiming [6-35] that "No new propulsion system has ever been, in the first experimental model, economically competitive with an established 'conventional system.'
If this had been made a requirement of our present propulsion systems, they would never have been developed." This statement is particularly interesting, since such a statement of unqualified support has never been made with respect to gas turbines, a power plant type lacking the political "clout" that the champion for nuclear power, Admiral Rickover obviously had.

Theoretically, developmental systems should never be handicapped by strict comparison to existing systems. However, in practice, developmental systems usually are compared to existing systems. This handicap is evident in the case of gas turbines, which were compared every step of the way toward their eventual adoption in the 1970's. The advocates of gas turbines appear to have been novices in the political environment in the Bureau in the early 1950's. They were primarily technology pushers and did not seek some very useful "user pull" which could have been obtained from both ship designers as well as those in OPNAV who were charged with the establishment of new ship characteristics. Instead they were content to play with the new technology on small scale. Admiral Rickover on the other hand took full advantage of the fact that nuclear power in the 1950's captured the public's as well as congressional leaders' imagination and managed to garner large amounts of R&D dollars, leaving the crumbs for the politically timid souls in the machinery area of the Bureau.

The political process of innovation adoption by the U.S. Navy extends beyond the organizational complexity of the Navy itself. The Navy is part of a complex "super organization," the marine field in
general, comprising equipment manufacturers, ship design agents, ship-
buiders, Department of Defense staff and Congress. At times, various 
parts of this "super organization" strongly influence innovation decisions, 
as evidenced in the two case studies of this thesis.

"Pressure-fired" boiler development also competed with gas tur-
bine adoption. [6-36] In the 1940's, the Navy had spent large sums of 
money developing and prototype testing closed cycle systems for submarine 
[6-35] and funding the development and testing of pressure-fired boilers 
for surface ship applications at the Naval Boiler and Turbine Laboratory 
(NBTL) throughout the 1950's. Thus the "pressure" was on to apply this 
technology to a ship class.

Because there were a number of existing propulsion plant options 
which were ready for adoption*, it was an especially bold decision to commit 
17 ships to this power plant type at that time without giving much of a 
chance to the other options. Nonetheless, the decision was made during 
the design of the DE 1040 class. Therefore, it is even more surprising 
that, in the next evolution of that class of destroyers, the DE 1052 class, 
the decision was reversed even before a single pressure-fired boiler 
equipped ship had been delivered to the fleet. Not only did the decision 
to switch come at a very advance stage of design, i.e., the detail design 
phase, but, instead of seeking a solution which would maintain ship size

* Other options, such as gas turbine boost for a steam turbine base power plant (COSAG), were in a very advanced state of development by the late 1950's. They passed full scale experiments at NBTL and were adopted by the British for a class of destroyers.
by using another power plant type which would occupy less space and weight than a conventional power plant (COSAG, gas turbine, etc.), the decision was to revert to a conventional steam power plant.

This abrupt change away from a power plant type to which nearly two decades of development and testing had been devoted and 17 ships were committed (none of which were completed and in the fleet at the time of the decision) appears to have been politically motivated. Interviews with the Bureau of Ships and Gibbs and Cox personnel verified this assumption [6-36].

Officially, according to Gibbs and Cox, winner of the contract for detail design, the major reason for the change in boiler type was that although 17 ships were committed to pressure-fired boilers, none were in operation and would not be until some time after the DE 1052 class construction program was underway. It seemed imprudent to them to commit a 50-ship class to a type of boiler which had not been proven in service and which did not permit fallback to a conventional type boiler because of space considerations. Given these misgivings concerning the pressure-fired boiler, the question arises regarding the rationale for committing the 17-ship class to the concept in the first place. Though there were some valid technical reasons for committing more ships to the pressure-fired boiler, they were overshadowed by what was clearly a politically motivated decision demonstrated by the following story.
Up to that time Gibbs and Cox had designed all U.S. Navy destroyers since World War II with the exception of the class of 17 ships in which the "pressure-fired" boilers were adopted. Thus a monopoly on warship design which lasted for two decades was suddenly broken at the time of the design of the DE 1040. Not only was the monopoly broken but a major innovation was introduced into the design. Mr. Gibbs' strategy was clear - discredit the design in a subtle way and as a result regain instantly the confidence of the Navy. He knew that by appealing to the underlying conservatism in the Bureau, he had a high chance for success. Mr. Gibbs was right. The Bureau was really dragged into adopting "pressure-fired" boilers in 17 ships without at-sea testing of one or two ships with this new boiler.

The Bureau was opting at the time of the design of the DE 1040 class to obtain an experimental DE and asked that it be specifically designated as an EDE. A rapid succession of decisions by the Ship Characteristics Board resulted in the commitment of 17 ships, instead of, one, to this new boiler type. Before the Bureau, so to speak, "woke up" the shipbuilding schedule did not permit a change back to conventional boilers because that would have meant a complete redesign of the ship to a significantly larger size. Mr. Gibbs also knew that coincidentally the Chief of the Bureau changed shortly prior to that time and that the new man had a strong machinery background and would understand and be concerned. As it turned out the strategy worked. The decision to switch back to conventional boilers signalled the death of the innovation of the "pressure-fired" boilers and firmly put Gibbs and Cox back in
the saddle as the designer of destroyers for the Navy. This incident
again lends strong support to the political nature of innovation
adoption and rejection.

During the SEAHAWK development, the political nature of inno-
vation adoption again surfaced. When the SEAHAWK Program was initiated
in September 1961 at CNO's direction, its objective was to provide
a destroyer escort in the FY 1965 shipbuilding program with optimum
Anti-Submarine Warfare (ASW) capability, minimum Anti-Aircraft Warfare
(AAW), reduced complement, and lower operating cost, which would be
economical to produce in quantity.

The program [6-37] envisioned a SEAHAWK I and SEAHAWK II version
The idea was that a ship could be developed for the FY 1965 shipbuilding
program which would not push the state-of-the-art too much (SEAHAWK I),
but that an R&D program which would run concurrently with SEAHAWK I would
yield improvements in a variety of ship systems which would then be
incorporated into SEAHAWK II, part of the FY 1968 shipbuilding program.

As the gas turbine case study [6-37] pointed out, Bethlehem Steel
Shipbuilding Division proposed a high-speed destroyer design propelled by
gas turbines in a COGAG arrangement as the solution. In spite of the
Bureau's evaluation that the design did not offer the major advantages
indicated by the Bethlehem report, Bethlehem did not stand still and
sought the political route to solve its own in-house problem, i.e., how
to occupy effectively Bethlehem's large engineering team which was
finishing the DE 1040 detail design and was looking for work.
These circumstances motivated Bethlehem to make an all gas turbine proposal with the promise of a very high speed ship. The proposal fell on deaf ears in the Bureau since the Navy had not considered high speed as the major requirement. Especially for the FY 1965 ASW destroyers, reduced manning and quiet operation, not maximum speed, was the issue.

Having received a cool response from the Bureau, Bethlehem's vice president in charge of shipbuilding, in an effort to obtain further design work, went directly to the CNO and convinced him that the Bureau was not designing the best ship that the state-of-the-art in the field of naval propulsion could offer but that Bethlehem could design such a warship - a 40-knot DE. This prompted the CNO to write a letter to the chairman of the SCB in which he expressed concern "that the study for SEAHAWK does not push the state-of-the-art far enough with particular regard to ship propulsion" and requested the increased speed as a requirement [6-37]. Bethlehem did receive a design study contract [6-37] quite clearly not on the Bureau's recommendation, but because Bethlehem had dealt directly with the CNO on the basis of promises which, whether they knew it or not, would turn out to be impossible to fulfill.

This political maneuver on the part of Bethlehem was partly responsible for the demise of the whole SEAHAWK Program three years later. Since the CNO demanded a 40-knot destroyer, the entire program was thrown back to ground zero; rather than developing a combined diesel and gas
turbine (CODAG) SEAHAWK I for the FY 1965 shipbuilding program, more and more studies were made, in an attempt to provide high speed. The necessary R&D funds were not released for hardware procurement and the SEAHAWK propulsion development was thwarted.

This move by Bethlehem played directly into the hands of certain factions in the R&D community who had several reasons to object to the SEAHAWK program as it was evolving at that time. Some felt that the Bureau was overemphasizing the platform side of the ship and not enough funds were being devoted to the sensor/weapon portion. Others felt that the requirements as initially stated could have been better executed by other than ships (e.g. submarines or aircraft). A third faction saw gas turbine development as a competitor for the R&D dollars devoted to nuclear naval propulsion. However, CNO had already made his decision just a few months before, that there would be a SEAHAWK program and it would be a ship, not an airplane or submarine, for which gas turbines in some combination would be the prime movers. It must have been on opportunity the gas turbine opponents couldn't dream of when CNO voiced his concern subsequent to the Bethlehem visit [6-37]:

"I am apprehensive and have serious reservations that the study contract for SEAHAWK does not push the state-of-the-art far enough with particular regard to ship propulsion."

The ASN R&D took advantage of this opportunity and stopped all full scale testing which was planned to start in less than two months. The
strategy worked and eventually after another two to three years of relatively low consumption of R&D dollars on paper studies for propulsion, the bulk of the funds were allocated to the development of ASW sensors, tactics and weapons. Again the political naivete' on the part of those who were pushing gas turbines helped retard progress toward the adoption of gas turbines.

The case of the FY 1967 DDG [6-38] is another demonstration of political influence on innovation adoption. At the completion of the preliminary ship design, the Secretary of the Navy requested information on the status of gas turbines worldwide as well as the results of studies made comparing steam with gas turbines for the main propulsion of the FY 1967 DDG. This request was made during a luncheon with several members of CNO's staff and the Chief of the Bureau present. In a matter of two weeks elapsed time, the Secretary of the Navy directed a change from steam to gas turbine propulsion for the FY 1967 DDG's and for the DDG's in succeeding FY programs [6-38].

This incredibly rapid sequence of events had to have been strongly politically motivated; the bureaucracy simply does not work so quickly. Yet this decision involved reversing a CNO decision, by the Secretary, a highly unusual move. First, it is highly unlikely that the Secretary's interest developed during a luncheon. Second, considering his volume of work, it is improbable that for the next two weeks he did nothing but concentrate on this problem. It takes several days to draft a letter
of such importance and chances are that the Secretary would have other comment on it prior to release. Yet the memorandum was issued only 14 days after the topic was first discussed between the Secretary and the military side of the Navy hierarchy.

During the design of the DDG, the political influence of Admiral Rickover showed its presence several times: the chairman of SCB decided to set back the design of the ship to ground zero after the completion of its Preliminary Design just because the ship size pierced the "magic" 8000-ton displacement mark above which a ship was to be nuclear propelled according to Admiral Rickover. Interestingly, there was not written law or instruction declaring an 8000-ton limit on nonnuclear propulsion and yet schedules were drastically altered and design cost increased just to avoid confrontation with Admiral Rickover.

The most marked demonstration of the Rickover political "clout" influencing innovation adoption in the naval propulsion field, came in mid-1967 when the CNO recommended that gas turbine propulsion not be considered for any destroyer design in the 1960's because gas turbines were an "untried and unproven propulsion scheme" [6-38]. This decision was made when most commercial fleets and major navies in the world already had operating ships propelled by gas turbines.

The next encounter of the gas turbine innovation with politics was when the "steam lobby" attempted to prod Congress to reverse the gas turbine propulsion decision for the DD 963. The political struggle
became so intense that divisions of General Electric (i.e., the one manufacturing steam turbines versus the other manufacturing gas turbines) were testifying against each other on Capitol Hill at one point.

The steam industry and its lobby had been very influential in blocking the gas turbine innovation for many years prior the the DD 963 design. Long-lasting personal relationships developed (sometimes over a period of 20 to 30 years) between Washington representatives of major steam hardware producers and the steam industry employees, kept alive through frequent visits, (weekly or even daily at times) telephone calls, professional society meetings, symposia and letters was a strong political tool in the hands of the steam industry and it was used very effectively. The political strength of the steam hardware industry and its efficiency in providing information and studies to Bureau of Ships personnel at all levels had an immeasurable impact in retaining steam plants to the detriment of gas turbine adoption.

Steam plant components are manufactured by many different companies - (at least three for each component). The gas turbine is produced by one concern which delivers a complete power plant. Only two U.S. companies manufacture these high-power gas turbine engines. Furthermore, the number of potential marine gas turbine engine sales by the two manufacturers never exceeds a small percentage of their aerospace and industrial applications sales. As a result, there is considerable difference in the impacts of these two industries considering the earlier-described "mechanics of influence"
directed toward Bureau of Ships personnel. The political influence of an army of industry representatives penetrating the working levels of the Bureau on the steam side against the two or three for gas turbines has had a significant influence in retarding the innovation adoption of gas turbines.

Another political move, similar to that made at the outset of the Navy's interest in gas turbines in 1939, was made by the Navy in 1970 to cement the innovation. Once again, the Secretary of the Navy asked the National Academy of Sciences to study the adoption of gas turbines for the DD 963. The Academy's report, issued in late 1971 [6-10], noted that the Navy had made the right decision in selecting gas turbines for the DD 963 and noted that it should have done so much earlier.

By 1973, it appeared that the gas turbine innovation had won a total victory. Every new surface warship design (FFG 7, Sea Control Ship and DG AEGIS) started after the DD 963 was designed to be gas turbine propelled. However, the staunchest opponent of gas turbines did not lay down his arms; he managed to outmaneuver everyone and in 1974, when Congress signed into law Title VIII stating that [6-39]:

"New construction major combatant vessels for the strike forces of the United States Navy authorized subsequent to the date of the enactment of this Act shall be nuclear powered...unless and until the President has fully advised the Congress that construction of nuclear powered vessels for such purpose is not in the national interest."
A result of Title VIII is that the issue of naval ship propulsion, instead of being resolved within the confines of the Navy, has become an issue which is debated in the halls of Congress. Even though we have adopted gas turbines for the fleet, success has cost the Navy delays in the approval of its new warship programs, lending strong evidence for the hypothesis that innovation adoption is a political process.

In an article for the Proceedings of the Naval Institute, Admiral Rickover supported Title VIII [6-40]:

"...we have to build a Navy strong enough to protect our national interests, and our economic and political survival. To me, it is clear that the striking force ships we build for such a Navy must have nuclear power."

The impact of the law regarding non-nuclear propulsion on the Navy's shipbuilding program was swift. The non-nuclear (gas turbine) propelled austere 6,000-ton ($250 million) DG AEGIS destroyer, designed to use the Navy's newest weapon system which was necessary in view of the growing Soviet threat on the ocean, was scrapped at the completion of its preliminary design phase. In its place, two others emerged both carrying the AEGIS weapon system: one was a DD 963 conversion (9,000 tons, $500 million) and the other, a nuclear version (18,000 tons, $1.4 billion).

Because the Senate favors the non-nuclear version and the House the nuclear version, the joint conference of the House and Senate Armed Services Committee for two consecutive years has been unable to agree on approving either ship. Design of a second gas turbine ship, the Sea
Control Ship, was halted at the completion of contract design. This was partly a result of oscillations associated with the Navy's V/STOL aircraft program, but also partially because of confusion relating to the new law (Title VIII), i.e., whether it is applicable to a small, aircraft-capable warship. Since 1973, when it appeared that the adoption of gas turbines was finally reaching the diffusion stage, two of the three surface warships designed to use gas turbine propulsion have been cancelled. The political nature of the process is clearly evident providing further substantiation of this hypothesis.

The history of the introduction of roll stabilization into U.S. warships, as described by the second case study of this thesis, reveals several politically-driven decisions, such as the formation of a distinguished committee on roll stabilization during the early stages of the adoption process in 1935. In this case, the committee lasted for more than five years and provided the man who was going to lead the actual work for the Navy. Their recommendation to appoint the National Academy of Science committee's choice to lead the Navy's effort to introduce roll stabilization into naval ships appears to have been politically motivated to assure that the committee would have a "friend" who was indebted to the committee in charge of the project.

Another political move which also parallels the gas turbine case was the establishment of the Hull and Hydrodynamics Panel in 1952; its first task was the issue of roll stabilization. In light of the ongoing
feud between a Navy laboratory and the Bureau on this issue, the minutes of
the first meeting along with the roster of membership in the panel indicate
the Chief of the Bureau created this forum in an attempt to settle differences
by airing them in a prestigious setting. The panel meetings, which ensued
over a period of two years, were indication of an overwhelming political
process [6-41].

For example, the Navy laboratory wished to retain control over
the subject of roll stabilization R&D in the Navy and not relinquish it
to ONR and its contractor, Stanford University. Also, because a naval
laboratory wanted to keep its testing facilities occupied, it attempted
to create an extensive model test program out of the issue of introducing
roll stabilization into the Navy, which served to retard adoption into
fleet ships.

The CNO's failure to set a policy for roll stabilization soon
after its first adoption into the DE 1037, was also politically motivated.
Lacking a unanimous endorsement from the fleet, and, not wanting to
reverse his original decision, CNO allowed his earlier decision on
introducing roll stabilization in the DE 1037 to stand, but he made it clear
that this was a one-time decision [6-42]. Since the DE 1037 decision, the
only destroyers which have received roll stabilizers were its evolutions,
i.e., the DE 1040, DEG-1 and DE 1052 classes (SCB Nos. 199A, 199B, and 199C).
In spite of extensive studies which were made on adopting roll stabilization
for the FY 1967 DDG, DD 963, FFG-7, DG AEGIS and DDG 47 and in spite
of the fact that each study recommended incorporating the innovation, none of these ships have adopted a roll stabilization device. This consistent rejection has been highly politically motivated as analyzed by the Commander, Naval Sea Systems Command in 1976 [6-43]:

"Will we put fin stabilizers on the DD 963?

"Having asked management's 'why' question, I'll give you management's 'because' answer: Because of economics...economics and politics. Pure and simple, it costs more than we can afford. And it could cause a delay in the published schedules, and politically, we - both the Navy and NAVSEC - can not afford still another delay in the DD 963, if we can avoid it."

Thus, in the case of roll stabilization, as well as in the case of the gas turbine, the case studies have shown that the adoption process is political in nature.

The setting up of prestigious committees such as the SDCC (with panels for hydrodynamics and propulsion, the National Academy of Sciences with similar panels, and the solicitation of opinions from industry, all fall into what Sapolsky [2-52] calls the strategy of "cooptation". Sapolsky defines this term as "attempts of organizations to absorb new elements into their decision making structure".

Other successful political strategies used by the Polaris project and identified by Sapolsky [2-52], such as what he calls "differentiation", "moderation", or "managerial innovation", are not evident in either of these cases. But then why should this be a surprise? Sapolsky is talking
about a very successful innovation and the two case studies discussed here are not in that category, even though gas turbines after a long struggle have been eventually adopted. Then there are other differentiating factors between Polaris or nuclear power, for example, and the two case studies of this thesis.

The various incidents which were cited from the case studies in support of the argument that the innovation adoption process is political as opposed to economic or technical occurred over a period that spans in one case two whole generations - in the other one generation, as compared with a few short years of struggle for both Polaris and nuclear power, with no change of leaders midstream. With the natural turnover of people in an organization over such long periods of time, the two case studies are in effect a conglomereration of many separate case studies (as opposed to only two) making it difficult to talk about one or two political strategies which were used by an advocate or retarding agents.

However, what appears to be clearly an underlying thread is the fact that whether the technology was roll stabilization in the 1935 time frame or gas turbines in the 1970's, the social structure of the organizations involved are clearly pluralistic, fractured into groups with their divergent interests. With this perspective the decision making had to be as the preceding discussion reveals, one characterized by bargaining and negotiation as the interest groups with their parochial priorities and perceptions vied for control, i.e., a political process. What also clearly emerges is that it is foolish to view the boundaries of this "organization"
as limited to the Navy proper because in most instances discussed, the influences as well as alliances sought by advocates or plainly affected parties, extended much beyond the confines of the Navy organization such as the National Academy of Sciences, equipment manufacturers, ship design agents and even Congress.

Decisions dealing with technological innovations cannot be void of either technical content or economic analyses. When an innovation is presented to decision making authorities at the various levels of the hierarchy the justification invariably has to be based on the facts of technical feasibility, superiority of performance and at least economic reasonableness if not superiority relative to that which it proposes to replace.

However, possibly contrary to popular belief i.e., that technical issues have to be dealt with in an accurate fashion, the precise technical logic gets laced with a great deal of uncertainty. Especially in the case of concepts or equipments which have yet to be adopted, both technical and economical analyses accompanying the presentation to the decision authority are largely based on assumptions. Thus the decision maker is seldom faced with black and white decisions.

Cases in point described earlier are the series-parallel turbine decision by the Chief of the Bureau, roll stabilization for the DD 963, and the decision to change back from the pressure-fired boiler to a conventional one.
As a result, and because invariably any technological change has its impact on the power structure of an organization, decisions on adoptions of innovations are driven not by the seemingly accurate technical or economic analyses but by the invisible underlying political forces: political in the sense that the activity from which decisions emerge is characterized by compromise, accommodation and bargaining among groups with diverse interests, so that the result is not necessarily chosen as a solution to a problem but a result of compromise and possibly even confusion.

For example, the research establishment intent to turn roll stabilization always into more studies and experiments, as opposed to buying a stabilizer from the British and installing it into a warship, certainly stemmed from parochial interests. The fact that they succeeded in doing this for decades should indicate that those organizational interests have managed to create enough confusion so as to prevail.

The killing of SEAHAWK, a story which embraces about 5 years of effort that led nowhere, was clearly not an exercise in economics or technical issues but a result of political strategy to sidetrack what appeared to be the beginning of a major investment in nonnuclear propulsion.

What emerges from the many specific incidents described as well as by the analysis of these incidents is that in the internally complex organization of the Navy (as probably in all similarly complex organizations) even though its daily work content is highly technical and
rests on economics, the dynamics of the organization cannot be ignored as a factor in decision making. In other words, it is not possible to understand the mechanism by which decisions are arrived at without resorting to a political perspective. While economic, financial and technical considerations impose constraints on decisions to innovate or not to innovate, the decisions themselves are the result of intergroup bargaining and individual predispositions - in short a political process.
6.2.2 Hypothesis A-2. The existence of other viable and technologically mature hardware options is one of the most powerful innovation retarders.

This hypothesis addresses the existence of technologically mature competitive systems as they retard innovation adoption. Both cases substantiate this hypothesis.

A number of systems competing with the gas turbine managed to delay its adoption for at least 10 years beyond the time that its adoption for warship propulsion would have been technologically feasible and would have provided a superior power plant for destroyer applications. As the case study shows, the adoption of gas turbines had been seriously contemplated for 25 years prior to the actual adoption. While the reasons given in the previously discussed hypothesis, as well as in those yet to be discussed, have most certainly influenced the lack of early gas turbine adoption (especially in the ten years prior to the DD 963 design), this hypothesis may have been the strongest retardant in the first 15 years of the 25-year "struggle".

The roots of the gas turbine's most powerful competitor go back to the early 1930's when Admiral Bowen, then head of the Bureau of Engineering, successfully developed the 600 psi/850° F steam plant [4-1] despite bitter opposition. This became the power plant in most U.S. destroyers during World War II.
During and immediately following the war, the admirals in charge of the Pacific and Atlantic fleets projected a requirement for an increase of 5 knots in destroyer speed. This forced the Navy to commit, in the late 1940's, to the development of a new steam power plant, doubling the steam pressure to 1,200 psi and increasing the steam temperature to 950°F. This decision (made in 1947) was finally accepted by industry in the mid-1950's. The 1,200 psi plant soon became an investment which was not about to be thrown aside lightly. The existence of the 1,200 psi steam plant, developed at great expense, created an environment in which the gas turbine, a fairly radical innovation, would have an unusually difficult road to adoption.

If the DD 931 class design had not adopted the 1,200 psi steam plant after the completion of preliminary design with the 600 psi plant [6-34], it is reasonable to believe that, by the late 1950's, the impetus to supersede the 600 psi plant would have been substantial enough to lead to an earlier adoption of gas turbines. Not all of the 1,200 psi steam plant's problems were solved in the 1950's, but, by that time, industry had conceded that the 1,200 psi plant was here to stay.

In the mid-1950's, a second development, nuclear power, became a competitor. Although initially applied to the most demanding vehicle, the submarine, it did not take long for its champion, Admiral Rickover, to push for, and succeed in having it adopted for destroyers as well. During the design of the DLGN 25, gas turbines were proposed to provide boost power with a nuclear base plant. This concept was studied in detail, but eventually lost out in favor of an all-nuclear plant.
An interesting fallout of the development of advanced propulsion plants for submarines was the pressure-fired boiler, which became another competitor to gas turbines. The pressure-fired boiler was intended initially for a closed-cycle submarine power plant prior to the advent of nuclear power in the late 1940's. However, since the Navy had invested considerable effort over a period of 15 years in developing the pressure-fired boiler and, since Admiral Rickover had prevented its installation in submarines, by the late 1950's it became another competitor to gas turbines further retarding adoption. Thus the Navy's decision in the early 1960's to adopt pressure-fired boilers on 17 new destroyers blocked again the opportunity for gas turbines.

The next competitor to emerge was diesel propulsion. During World War II and the early 1950's, the Navy was deeply concerned with mobilization requirements because of the potential need to repeat the crash program of World War II to build hundreds of destroyers. As a result, an alternate power plant which did not use the same industrial base required to manufacture main steam plant components was to be tested in an actual installation for the propulsion of destroyers. Accordingly, in the mid-1950's, the Navy committed the design of a new class of destroyer escorts to diesel propulsion, once more denying an opportunity for adoption of gas turbines.

The most persistent competition to fin roll stabilization was presented by passive and active anti-roll tanks. The Royal Navy was the first to use the passive variety back in the 1870's. Their first installation into a U.S. warship was delayed until the early 1930's. The SALT LAKE CITY,
the first of the 10,000-ton cruisers built under the Washington Treaty, went on sea trials in 1929 followed by its sister ships, PENSACOLA and NORTHHAMPTON, in the early 1930's [6-45].

Reports on very bad rolling characteristics of the NORTHHAMPTON class prompted an investigation lasting several years, on board full-scale ships as well as with models at a Navy laboratory. Bilge keels and passive anti-roll tanks were installed in two cruisers on an experimental basis. The commanding officer and the admiral commanding the cruisers informally expressed the opinion that ship performance was far better than its original configuration and that the rolling tendency had been greatly reduced. Though tanks in the size fitted were inadequate, there was no doubt that the deepened bilge keels and the weight added to the upper portion of the ship had improved the rolling characteristics of ships in that class.

Unfortunately, an extensive study of roll stabilization was not performed on these ships; only limited instrumentation was allowed on board. Thus, the resultant conclusions regarding the adoption of roll stabilization devices in future ship designs were not overwhelmingly clear.

In the mid-1920's, fin stabilizers were patented by Motora in Japan [6-46]. The U.S. Navy was unaware of this innovation until the late 1930's and made no attempt to substitute fin stabilizers for tanks. Since the tanks were not fully satisfactory, the Navy requested in 1935
that a special committee on ship roll stabilization be formed by the National Academy of Sciences to study this entire matter [6-45]. Again, tanks were investigated as an option. The committee recommended installation of an active-type tank stabilizer in a full-scale ship (completed by 1940 in the 1,200-ton destroyer, HAMILTON). Results were again inconclusive. During World War II the subject of roll stabilizers became a "back burner" issue in the U.S. Navy.

These engineering concerns and the outright failure of the HAMILTON experiment did not deter the same person who was in charge of the HAMILTON experiment from convincing the Navy in 1946 to make another ill-fated experiment on the minesweeper PEREGRINE [6-41]. Meanwhile, during the decade preceding the PEREGRINE experiment, the Denny-Brown fin stabilizer had been installed on close to 100 Royal Navy ships.

The successful British installations combined with the departure of the anti-roll tank "champion" from the Washington scene in the late 1940's, and the establishment of the Hydrodynamics Panel at the Bureau of Ships in 1952 [6-41], eventually combined to eliminate the use of tanks from consideration for destroyers/cruisers (tanks, as competitors to fin stabilizers did not surface again until the DD 963 class destroyer design). Finally by 1959, more than 30 years after Motora had patented the concept and 20 years after its first British warship installation, the U.S. Navy had its first full-scale fin roll prototype installed in the GYATT (the first guided missile destroyer of the U.S. Navy).
Another hardware option competing with fins was bilge keels. Since bilge keels are mechanically very simple, inexpensive to install, present no maintenance problems (they have no moving mechanical parts) and are somewhat effective in reducing roll, they were incorporated fairly early. In the 1930's roll stabilization studies and model experiments with the 10,000-ton cruisers indicated the need to deepen the bilge keels incorporated in the original design [6-45]. Bilge keels were routinely incorporated in all warships, including those few which eventually received fin stabilizers. Though their ability to reduce roll is very limited, bilge keels did satisfy a need. Thus, even though only a token response to roll stabilization, bilge keels were competitors to fin roll stabilizers.

Further evidence of competition between hardware systems is provided by the first U.S. Navy installation of a roll stabilization device in 1915 on the destroyer WORDEN. This stabilizer consisted of a large, electrically driven, gyroscope deep in the ship. It was expected to reduce rolling without reducing metacentric height. Installation of a gyro-stabilizer was approved for the battleship design of 1917. In 1915, while the FY 1917 battleships were being designed, the Bureau of Construction and Repair regarded the gyrostabilizer as well worth the added weight, but by the time these battleships reached the construction phase, the roll stabilizers had been eliminated. The reason was that the gun fire control director had been sufficiently improved to the extent that the Bureau of Ordnance considered additional roll damping unnecessary. The need for stabilization was once again ignored and its adoption was postponed. Again, the existence of a competing system strongly influenced the innovation adoption process.
Some proponents of the purely political view of the innovation adoption process ("strong divisions within the company may get their way without regard to the welfare of the whole" [6-18]) may regard this hypothesis concerning innovation competitors as an outgrowth of the hypothesis that innovation adoption is a political process. However, there is strong evidence for the independence of this hypothesis. The competing technological systems just discussed were not necessarily winners in a battle fought among proponents proposing to solve the same problem in different ways. Often they were winners simply because they were more highly developed and thus were considered safer investments. For example, the competitors to gas turbines during the first 15 years of attempts for adoption were in a more advanced stage technologically than the gas turbine at the time that they won the competition. The case studies indicate that, in most instances, regardless of the Navy's organizational structure, the technological competitors that were chosen over the gas turbine were more completely developed at the time. The same argument can also be made, up to the late 1940's, for fin roll stabilization.

The 1,200-psi steam plant was developed in the late 1940's at a time when gas turbines were in the experimental stage with a maximum size of 2,500 hp (60,000 to 80,000 shp is required to propel a destroyer). Nuclear power was developed and available before a viable gas turbine could compete in the appropriate size. In addition, arguments for nuclear propulsion were unique (very high endurance). The argument for diesels was not on a technological or economic basis, but rather on an industrial
output capacity basis. Diesels were a viable alternative which could meet the the demands of an all-out mobilization like that during World War II.

In the case of roll stabilization, improved gun fire controls were not developed to eliminate roll stabilizers. Once the system existed and performed the desired function, roll stabilization development was retarded, since the value of roll stabilizers for other than stabilizing gun sights was not recognized at that time.

Certainly, in many cases, the competition among different options had political overtones as well, e.g., tanks versus fins in the late 1930's and 1940's [6-45]. In this case, it was the power of the one man in charge, with strong bias toward his patents embodying the activated tank concept which postponed adoption of the competing system for over a decade, longer than the perception of the technical performance merit of tanks warranted. However, the discussion of this phenomenon is reserved for Hypothesis A-3, i.e., the issue of innovation champions.

In conclusion, the message of Hypothesis A-2 is that the two case studies provide proof of the fact that even when the innovation was ready to be adopted from the standpoint of technological maturity, with the apparent potential for superior performance when compared with already accepted options, its adoption was retarded by the mere fact that the already accepted options could provide sufficient performance without the "unknown-unknowns" inherent in new, untried options.
6.2.3 Hypothesis A-3. The lack of an innovation champion strongly retards innovation adoption.

A number of researchers [2-49, 2-20, 2-21, 6-48] have postulated this hypothesis, but mostly in the inverse sense. This fact is quite understandable since Davis, Schon, Sapolsky, and Morrison have selected successful innovations as case studies and, in fact, not just any successful innovation but those of world importance, e.g., nuclear propulsion, jet propulsion, the helicopter, rockets, stainless steel, intercontinental ballistic missiles launched from submarines (Polaris) and continuous aim gun firing systems.

Morrison's [6-48] study of the introduction of continuous-action gun firing systems into the U.S. Navy calls Sims "the engineer of the revolution." As the case study points out, it required the intervention of the President of the United States to make Navy officials accept the new combat-tested method which offered advantages over the technique in use at that time.

Davis [2-49] named champions for each of the three naval case studies he investigated, and he identified four distinct characteristics of an innovation champion:

a. He is a man from the broad middle ranks.
b. He is not the inventor of the innovation he promotes.
c. He is a passionate zealot.
d. He does not pay attention to possible consequence for his career.
Sapolsky [2-52] compared two well-known champions of well-known innovations, Admirals Raborn and Rickover and assessed their skills in bureaucratic politics. Schon [2-20] postulates that the most effective way to introduce innovations into large organizations (which by nature oppose the upsetting of changes which radical innovations inevitably create) is to cultivate innovation champions. Thus, the salient characteristics of innovation champions and the techniques they used to succeed in getting their innovations adopted have been studied by others as well [2-49, 6-48, 2-52].

By contrast, the two case studies of this thesis had no champions. Therefore, the case studies provide an opportunity to examine the characteristics of two innovations which lacked a "passionate zealot" to guide them to success. These innovations drifted on an unsteady course for long periods of time guided by what the NRAC committee called, in the case of propulsion, "diffused management" [6-11].

In both case studies, there is evidence indicating attempts to seek advocates for the innovations. None of the advocates of the gas turbine or roll stabilization provided enough long-range support to justify being called a champion of the innovation. One person did have significant impact during the roll stabilization adoption process but it was negative to the effort.

The gas turbine concept was first introduced into the Navy in 1938 by a young naval officer returning from advanced academic training
in Europe; however, this individual disappeared from the scene without any evidence of further participation. Almost a decade later, another naval officer returned from training in Switzerland, having earned a Ph.D. in mechanical engineering, championed the "free piston" type gas turbine for five years, but he too disappeared from the naval propulsion scene after his failure to achieve its adoption [6-49]. After 14 years of R&D support, not a single unit reached the fully operational state [6-49]. During the design of the Navy's post-World War II destroyers, the machinery design organization proposed using gas turbines alone or in combination with other types of propulsion plants, but no strong advocate emerged.

In the early 1950's, a new organization was established in the Bureau for the express purpose of developing gas turbines [6-35]. Several officers and civilians in the Bureau devoted a good portion of their professional lives to the development of gas turbines. Key individuals inside the Navy's engineering organization authored numerous professional papers on the subject between 1940 and 1960, including a one-time Chief of the Bureau of Ships [6-50, 6-51, 6-52, 6-53]. However, these individuals were "technology pushers" not advocates of "user pull." Although a multitude of papers on gas turbines were presented by engine and propulsion system specialists, not one paper was found authored by a ship designer during that period.

"Technology pushers" were busy finding R&D dollars to develop new engines or to adopt already-developed engines for marine use. No one worried about marketing these engines for use in new ships while they
were developed or even ahead of their development. On the other hand, the user community has generated no champions of gas turbines either, or of any other significant naval propulsion plant type throughout recent history.

Interestingly, the few champions of naval propulsion systems have all been "technology pushers" and resided in the machinery community of the Navy. Admiral Bowen, champion of high-pressure steam, was the head of the Bureau of Engineering; Admiral Rickover also emerged from the machinery division of the Bureau of Ships.

The use of gas turbines was proposed for each new U.S. destroyer design by organizations within the Bureau of Ships as well as by private ship designers like Gibbs & Cox [6-49] and shipbuilders like Bethlehem [6-38]. However, no single staunch advocate emerged from within the Navy to champion the gas turbine when the decision on its adoption was made; someone with enough "clout" like Admiral Rickover. Even the establishment of a separate organization for developing gas turbines in the Bureau did not seem to help foster an environment for the surfacing of such a personality.

Several factors may explain the lack of a champion for gas turbines. In contrast to nuclear propulsion, gas turbines did not present a major new operational feature such as "infinite endurance," or dramatic reduction in cost, manning or weight and space. Also, until the mid-1960's,
available gas turbines were fairly small in size relative to the power demand of a destroyer propulsion plant. The gas turbines of that era consumed a lot more fuel than equivalent steam plants, and they required a fuel type which was much more expensive (NDF versus NSF). Gas turbines were not a technologically superior alternative; they were an incremental advance in ship propulsion, especially in the 1940's and 1950's. Many people did not see the potential success but did recognize the risk associated with the championing of the cause.

Perhaps more important than the technology's state of the art were sociological/environmental causes. During the 1950's, Admiral Rickover emerged as a champion of nuclear power for naval propulsion. It is hard to imagine that a second champion in the same field could have been tolerated within an already disgruntled organization.

Unlike private industry, where the existence of a viable business entity may depend on successful innovation adoption, in naval propulsion, within the Navy, there were definite consequences for the failed advocate of an innovation, but no negative consequences for those who failed to adopt sensible innovations. An engineering naval officer in charge of the machinery organization or one of its components would advance in his profession to higher and higher rank if, on his watch, the organization "stayed out of trouble." The champion of a successful new concept might gain recognition and possibly increase the
chance to make flag rank, but the incentives were weak considering the potential punishment. Since introducing gas turbines represented an incremental improvement in comparison with nuclear propulsion, the operating side of the Navy considered it merely an engineering trade-off.

A roll stabilization advocate emerged for almost a decade, but championed a losing proposition; however, the strength of an advocate is well demonstrated by this case. The Special Committee on Roll Stabilization of the National Academy of Sciences immediately saw the potential of anti-roll fins in 1936 and recommended an extensive experimental program to learn more about them. The Committee recommended Dr. Minorsky, inventor and advocate of activated anti-roll tanks to manage the whole Navy program. Dr. Minorsky, an MIT staff member at that time and holder of patents on activated tanks, managed to redirect the committee's recommendations to experiment with fins; instead, he encouraged the Navy to concentrate its research on activated tanks over the next decade, delaying the adoption of roll stabilization for warships in the U.S. Navy for at least 15 years [6-45].

Dr. Minorsky succeeded in retarding the adoption of fins in favor of tanks because of the fins' lack of effectiveness at slow and zero speed. The case the Committee's report made against fins was based on aircraft carriers and their mission, while the proposed experiments were to be made using a destroyer. Although the HAMILTON experiment in 1940 failed, Dr. Minorsky convinced the decision makers to approve another full-scale
experiment six years later. It was an even greater failure [6–41]. After two failures and ten years without progress in roll stabilization, Dr. Minorsky joined Stanford University and obtained funding from ONR to continue to study activated tanks.

Unfortunately, there were no advocates for roll stabilization on the "user" side through the 60 years of attempts to adopt the innovation for U.S. warships. Its natural source of advocates would have been the "payload" communities, i.e., the Bureau of Ordnance (BUORD) or the Bureau of Aeronautics (BUAER) [6–45]. Neither championed the innovation. In 1918, when the first gyrostabilizers were to be installed on the battleships of 1917, BUORD stated that improvements in gun fire control systems obviated the need for roll stabilization. Additional distilling plants were substituted into the spaces intended for the gyros.

More than 20 years later, the Bureau of Ships again sought roll stabilization advocates. Subsequent to the HAMILTON test the Bureau sent inquiries to BUORD and BUAER [6–45] to determine their interest in roll stabilization. The letter stated that the anticipated roll reduction was from 35 degrees to 5 degrees at the expense of 1.6 percent of the ship's displacement. Specifically, the letter addressed the potential impact on BUORD and BUAER by stating:

"The weight distribution of a recent 1,600-ton destroyer design allows 180 tons, or 11 percent of this displacement for the material under the cognizance of the Bureau of Ordnance. Similarly, the most recent airplane carrier design allows 538 tons, or 2 percent
"of the displacement, for material under the cognizance of the Bureau of Aeronautics. It appears that such military advantages which may result from effective stabilization will primarily benefit the Ordnance installation in the case of the destroyer and the Aeronautics installation in the case of the carrier."

The Bureau of Ordnance was requested to examine the potential contribution of ship roll stabilization to the effectiveness of destroyer armament and to advise the Bureau of Ships what concessions in other ordnance weights could be made to obtain this feature. Similarly, the Bureau of Aeronautics was requested to advise the Bureau regarding carriers. Clearly, the Bureau of Ships was seeking advocates for the innovation.

The response indicated no serious interest. The Bureau of Ships had no control over either the weapons or aviation payload its ships were to carry and could not dictate a weight trade-off of payload for roll stabilizer as a function of overall ship effectiveness. Thus again the Bureau had not succeeded in obtaining advocates for the innovation.

Twenty years later, it was still difficult to find an advocate on the payload side of the Navy or in the Bureau of Ships itself. The case in point was the DE 1037 class destroyer design which eventually became the first class to adopt fin roll stabilization.

The usual concern with maximum ship speed prompted a feasibility study on increasing ship speed by 1 knot. The study summary [6-42] reveals the prevailing mood, "Since the SCB has indicated a willingness to reduce armament somewhat in order to obtain speed, and since BUSHIPS does not seem to favor activated fin stabilizers..."
In response to a formal request by the CNO to study impacts of an increase in ship speed, the Bureau recommended eliminating roll stabilization on September 15, 1958 by stating [6-42]:

"The elimination of dynamic roll stabilization without otherwise changing the design would result in a speed increase of approximately two tenths of a knot, a decrease in full load displacement of 70 tons and a reduction of about $500,000 in estimated cost."

Another impact of not having an advocate was that equipments got moved around during the design phase and often ended up in an unfavorable location. Two different design organizations existed in the Bureau of Ships, i.e., one for preliminary design and one for contract design. The preliminary design organization had no control over the further development of its completed design. Consequently, many changes were often made to a preliminary design. This lack of configuration management was further aggravated by the fact that a third design organization performed the detail design work following completion of the contract design. The detail design of the ship was and still is done outside the Navy under a shipbuilding contract. Having multiple design organizations had made rigorous configuration control virtually impossible.

The incident described in the roll stabilization case study regarding the relocation of the fins on the DE 1037 after the completion of the contract design, in itself, does not have major significance for the process of innovation. It does, however, make clear that the reason for moving the
fins was a concern about other functions in the ship, and the roll stabilizer, having no strong advocate, was placed in an inferior location, as subsequent events proved.

As a result of this relocation, sizable maintenance problems developed for the fin control mechanism [6-54], eventually causing removal of the roll stabilization units from this destroyer class by 1976. The holes in the ship hulls were plugged, thereby returning the DE 1037 class to a nonstabilized status while only half way through their service lives.

Lack of a roll stabilization advocate also hindered the adoption of fin stabilizers into the missile destroyer being designed in the early 1960's to carry the TYPHON Weapons System.

As the case study clearly points out, the preliminary conclusion reached by the BUSHIPS-BUWEPS TYPHON Coordinating Committee was that roll stabilization appeared to offer no cost advantage. The committee decided [6-47] that:

"The saving in topside weight would result in an increased righting arm, but the total ship weight would increase, and the loss in fuel storage space would result in a decreased cruising radius unless compensated for by making the ship larger. From an operational standpoint, it does not appear wise to make the operation of the weapon system against low altitude or surface targets dependent on the operation of the roll stabilization system."

The British would have strongly disagreed with this statement. According to the Royal Navy [6-47], their primary postwar impetus for incorporating
roll stabilization in destroyers was their need for a steady missile-firing platform. Although there have been technical problems with roll stabilization, political and economic limitations have been the basic factors retarding its adoption, accentuating the need for an advocate.

The warship design process starts with the definition of requirements when there is little data on which to base a ship cost estimate. Eventually, various bureaucratic factions begin advocating hardware not included in the initial cost estimate. As hardware is added, planners make an effort to reduce requirements in other areas. The obvious targets are systems with high cost and the weak justification for retention, i.e., not being absolutely essential to the integrity, safety or the offensive capability of the ship.

The only practical way to deal with the motion qualities of a ship in a seaway is to use statistical measures, adding to the weak position of fin stabilizers when they are compared with equipment like another computer on board the ship or an additional communication antenna or radar. For example, the decision to eliminate a $3/4 million device which enables the ship to recover helicopters in the North Atlantic 92 percent of the year versus 78 percent is relatively (especially in view of a lack of a strong advocate) much easier than a decision to eliminate an electric power generator or to not provide space for another 10 people aboard, since both options are very tangible and well understood and have strong advocates within the Navy's organization. Roll stabilization is an expensive item,
costing from $650 thousand to $800 thousand as installed today. Without a strong advocate in the decision-making process, its chances for adoption are low.

Since the operator of the fleet does have an interest in roll stabilization, because it provides increased comfort, extends operating ability, and decreases wear and tear on the ship, it seems unusual that a fleet representative has not become a champion for roll stabilization. The reason is that even though the ultimate decision makers for innovation adoption decisions on duty in the Pentagon come from the fleet operators' ranks, they are sometimes assigned two conflicting tasks. One is to formulate the annual fleet budget for congressional approval, while the second is to formulate the requirements for new warships. With inflationary pressures and a deteriorating fleet requiring replacement, budgetary consideration overshadow the requirements issues for ship items lacking strong advocates. The fleet representatives while in their Pentagon assignment cannot be strong innovation advocates because of their simultaneous budgetary responsibilities. In short, the same people cannot be both advocates and compromisers, at the same time.

Neither the gas turbine nor the roll stabilization innovation had a strong advocate. This lack of an innovation champion retarded the adoption process in both cases. The gas turbine was eventually adopted into the fleet without an advocate; the absence of this strong influence remains an impediment to ship roll stabilization.
The three hypotheses discussed so far characterize the process of innovation adoption.

In most cases when an innovation matures to the stage at which it is sensible to adopt it, it is faced with two major problems.

First, it is faced with a number of hardware system competitors, mostly well entrenched, since they have provided the function up to that time. Consequently, operators are familiar with the characteristics of those equipments, and the maintenance and repair facilities required of a vast organization like the Navy in order to support them worldwide. Also the manufacturers who produce the existing equipment have capital investment in facilities and tools for their manufacturing. In short, a vast network of "friends."

To make matters worse, like in the case of gas turbines, when the new product does not even completely replace an old one but merely provides another option to perform the same general function, it has an even harder time being accepted. If the new technology is clearly superior to the old one and offers some completely new features which the existing hardware does not possess, once the switch is made the old disappears and is forgotten.

But, if the new equipment does not eliminate the use of the existing hardware, case in point gas turbines, then the old one lingers on, preventing the adoption from being fully consumated.
Kircher [5-44] draws on the analogy of Alice in Wonderland looking through the looking glass. People are hemmed in, he says, by the economics of a market that offers only marginal profits, hampered by entrenched patterns of national and local politics, and stymied by the complex problems of using a new technology alongside, rather than in place of, existing ones.

Second, aside from the real, tangible and fairly easily understood hardware competition, innovation is upsetting to the human organization responsible not only for the existing hardware which competes with the innovation but to a much larger segment of the organization extending far beyond the specific hardware which it potentially replaces. What Quinn and Mueller [6-107] call "vested interests and entrenched ideas" have to be recognized and dealt with since issues, like careers, competition between groups, differential perception and other similar factors result in multiple kinds of conflict. The ideas of Lawrence and Lorch [2-33] on confrontation as the most effective strategy for reducing these kinds of conflict are highly questionable. The hope of resolving this type of conflict between managers of two differentiated areas in the organization, by having them openly exchange accurate information with open feelings, is small. Instead what really happens is that the competing groups choose one of two alternatives:

a. Competitive strategies
   1. Seeking prestige
   2. Seeking power relating to those they are dependent on
b. Cooperative (collusive) strategies

1. Bargaining
2. Coopting
3. Coalitions.

In short, a political approach.

Under these circumstances of competition from other hardware options and, by necessity, political processes which characterizes the innovation adoption phase, the need for an innovation advocate is accentuated. In the two case studies of this thesis, innovation advocates did not emerge. Therefore, the other two hypotheses, A-1 and A-2, governed the adoption process, as a result of which it took decades for these two innovations to be adopted.
The Role Of Organization Structure In Innovation Adoption

6.3.1 Hypothesis B-1. The greater the diversity of an organization, the smaller proportion of proposed innovations which will be adopted.

Researchers studying the innovation process have long recognized that [2-7] "...innovation is not an instantaneous act. Rather it is a process that occurs over a period of time and consists of a series of actions."

The Rodgers and Shoemaker [2-7] studies focused on the individual and his or her behavior in adopting innovation. Even on an individual level, the process always occurs within an environment, such as a community, so it is never devoid of environmental influence. However, the impact of the adoption decision is primarily upon the individual. In contrast, the process of adoption within an organizational framework is much more complex, and the consequences of adoption affect many members of that organization.

Empirical as well as theoretical studies of innovation adoption in large organizations have been carried out. Researchers in this field (see Table 1 of [6-55]) have somewhat differing views; however, the majority identify two major stages in the adoption process: initiation and implementation. Initiation has various substages, such as knowledge, awareness, evaluation, search, decision, and selection. Implementation comprises the act of adoption and diffusion.
Of the various variations on the same basic theme (Table 6-1), it is Wilson's explanation which is one of the clearest. Wilson [2-30] divides the initiation stage (which he calls "conceptionalization of an innovation") into "invention" and "proposal of an innovation" phases.

Wilson's theory [2-30] has three propositions which essentially state that the organization which invents and proposes many innovations is also the one which adopts very few. Wilson defines a diverse organization as one which processes many complex sets of tasks simultaneously; thus, the information is not processed in a purely vertical fashion. The

<table>
<thead>
<tr>
<th>TABLE 6-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>A SUMMARY OF THE EXISTING MODELS OF INNOVATION PROCESS</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem recognition</td>
<td>Conception of change</td>
<td>Stimulus</td>
<td>Recognition</td>
</tr>
<tr>
<td>Search</td>
<td>Proposing of change</td>
<td>Conception</td>
<td>Fusion</td>
</tr>
<tr>
<td>Adoption and Implementation</td>
<td>Adoption</td>
<td>Proposal</td>
<td>Action</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Recognition</td>
<td>Evaluation</td>
<td>Issue perception</td>
<td>Problem awareness</td>
</tr>
<tr>
<td>Idea Formulation</td>
<td>Initiation</td>
<td>Formation of goal</td>
<td>Diagnosis</td>
</tr>
<tr>
<td>Problem Solving</td>
<td>Implementation</td>
<td>Search</td>
<td>Search/selection</td>
</tr>
<tr>
<td>Solution</td>
<td>Routinization</td>
<td>Choice of solution</td>
<td>Plans for innovation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge</td>
<td>Idea generation</td>
<td>Knowledge awareness</td>
<td></td>
</tr>
<tr>
<td>Persuasion</td>
<td>Problem solving</td>
<td>Formation of attitude</td>
<td></td>
</tr>
<tr>
<td>Decision</td>
<td>Implementation</td>
<td>Toward innovation</td>
<td></td>
</tr>
<tr>
<td>Communication</td>
<td>Diffusion</td>
<td>Decision</td>
<td></td>
</tr>
<tr>
<td>Action</td>
<td></td>
<td>Initial implementation</td>
<td></td>
</tr>
</tbody>
</table>

563
organization consists of a large number of decentralized entities, each with its own formal hierarchy. A diverse organization, as understood by Wilson, lacks central policy-setting authority.

Wilson illustrates this theory by comparing the innovation process in New York City and in Chicago. He views the New York City government as a diverse organization, while he considers the late Mayor Daley's control over Chicago's government analogous to a more centralized and authoritarian organizational structure. Though there are many innovation proposals in New York, very few are adopted; whereas, there are fewer innovations proposed in Chicago, most of them are adopted.

The Navy, as shown in Appendix A, is certainly a diverse organization. This hypothesis suggests that, because the Navy is a diverse organization, many proposals for innovation are studied, but few are adopted. How well the two case studies of this thesis support this hypothesis is addressed in this section.

The facts gathered in the two case studies demonstrate that the Navy is indeed a diverse organization in which many innovations are proposed, studied, and tested. Yet, many never reach the adoption phase, and those that do are often decades in the process.

In the early 1940's, the Bureau of Ships contracted with the Allis-Chalmers Company to develop an industrial gas turbine for naval use, a program augmented soon after by a contract to Elliott for another
gas turbine. By 1943 the Bureau had invested in a new development, the so-called "free-piston" gas turbine, which it supported for the next 14 years in spite of disappointing results and without a single practical application [6-49]. (During that same period, the French Navy had actually installed the SIGMA Model CS-34 "free-piston" plant into 15 minesweepers and 2 frigates [6-56].)

Another R&D investment in a power plant of questionable value was initiated in June 1946. A group of carefully-selected engineers was assigned to this special submarine-cycle plant development program under the full-time direction of two naval officer's in the Bureau of Ships. By 1952 this program had not reached the stage of even one plant's evaluation, even though a total of $24 million had been spent, and three closed-cycle plants had been manufactured (by Ellis, Alton, and Wolverine).

With the advent of nuclear power for submarines, the Chief of Naval Operations (CNO) attempted to stop the R&D investment in these power plants. However, the Bureau of Ships continued financing several of these plants until the late 1950's when the attention of their proponents was diverted from the submarine application to that of destroyers.

Full-scale experiments with Foster Wheller and Babcock & Wilcox pressure-fired boilers were conducted at the Naval Boiler and Turbine Laboratory (NBTL) in the mid to late 1950's. In 1960, this type power plant was then adopted into a single class of destroyers (the DE 1040 and its missile ship version the DEG-1) but was abandoned immediately thereafter.
Another significant investment was made to develop a combined steam and gas turbine (COSAG) power plant, including construction of a full-scale shore-based prototype. In 1953, the COSAG was studied for two applications: the DL-4 destroyer (80,000 shp) and the DD 931 class destroyer [6-35]. Tests were successfully completed, but the Navy decided not to adopt this type of power plant for any destroyer. (The British visited the test installation at NBTL in 1956 and promptly committed a class of eight destroyers to this power plant concept. The first was delivered to the Royal Navy fleet in 1962.) These three instances ("free piston" gas turbines, pressure-fired boilers and COSAG) show that, as this hypothesis predicts, large numbers of innovations were investigated but none actually adopted.

The impact of the organization's diversity on preventing innovation adoption is clearly demonstrated by the different attitudes within the various Bureau organizations during the mid-1950's. In 1954, the Ship Design Coordinating Committee decided that shipboard installations of new developments should be made as early as possible. The example the Committee had in mind was the COSAG power plant development just discussed. The Bureau was planning to install the COSAG plant in FY 1957 DD, which would have meant a ship delivery in 1961. The Committee thought this plan was unduly delaying adoption and that, unless more zeal was exhibited by the Bureau, the COSAG power plant might "wither on the vine" as had many previous power plant developments. However, the Machinery Design Branch disagreed with the Committee's recommendation concerning installation of a COSAG plant in a destroyer. It rejected proposals for a FY 1954
destroyer program which would have delivered the ship in 1958. However, this group wanted to continue toward a FY 1956 destroyer which would have delivered the ship in 1960. The committee's recommendation was not heeded. Its prediction was realized precisely—this potential innovation was never adopted.

Another example of the effect of organization diversity on innovation adoption was provided by the first and only post-World War II diesel-propelled destroyer design, the CLAUD JONES (DE 1033) class. The DE class under construction in the early 1950's was a 600 psi steam-propelled ship. Primarily because of desire for further austerity and a concern about the country's ability to achieve the necessary warship production rates in case of a repeat World War II situation, diesel propulsion was selected in 1955 for the next class of destroyer escorts, the CLAUD JONES class.

Dissatisfaction with the diesel surfaced in the Preliminary Design and Machinery Design branches [6-57] shortly after the contract design was finalized in September 1955. In August 1956, the Preliminary Design Branch again recommended returning to steam propulsion.

Almost a full year later, a group of senior naval officers and civilians evaluated the DE 1033. They concluded that it was relatively ineffective both as a convoy escort and as an ASW ship because of its low speed. The deficiency was particularly important considering the trend toward increased submarine and convoy speeds; however, the commanding
officer of the DE 1033 asserted that DE 1033 performance was superior to the steam driven DEALEY [6-56]. Personnel in charge of maintenance for the Pacific Fleet reported considerably more maintenance trouble with their steam-powered ships than with the diesel-powered DE's. Nevertheless, the engineering organization, the Bureau of Ships, switched the DE propulsion systems back to steam, after four ships of the CLAUD JONES class had been committed to diesels -- another example of organizational diversity's impact on innovation adoption.

Organizational diversity also played an important role in preventing the introduction of gas turbines during design of the first nuclear propelled destroyer, the DLGN 25. Though the propulsion plant is an integral part of the whole ship, the design of the DLGN 25 plant was handled as a separate entity starting in 1955. In that year, the Chief of the Bureau wrote to W.F. Gibbs (president of Gibbs and Cox) regarding nuclear destroyer studies. He stated:

"In order that from now on, this work may be conducted within the framework of the Bureau's organization, it is requested that you deal directly with the Assistant Chief of Bureau for Ship Design, Rear Admiral A.M. Morgan, for the ship as a whole, and with the Assistant Chief of the Bureau for Nuclear Propulsion, Rear Admiral H.G. Rickover, for matters pertaining to the propulsion plant. [6-58]"

This letter provided significant insight into organizational politics within the Bureau at that time and reflects the abnormal relationship that the nuclear reactor branch had (and still has) with the rest of the organization which take part in warship design. Since
the reactor is the heat source within the complex set of equipments making up a naval ship propulsion plant, logic would dictate that the naval reactors group be a subset of an organization responsible for the design of the total power plant. In this way, those who perform the engineering trade-off studies prior to the choice of power plant type and configuration for a particular ship would ask the naval reactors group, along with other equipment branches of the machinery organization, to provide necessary information, such as weight, cost, volume, services required, fuel consumption, maintenance, and operational manning requirements. Instead, one component of a very specific power plant type (one of many, employed in naval ships) was given special status. When a single equipment branch, such as the naval reactors branch, gains so much prominence that it is excluded from its normal role in engineering analysis and design, another diversity factor is introduced into the organization.

In view of the political leverage of the naval reactors branch, selection of a combined plant option for the DLGN 25 (a nuclear base-plant with another boost plant such as a gas turbine or pressure-fired boiler) was unlikely. Naturally, when the reactor branch is given authority to deal with the power plant design as a whole, they will not be likely to introduce an element of risk into the design for which they are held responsible by adding plant complexity and yielding control over part of the power plant, i.e., the boost power portion, which is the responsibility of another part of the organization. This proved to be the case in spite of compelling logic in favor of such a combination.
For these reasons, prospects for introducing gas turbines combined with a nuclear power plant into U.S. warships were very slim from the beginning of the design of the DLGN 25. The events during the DLGN 25 design support this hypothesis, i.e., the greater the diversity of an organization, the smaller the proportion of adopted innovations.

Numerous propulsion plant innovations were proposed during the design of DLGN 25. The propulsion system branch studied several combined nuclear and gas turbine (CONAG) plants as well as a combined nuclear and pressure-fired boiler (CONAPFB) scheme, using pressure-fired boilers to provide boost power instead of gas turbines. If either the pressure-fired boiler or gas turbine augmentation had been acceptable in principle, it appeared that the propulsion systems branch could have done much to improve the design. Though naval reactors branch personnel were aware of these studies, they had not been consulted regarding actual details of such plants, since the studies were undertaken primarily on an exploratory basis.

Admiral Rickover defeated both proposals on the basis of schedule. However, the chairman of the SCB chose to explore these possibilities fully, in view of the stated objective of CNO to obtain the maximum number of ships out of a relatively fixed shipbuilding budget. Combined plants appeared to offer the possibility of a smaller, less expensive ship, with approximately the same cruising range (at a slower speed) as the all-nuclear plant.
The Bureau was requested to present the SCB with results of feasibility, principal characteristics, and cost studies of DLGN and DDGN types powered by combined nuclear and gas turbine and/or oil-fired boiler plants. Meanwhile, the Bureau and Admiral Rickover proceeded with an all nuclear design for the DLGN in the FY 1959 shipbuilding program, for which a 60,000 shp nuclear power plant was being developed in cooperation with the Atomic Energy Commission.

In its presentation to the SCB, the Bureau presented as many technical disadvantages of the combined plants as possible [6-59] and reemphasized the schedule constraint. The Bureau stated that if the ship were to be included in the FY 1959 shipbuilding program, it was essential that its design and its propulsion plant development proceed expeditiously. It did, as an all-nuclear power plant. The CNO expressed his appreciation for the effort but directed that no more studies of combined plants be made. Once again, the gas turbine case study provides proof for the hypothesis that organizational diversity leads to many proposals for innovation but results in a small proportion of successful adoptions.

The design which incorporated pressure-fired boilers into a U.S. Navy warship for the first time offers further opportunity to prove the hypothesis under discussion. The organizations which had a strong interplay in most nonnuclear propulsion system designs for warships were (1) the requirements-generating side of the Navy (OPNAV) (the SCB and the CNO) and (2) the engineering side of the Navy, i.e., various technical
organizations within the Bureau of Ships, such as the Preliminary Design branch, the Hull Design Branch, the Machinery Design branch (the design coordinators and the propulsion system section), as well as the machinery equipments branches.

The SCB instigated development of an improved DE power plant in 1959 when it requested a study by the Bureau on the feasibility of increasing the DE 1037's minimum speed to a substantially higher value without increasing the existing hull dimensions. Based on the study results, a decision was made to adopt the pressure-fired boiler power plant for two new destroyer classes which were to become the DE 1040 and DEG-1 classes.

As the design evolved, elements of the Machinery Design Branch, as well as certain equipment organizations, attempted to use this innovation as a vehicle for the adoption of other subsystem and equipment innovations, such as non-condensing turbo-generators for sonar, ship service turbo-generators exhausting to the main condenser and an auxiliary boiler for in-port use.

The Propulsion System Design branch was concerned that adoption of additional innovation might eventually lead to rejection of the pressure-fired boiler (PFB) concept as it might be considered the cause of all subsequent problems, even of specific equipments which had no direct connection with the PFB concept [6-36]. Thus, the Propulsion System Design branch argued that the rest of the plant should remain as conventional as
possible and not incorporate new features yet unproven by laboratory test or previous ship installations [6-36]. This recommendation was not followed. As a result, the new developments introduced proved to be headaches for those in charge of fleet maintenance and gave a bad reputation to the concept of pressure-fired boilers. Subsequent to its first adoption into 17 DE's, the innovation did not make the transition into the diffusion phase.

As Lawrence and Lorsch [2-33] point out, the tasks are differentiated in diverse organizations. Each component of the organization pushes for solutions which appear advantageous from its viewpoint. A case in point was the SEAHAWK Project [6-37]. There were many reasons for the ultimate demise of the SEAHAWK Project, which would have introduced gas turbines into U.S. Navy destroyer escorts during the 1960's. One of the reasons stems from the organizational diversity of the Navy and the Department of Defense. Because of diverse interests within the Navy, the SEAHAWK program was stretched over a period of more than four years and was eventually terminated. One of the primary problems was disagreement over the objectives of the program within DOD, especially in the Navy.

Initially, a two-part program was planned: the first step was developing a ship with a combined gas turbine and diesel propulsion plant for the FY 1965 shipbuilding program, followed by a straight gas turbine power plant for the FY 1968 shipbuilding program.

The proposed approach was a product of deliberations within the design organization of the Bureau where a captain had been assigned to
lead the SEAHAWK Project. However, disturbances from other organizations gradually surfaced. OPNAV first issued a new set of requirements, specifying a much higher speed than at the outset of the program.

The requirement for a maximum speed of 20 knots was replaced by a requirement in excess of 30 knots [6-37]. The ship size also increased to accommodate a plant which could attain the increased power requirements. The new design reflected a ship of DD size, with total shaft horsepower requirements ranging from 50,000 to 80,000 as opposed to the DE size ship with approximately 37,000 horsepower envisioned in the earlier studies. To lend further uncertainty to the program, several different machinery arrangement concepts for the CODAG, and COGAG plants [6-37] were also being discussed.

The next impediment to the program came from the Navy's R&D organization which withheld the funds necessary to buy machinery components required for the land-based test program at NBTL. Later, the R&D organization at the DOD level (the DDR&E) reduced the budget. Awarding the design to private industry, specifically, Bethlehem Steel and Gibbs and Cox, resulted in a tremendous rivalry between the Bureau's machinery design organization and the outside organizations [6-37]. The Bureau did not want to give up designing the power plant, so, in addition to acting as the reviewer of the outside designs, it proceeded with its own designs as well. This dual role led to a situation in which the Bureau attempted to discredit the outside designs. This, in turn, lengthened the evaluation process and contributed to the program's eventual termination.
A DDR&E report was the final cause of SEAHAWK's failure*. The report claimed that not enough work had been accomplished to identify the most promising new naval propulsion system, and that the Navy had not devoted enough effort to the issues of manning, noise reduction and increased reliability [6-37], despite strong evidence from minutes of the meetings between the Bureau and SCB to the contrary [6-60]. The directive from DDR&E put the SEAHAWK propulsion system work (which had by then been underway for four years) back to almost ground zero. Once again, organizational diversity played a significant role in preventing an innovation from being adopted.

One of the best examples of the negative influence of organizational diversity on innovation adoption is provided by the last destroyer design (before the DD 963) which failed to introduce gas turbine propulsion into the fleet—the FY 1967 DDG. The Bureau had developed preliminary designs for both gas turbine and steam propulsion systems and presented the results to a full SCB meeting in July 1965. Although the board selected the gas turbine option, CNO subsequently reversed this decision. Because of the problems in the fleet with 1,200 psi plants at that time, it was decided (after 20 years of 1,200 psi steam experience) to revert to the World War II vintage 600 psi plant for a ship which was going to be delivered to the fleet in the 1970's.

* This report was authored by proponents of nuclear propulsion who were working on the DDR&E staff at the time.
The next intervention in the FY 1967 DDG design was from a source outside the day-to-day design decision organization, i.e., the Secretary of the Navy (SECNAV). The Secretary reversed the CNO's decision and ordered gas turbine propulsion for the DDG's.

This design change provided an opportunity for others to introduce new requirements, such as more stringent silencing; the new requirements all contributed to increased ship size. In fact, the ship displacement figure passed the 8,000-ton mark, the point at which it was unofficially understood that nuclear propulsion was to be considered for warships (according to Admiral Rickover).

After the SECNAV decision, the Naval Reactors branch did, indeed, call the Preliminary Design branch to suggest a switch to nuclear power [6–38]. To avoid this situation, the Preliminary Design branch endeavored to reduce the ship's size from 8,400 tons to less than 8,000 tons. The nuclear reactor organization's political power was quite evident, since the chairman of the SCB agreed to reduce endurance by 1,000 miles, reduce the habitability standard for head room in the ship from 6 feet-10 inches to 6 feet-3 inches and delete an emergency generator, in order to achieve a displacement under 8,000 tons. This effort illustrated the influence one subset of an organization can have on the entire organization. The CNO expressed concern regarding the acceptability of an 8,400 displacement to DOD and Congress [6–38], possibly because of the influence of nuclear propulsion proponents in those areas. As a result, the development schedule was further delayed and preliminary design started over [6–38].
In support of the nuclear propulsion advocates, the House of Representatives authorized construction of two DLGN's (36 and 37) in lieu of the DDC's. The FY 1967 DDC's (by this time retitled the FY 1968 DDC's) was terminated on June 21, 1967. Thus two and a half years of effort to adopt gas turbines as main propulsion prime movers of a major warship, ended in defeat again. This was the second consecutive time that "organizational diversity" in the form of naval reactors branch's influence prevented the adoption of a major innovation proposal, i.e., the use of gas turbines for propulsion.

Secretary of Defense McNamara issued a DOD directive in 1965 requiring that all future major weapon systems including new ships, be designed and procured in one package. This directive allowed the Navy to establish performance requirements to which competitors in private industry were to design a complete ship including the selection of power plant type. The winner of the design competition was to then build the ships. No so-called "positive guidance" by the Navy was allowed during the design phase which precluded influence from naval organizations. A new destroyer design, which eventually became the DD 963 class, was developed under this system.

All three competitors for the DD 963 design submitted gas turbine-propelled ship configurations. As a result, there was only one alternative for the organizations within the Navy which favored nuclear or conventional steam propulsion for these destroyers; they could attempt to influence Congress after the designs were completed and the winner selected. The opponents of
gas turbines succeeded in convincing Mr. Rivers, Chairman of the House Armed Services Committee, to request a hearing by the Seapower Subcommittee on the propulsion alternatives for the DD 963 in May 1969 [6–61]. Apparently, Mr. Rivers requested the hearing in response to pressure brought by the steam equipment manufacturers, as well as by those who were pushing nuclear propulsion for all warships in an attempt to reverse the gas turbine decision of all the major bidders.

The Subcommittee report [6–61] endorsed the gas turbine selection, but with some reservations. The report suggested that the Navy be allowed to decide whether the total package procurement method of contracting should be employed in the case of the DD 963 (the ship for which the whole issue was raised), thereby giving the Navy's gas turbine opponents an opportunity to influence the decision through the Navy's in-house system.

A minority report was also prepared endorsing steam propulsion or nuclear [6–61]. The minority report was ignored but further hearings were held which indicated that Congress intended to watch the DD 963 design development and production closely.

Thus, as the gas turbine case study shows, to adopt the gas turbine innovation successfully, it was necessary to circumvent the organizational diversity by putting the propulsion system design decisions beyond the reach of certain organizational components of the Navy.

The roll stabilization case study also provides support for this hypothesis. As early as 1916, at the time of construction of the U.S. Navy's
World War I battleships, the General Board decided to put a gyrostabilizer in the MARYLAND, but the Bureau of Steam Engineering wanted to use the space for a distiller instead. Since the Bureau of Ordnance decided that it did not need the roll stabilizer, the ship roll stabilizer was not installed. Thus, the diversity of the Navy's organization led to rejection of roll stabilizers in 1916.

In 1925, an improved gyrostabilization device was rejected. This time, the fleet operators were responsible for the rejection [6-62]. The influence of organizational arrangement was reflected in the Navy's ability to trade-off conflicting requirements which, in turn, drove toward rejection of roll stabilization. The Bureau of Ships had no control over the Bureau of Aeronautics or the Bureau of Ordnance. Both of these Bureaus were responsible for complex "payload" items on warships, such as planes and guns. The trade-off of ship roll stabilization should have been strongly influenced by the requirements imposed by such payloads, as well as by the trade-offs between ship roll stabilization and other design features introducible into those payload items themselves (a case in point, gun fire control versus ship roll stabilization).

The Bureau of Ship sought explicit maximum motion requirements from both Bureaus, but neither showed much interest in the subject. This loss of possible advocates for roll stabilization left the problem for technology "push" as opposed to the more effective user "pull" [6-62].

The roll stabilization case study reveals yet another example of the diversity of the Navy's organization, i.e., the Office of Naval
Research (ONR). Acting independently from the rest of the Navy, ONR increased the number of proposed innovations but did not increase the ratio of adoptions. In the case of roll stabilization, ONR ironically put its money into the lost cause of activated roll tanks [6-41] after they had failed in two full-scale experiments performed over a period of a decade under the sponsorship of the Bureau of Ships and conducted by a Navy laboratory. What is even more puzzling and depicts organizational diversity at its "finest hour" is that the man ONR sponsored to study activated roll tanks for ship roll stabilization was the same man who conducted the two previous major experiments which failed [6-41].

In an attempt to achieve more innovation adoptions, the Bureau established the Ship Design Coordination Committee (SDCC). This committee's task appeared to be what Lawrence and Lorsch [2-33] term "integration". Interestingly, while the committee existed for about two years, it did not achieve an integrating role at all. Instead, it became another diversity factor in an already diverse organization.

An indication of organizational rivalry's impact on delaying innovation adoption is presented in the deliberations of the Hydrodynamics Panel of the SDCC. Personnel at the Bureau of Ships were tempted to adopt the British system of fin stabilization, while ONR and one of the naval laboratories were opting for more experiments with small scale models and the development of a completely new control system for fins [6-41].

Another rather independent Navy organization, OPTEVFOR, comes to the forefront in the roll stabilization case study. This organization is
responsible for the operational test and evaluation of new systems aboard naval ships. Naturally, it plays a very significant part in the adoption process since it renders one of the final verdicts for new systems to be introduced into the fleet. Since this organization reports to the operating side of the Navy, not the material side, it is another diversity factor in the Navy's organization. Its independence and judgment-rendering capacity were prime factors in the adoption process for fin roll stabilization. Indeed, the first adoption of fin roll stabilization for a class of destroyers followed rapidly after OPTEVFOR's favorable verdict on the "GYATT" destroyer installation [6-63]. However, in the final adoption stage, the impact of the Navy's diversity on innovation adoption became even more visible.

During the DE 1037's design phase, the SCB undertook a study on whether to opt for more payload and higher speed.

Various organizations in the Navy aligned themselves on the issue of stabilization at that time as follows:

a. Destroyer Force Commanders of both the Pacific and Atlantic Fleets were for roll stabilization.

b. The Commanders of both the Atlantic and Pacific Fleets were against roll stabilization.

c. The Bureau of Ships was uncommitted.

d. The CNO (who was previously in favor of adoption) refrained from taking a definite pro-stabilization stand.
In reply to Fleet Commanders, he wrote [6-42]:

"The Chief of Naval Operations appreciates the advantages to be gained through stabilization of destroyers. It is intended that stabilization provided in new construction destroyers when such installation can be considered acceptable within the parameters of weight, space, and cost and without penalty to endurance, speed or other military characteristics. To date, the Ocean Escort DE 1037 is the only class for which roll stabilization has been approved. Continued study is being made on further application of stabilization. Future decision will be largely influenced by results of heavy weather tests recently conducted on the GYATT."

This statement by CNO was responsible to a significant degree for fin stabilization not being adopted in U.S. destroyers, except for the DE 1037 class (to which CNO referred in his statement) and its immediate evolutions, the DE 1040's and DE 1050's - again indicating the powerful influence of organizational diversity on innovation adoption. Unlike the series-parallel steam turbines case [6-35] discussed in support of hypothesis A-1 in which unanimity of opinion led to adoption, the lack of unanimity in this case resulted in rejection (except on those ships for which CNO did not reverse his original decision for adoption).

The deliberations in 1961 over whether to adopt fin roll stabilization for the missile destroyer which was to carry the Typhon weapon system and, in 1965, for the FY 67 DDG, appear to have been repeat performances of earlier debates fueled by the organizational diversity of the Navy.

Again, as in the case of gas turbines, when the organizational diversity factor was eliminated, the decision to adopt roll stabilization
went through without difficulty. A prime example is the DD 963 design by industry. As shown in the case study [6-46], the motion stabilization requirements were derived, alternatives were evaluated and one was picked. The design organization at Litton, winner of the design competition, was a young, project-oriented organization, unsettled in its ways, with minimum "diversity" and strongly controlled at the top. Unfortunately it lacked knowledge of the history described in the roll stabilization case study of this thesis, resulting in a poor system choice, i.e., simple non-activated tanks. This decision was driven mostly by the life-cycle cost criterion by the rules for the method of ship procurement. Had the rules been different and the record better known to the Litton engineering personnel, it is safe to speculate that the selection of fins would have been as straightforward as was the selection of tanks.

In 1971, the design of U.S. warships returned to in-house execution. The organizational diversity present prior to the DD 963 remains and has helped to defeat the incorporation of roll stabilization in all recent designs, i.e., the FFG's the DG AEGIS destroyers and the Strike Cruiser (CSGN).

Thus, both case studies give substantial support to the hypothesis that the more diverse an organization is, the smaller the proportion of proposed innovations which get adopted. Both cases show that when organizational diversity was removed as a factor in the decision-making process, both innovations were adopted.
6.3.2 Hypothesis B-2. Separate chains of command for the R&D and design organizations, spatially separated and lacking effective integration mechanisms, hinders innovation adoption.

The concept of invention is present in the context of R&D; it is tied to the concept of ideas. Associated with it are words such as "inventor," "creativity" and "idea generation." Schon [6-64] states that invention carries with it the concept of an amateur, untrained and independent genius, typified by men like Edison and Morse. Invention is also defined as "undirected science" [2-23] or as a process which provides an initial concept leading an innovation [6-65]. Marquis [6-66] views invention as part of the innovation process. Invention has also been viewed as a variant of idea generation with no particular marketable end product in mind. Most writers agree that though there is no shortage of ideas, the benefit of invention is in putting ideas into practical use [6-67]. Levitt [6-67] uses the word "ideation" to describe the overflow of simple creative ideas. Mueller [6-68] equates invention with conception of the idea. Invention is discovery - the first perception of something whose existence was hitherto unknown. It is equated with basic research, applied research and, in some cases, all phases of product development with the exception of application and innovation adoption.

The research phase of R&D should not be expected to yield any tangible applications: discovery and increased knowledge should be the only objectives. In both private industry and the Navy, basic research is allocated a very small portion (approximately 2 percent or less) of the funds devoted to R&D. The other 98 percent is application oriented.
Sociologists and social psychologists have done extensive research on creativity and the type of environment in which it flourishes [2-27], [2-25]. One result of this research has been the establishment of large laboratories dedicated to creativity. Over the last few decades, many large research laboratories have been constructed in beautiful countryside settings, far from the day-to-day world of application. A large percentage of total R&D efforts of corporations with such laboratories (e.g., Bell, IBM) is devoted to support these institutions. During the business prosperity of the 1950's and early 1960's, little effort was made to analyze the productivity of these laboratories or their relevance to the overall mission of the corporation. However, starting in the late 1960's, these same corporations commissioned studies on laboratory productivity, relevance of results, the effect of communication patterns, both within and outside the laboratories, the organizational structure of the laboratories and their place in the overall corporation structure.

The Department of Defense sponsored a retrospective study appropriately titled Hindsight study [2-23] to examine the relevance of DOD R&D as well as the role and effectiveness of in-house laboratories. The objectivity of this study has been seriously questioned [6-69]. The study's conclusions favored in-house laboratories. Possible researcher bias and the relatively brief time space investigated (20 years) left serious doubts regarding Hindsight study's validity. However, sociologist and social psychologists have pursued a much more rigorous line of research towards the objective of understanding the social forces at work within R&D organizations and between R&D and other corporate organizations.
Many of these organizational analysts have emphasized the importance of organization differentiation with the attendant integration difficulties (Lawrence and Lorsch [2-33], Katz and Kahn [6-24]). If R&D organizations are viewed as differentiated systems, as they are in the case of the Navy's laboratories and ship design/development organization, they too face the problem of internal integration. There is much evidence concerning this integrative difficulty, both in the literature by those who have investigated this phenomenon, and in the two case studies in this thesis. For instance, Rosenbloom and Wolek [2-26] found integration and communication difficulties in a set of R&D organizations because of different information processing patterns between professional and operational task areas. Similarly, Whitley and Frost [6-70], Taylor [6-71], Lorsch and Morse [6-72], and Allen [2-29] have found intraorganizational network specialization and associated communication difficulties in multiple R&D organizations.

To develop new products within a large corporate structure, the R&D organization must gather, process, and transmit information to perform the basic problem solving and coordinating requirements of its component areas. Communication flow is the primary mechanism for effecting this information transfer.

R&D organizations are frequently conceptualized as information-processing systems [2-31]. However, organizational differentiation (in the Lawrence and Lorsch [2-33] sense) and the accompanying network specialization, make communication flow across organizational subsystems problematic (March and Simon [6-23], Dearbon and Simon [6-73]). Communication flow
across organizational boundaries is difficult because of task requirement and coding differences and is often characterized by bias and distortion (Wilensky [6-74], Allen [2-77], O'Reilley and Roberts [6-75]). The problem then arises in identifying the information network mechanisms connecting differentiated networks to their multiple external domains.

In a differentiated R&D structure, "gatekeepers"* function to connect internal organizational networks with external sources of information. Researchers (e.g., Menzel and Katz [6-76], Allen [2-29], [6-77], [6-78] have found that direct and extensive contact across organizational boundaries is inefficient because of coding and linguistic differences and internal and external communication difficulties. These analysts theorize that external information flows into organizations through the "gatekeepers". From the work team's perspective, there are multiple external information domains. Internal laboratory differentiation, as well as differentiation from the rest of the organization, necessitates communication flow across organizational element boundaries.

Since research is intensively idea-oriented, the approach to communications has particular relevance. Maier [6-79] and Pelz and Andrews [2-25] report that communication leads to performance. However, Allen [2-29] found that only certain patterns of communication flow were related to performance, while Farris [2-43] provided evidence that the opposing patterns

* A concept developed by Allen [2-29] characterizing individuals in an R&D organization who act as opinion leaders and who act as the link to the outside professional world for the R&D organization.
were related to performance. The "gatekeeper" hypothesis has prompted research with both supportive and contradictory results (Taylor [6-71], Whitley and Frost [6-70], Walsh and Baker [6-80]). However, innovation studies emphasizing the role of "gatekeepers" in facilitating the transfer and development of innovations do not speak to the organizational locations of these roles (Von Hipple [1-3], Chakbakarti [6-81]). Thus, though the literature provides insight to the communications process in and among R&D organizations, it also presents contradictory and unintegrated results, thereby making the task of optimum organization design, which will facilitate innovation adoption, extremely difficult. Therefore all that can be expected from the results cited above are general guidelines for "do's and don'ts."

Woodward [2-32] and Hall [6-82] first identified technology or task characteristics as important organizational variables. The effects of technology on organizational structure have been investigated by Perrow [6-83], Hickson et al. [6-20], and Aldrich [6-84]. Most measures of technology deal with a dimension of task complexity. For example, Woodward [2-32] studied technological complexity, Zwerman [6-85] discusses job complexity, Morse [6-86] compares task uniformity and complexity, while Perrow [6-83] focuses on a routine/non-routine dimension. These studies support Thompson's [6-25] and March and Simon's [6-23] observations that technology is a source of uncertainty. The literature cited above suggests that the more complex the task (e.g., research versus production) the more the organizational structure must be less formal and less organizational barriers must be tolerated.
At the organizational level of analysis, Thompson [6-25], and Katz and Kahn [6-24] have suggested that the more complex the environment, the more uncertainty to which the organization must respond. Therefore, in this type of situation, the organization must be flexible, adaptive, and less constrained by formal rules and procedures. Under conditions of stable environments, more formal structures are appropriate because of reduced information-processing requirements. Studies testing these hypotheses have generally been supportive. Harvey [6-104] and Burns and Stalker [6-87] found that within a changing task environment, the more successful organizations were less structured than their counterparts. For stable environmental conditions, reverse patterns were present. Miller [6-88] and Burns and Stalker [6-87] established that successful organizations in stable environments were more formal and structured than the less successful organizations.

The analysis presented as part of the discussion of Hypothesis B-1 and information presented in Appendix A, show that the Navy's organization is very complex and operates in an uncertain environment.

These facts, coupled with the results of research on organizational design and information processing in R&D organizations, provide support for the conclusion that the engineering and research segments of the Navy's organization should have a flexible structure. A less formal structure would be more adaptable to conditions of environmental uncertainty and the large information-processing demands resulting from the highly technological content of the Navy's work. Thus, an important
question arises in view of the issue of communications: which segments of the organization should be more closely linked (basic research with applied research or applied research with design development) to improve chances for innovation adoption?

As Lawrence and Lorsch [2-33] and March and Simon [6-23] have observed, differentiated subunits develop local rationality, that is idiosyncratic norms, values, and time frames, which make communication across boundaries problematic. Glazer [6-89] and Kornhauser [6-90] discussed the difference between the broad professional interests and more local interests in industrial laboratory settings. Smith [6-91] looked at research versus applied groups in R&D laboratories. Attempts to coordinate interdependent, but differentiated subunits in a large complex organization must address the conceptual and linguistic differences existing between system boundaries. Communication difficulties will be exacerbated the more dissimilar the tasks are and as both the number of boundaries between units and organizational distance increase. Morton [6-92] postulates that the relation between distance and organizational boundaries is under managerial control. He develops a number of innovative proposals to effect communication across organizational boundaries.

If units have no task interdependence, there are no coordinative requirements. However, most subunits have work interdependence with other organization work areas. If unit structure requires information-processing, that structure should be responsive to differences in task interdependence. If units are task or organizationally interdependent,
their efficient interworking depends on limited structure, i.e., informal contact, low formality, low reliance on the supervisor, and relatively high communication volume. This limited structure, high-interaction pattern leads to effective communication between closely located organizations.

On the other hand, if the units are task or organizationally distant (e.g., a research unit interdependent with Navy contracting or finance), high interdependence will not be achieved through limited structure and widespread contact. Coding, linguistic, and task differences between the differentiated units make widespread informal face-to-face contact inefficient. Networks develop specialized roles to meet the integrative requirement of high interdependence between organizationally distant subunits. Therefore, direct contact with distant areas will be constrained.

Figure 6-1 of Morton's book [6-92] depicts the structure of the Bell Telephone Company and its associated parts, such as Bell Laboratories and Western Electric. Though Morton's recommendation for an appropriate combination of spatial bonds and organizational barriers may not be universally applicable, conceptually it helps in focusing on the problems of a very large modern organization in a highly technological business, similar to the Navy.

The principle characteristics of R&D and their associated organizational implications as seen by Drewry [6-93] are shown in Table 6-2.
The prevailing myth tells us the secret of Bell Labs' success is due to its autonomy. The diagram above may account for the myth, for it is true that Bell Labs is separated organizationally from Western Electric, the recipient of the Lab's R&D. Bell and Western are linked via top management of AT&T, but each has its own president. In this sense, Bell Labs is autonomous.

But Bell Labs is also part of an integrated system, as this flow chart shows. Author Morton describes the functions within the boxes as specialized parts of an information processing mechanism, with information flowing both forward and back. The specialized goals of each part—whether Basic Research or another—must be relevant to the overall goals of the integrated system. The main flow of information is forward, with enhancement and innovation added at each stage. The feedback flow represents appraisal and new needs. Feedback is thus the error-correcting evaluation of the main output of each stage.

Until the end of the war, two barriers existed between Bell Labs and Western. One was organizational: each had its own president. This barrier still exists. The other was spatial: Bell Labs was physically separated from Western. But two barriers became a handicap to the forward flow of new designs and the feedback effect from manufacturing to design. Hence the spatial barrier was eliminated and replaced by a spatial bond, as is shown in the next diagram.

The spatial bond was created by moving the Labs' Development & Design groups onto Western premises. This bond enhances the day-to-day communications between Labs and Western engineers. Because a spatial barrier now exists between Applied Research and Development & Design, these two BTL functions are integrated organizationally within the Labs at the lowest possible level consistent with group size and their technologies. As this diagram shows—as well as the one below—a barrier of one kind is always accompanied by a bond of another. Further, two barriers never exist side by side, lest information flow be impeded.

Spatially and organizationally, the specialized parts of the system are now linked together as seen here. An organizational barrier at the highest possible level (vice presidential) within the Labs protects the freedom and continuity of long-term basic research. Conversely, the fact that Basic Research and Applied Research are located on the same property provides a strong space bond between them. This bond aids flow of information and people, encourages dialogue on relevance of research areas.

**FIGURE 6-1 BELL LABS: THE MYTH VS. REALITY**
**TABLE 6-2**

**CHARACTERISTICS OF R&D AND ORGANIZATIONAL IMPLICATIONS**

<table>
<thead>
<tr>
<th>CHARACTERISTICS</th>
<th>ORGANIZATIONAL IMPLICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent investigative and analytical activities of basic and exploratory research.</td>
<td>Autonomous operations of basic research suitable to a functional organization of technical disciplines.</td>
</tr>
<tr>
<td>Application of basic research to developmental systems.</td>
<td>Necessitates R&amp;D project management organized along hardware lines.</td>
</tr>
<tr>
<td>Emphasis on sophisticated problem solving and inventive extension of state-of-the-art.</td>
<td>Personnel qualifications encompassing creativity and high degree of specialized training in basic disciplines (e.g., physics, hydro-dynamics, mechanics), and applied research.</td>
</tr>
<tr>
<td>Responsive to requirements of projected missions and corresponding needs of ship designer.</td>
<td>R&amp;D organizations receive direction from design organizations.</td>
</tr>
</tbody>
</table>

**SOURCE REF (6-93)**

This analysis reveals a division between basic/exploratory research and development engineering. The former deals with basic engineering disciplines; the latter is the synthesis of these disciplines into concepts for specific functional hardware applications.

The goal in basic and exploratory research is progressive extension of the state-of-the-art in each discipline. The nature of the work requires independent research for which interaction with current needs is unnecessary. Roman [6-94] describes exploratory research as "passive," meaning it is essentially non-directed, i.e., the research scientist has free reign and unfettered creativity. Thus, basic and exploratory research
activities should not be dominated by any other activity. Drewry summarizes his observation, "According to Sorrell's [6-95] guidelines, these activities should be located in separate organizations."

In contrast, the engineering development activities make specific applications of basic research to the process of solving sophisticated engineering problems. This type of activity is directed or "normative" R&D in which a need is identified and an extension of the state-of-the-art is actively pursued to satisfy the need (Roman [6-94]). In the Navy Department, such needs are established through a process of threat evaluation, mission analysis, and design analysis. Threat evaluation determines mission needs, mission analysis measures ship performance needs, and design analysis defines the developmental hardware necessary for achieving performance levels to satisfy mission objectives. According to Drewry [6-93]:

"To assure relevant contributions by the R&D organization, the design engineering organization must have the authority to direct the engineering development activities of the R&D organization. This conclusion is consistent with Sorrell's guideline that an organization which produces a component (in this case, developmental hardware) for the finished product (i.e., new ship design) of another organization should be placed under the latter's jurisdiction."

The Navy has centralized the administration of its laboratories and thereby a substantial portion of its R&D function under a Director of Navy Laboratories (DNL) (see Appendix A). Developmental needs must proceed along the chain of command from the design engineering organization to the Chief of Naval Material (CNM), and then descend through the DNL to the
appropriate laboratories. A more direct approach would be through the engineering organization. Thus, definition of engineering developments to be investigated and the overall direction of such development programs, would come from the group which is continually assessing design options to satisfy the performance levels dictated by mission objectives.

The problem of accommodating the need of basic/exploratory research activities for independence and the need of R&D engineering development activities for direction from the design engineering organization remains unresolved. Drewry suggests the following solution [6-93]:

"The R&D organization is given a 'matrix-type' structure as shown on Figure [6-2]. The long-term, stable, functional side of the organization is structured along basic discipline lines. The flexible and adaptive project side is comprised of individual engineering development projects. The functional groups perform basic/exploratory research on a level of effort basis as well as perform developmental engineering tasks directed by the various on-going projects. Two sources of funds flow into the entire R&D organization: one from DNL for the basic and exploratory research work, and the other from the design engineering organization through the R&D project offices. The principle of 'unity of command,' while always tarnished by the matrix form of organization, remains essentially intact since basic and exploratory research is passive in nature and would not compete with the direction and thrust of engineering development."

Though this solution primarily attacks the funding control issue, if implemented, it would force improved communication and alignment of goals between design engineering and development engineering organizations, and has the potential of enhancing innovation adoption.
FLOW OF FUNDS FROM DESIGN ENGINEERING ORG FOR 6.3-6.6 R&D

FLOW OF FUNDS FROM DNL FOR 6.1-6.2 R&D

SOURCE: REF [6.93]

FIGURE 6-2 MATRIX R&D ENGINEERING ORGANIZATION
Existing differentiation between Navy laboratories and the design development activities, without the organizational interaction suggested by Morton [6-92] and Lawrence and Lorsch [2-33], has a negative effect on innovation adoption. The cases of the gas turbine and roll stabilization innovations support this hypothesis. The negative impact of the postulated hypothesis under consideration manifested itself in numerous ways:

a. Failure by the design organization to involve the laboratories in design trade-off decisions, thus missing the potential benefit of the laboratories' facilities and the experience of their resident researchers;

b. The organizational and physical remoteness of the laboratories from user organizations and the attendant inflexibility in reducing the size of laboratory personnel;

c. The inability to shift emphasis, whether from exploratory research to application or from one discipline of declining need to a designated high priority need;

d. Lack of continuous integrating mechanisms between design and research personnel on either the budgeting side or technical side;

e. Preoccupation in the R&D establishment with advancing the state-of-the-art of knowledge at the expense of efforts toward effective application of known phenomena or of already-invented systems.

The following discussion provides examples from both case studies illustrating these effects of the lack of integration between the Navy's R&D and design organizations.
The Propulsion Panel meetings of the early 1950's provide insight into these laboratory and design engineering interface deficiencies. The Bureau's R&D organization requested that laboratory personnel participate in meetings concerning prospective main propulsion plants. Laboratory personnel were also asked to assist in major program planning conferences and, in some cases, to participate in writing contract specifications. This policy was endorsed by the Bureau, because laboratory personnel had criticized the Bureau for proceeding on a project without laboratory consultation, and then required the laboratory to develop design changes during the test period. These calls for help usually occurred after a sizeable financial investment in the project and could have been avoided by laboratory evaluation during the early design stages.

During the two-year existence of the Propulsion Panel, the issue of inadequate funding capability for non-nuclear propulsion plant development surfaced. The Bureau's Machinery Design Division partially attributed the lack of funds to the existence of the large number of laboratory personnel using up too large a fraction of the development funds [6-35].

The differentiation present in complex organizations such as the Navy, without adequate provisions for integrating functions between R&D and design engineering has sometimes led to fatal delays in development programs. One such situation was the development of the pressure-fired boiler propulsion plant.

The Main Propulsion Panel surveyed the status and results of the engineering study sponsored by the Bureau on the application of
pressure-fired boilers [6-35]. The Panel decided that the supercharged boilers offered several major advantages over the conventional DD 931 class steam plant and recommended development and testing of the pressure-fired boilers.

The response from the R&D planning organization and the Machinery Design Division was mixed. The R&D planning organization contended that the savings in weight and space resulting from use of a supercharged machinery plant on the DD 931 were of such magnitude that a new ship design should be prepared to fully exploit the advantages offered. The organization concurred with the Panel's recommendations for land-based testing and funding appropriations, but disagreed with the Panel's recommended schedule and projected DD application for the FY 1958 program. Although it might have been possible to complete testing at NBTL by April 1958 (based on a contract date of May 1, 1955 and hardware delivery by April 1957), it was not considered advisable to associate this plant with a specific hull until components were successfully tested at NBTL, since there was a tendency to compromise testing to avoid delaying a specific building program. Also, once the plant was associated with a specific hull, outside activities, such as the CNO, were expected to associate normal delays in the testing program as proof of unreliability in the ship installation. Since there was no agreement on the precise direction for the development program, the necessary dollars were not appropriated, and the program was delayed and the research curtailed.

In the early 1960's, when the decision was made to adopt this concept into 17 destroyers (DE 1040 and DEG 1 classes), development was
incomplete. Numerous design problems arose later and the innovation was dropped from the subsequent evolution of the class (DE 1052 class). No further diffusion of the pressure-fired boiler concept occurred. Considering the large amount of R&D funding for supercharged boilers over the 15-year period, starting in 1946, incomplete adoption was extremely wasteful. Better organizational integration between R&D and design engineering in the early development stages could possibly have prevented this course of events.

The SEAHAWK Project is a classic example supporting the hypothesis under discussion. The project's demise was caused by failure to integrate the differentiated activities of the Navy's design and engineering organizations with that of the Navy's R&D organization, as well as with the Director, Defense Research and Engineering (DDR&E) [6-37].

A major turning point for the SEAHAWK Program occurred at the end of October 1962 and, in effect, marked the eventual demise of the SEAHAWK Program [6-37]. In lieu of the planned SEAHAWK Program, the Secretary of the Navy (after a review of SEAHAWK by his Assistant Secretary for R&D) requested that the Navy accelerate and augment RDT&E efforts on surface ship ASW systems and projects. (These included SQS-26, VDS, MK 46 torpedo, steam plant silencing, and the DASH helicopter.) He also wanted to initiate and focus increased attention on selective R&D for longer range ASW programs directed toward significant improvements in ASW systems capability. This direction to the R&D organization resulted in the following:
a. A shift in emphasis to R&D for the ASW weapon/sensor areas
b. The ship platform became secondary
c. R&D in lieu of adoption of innovations became more important.

The CNO and the SCB chairman supported this decision, expressing concern that SEAHAWK designs were not sufficiently advancing the state-of-the-art. The new set of program goals led to the reinvolvement of the vast Navy R&D community in the program, which, in the author's opinion, signaled the eventual death of SEAHAWK.

The development schedule for the SEAHAWK I CODAG plant was extremely tight. However, no funds marked specifically for CODAG had been made available by the Bureau's R&D organization by mid-July 1963, even though the Deputy Chief of the Bureau established the requirement in February. The need to obtain FY 1963 R&D funds for SEAHAWK development culminated in the submission of an emergency fund request. Subsequent to the Secretary of the Navy's redefinition of the SEAHAWK Program, the request was cancelled because it did not accurately reflect SECNAV's definitive requirements. The Bureau proposed to use the AGDE (an experimental destroyer escort of the DE 1040 class) in the SEAHAWK Program as a test vehicle, in an attempt to recapture some funds.

Delays in funding approval and the redirection of program objectives caused two years of design competition and planning to end in a new and more comprehensive R&D program.* In October 1964, the development

* The Coast Guard learned of the Navy's effort in the CODAG area in 1962. In October of 1962, the Coast Guard requested a visit clearance
plan for shore-based testing was completed and submitted to ASN (R&D) for approval. The Chief of the Bureau also requested that DDR&E release $2.955 million of the withheld 1964 funds. By this time, the CODAG plant for SEAHAWK was a thing of the past. The Navy was proposing to develop a gas turbine regenerative cycle power plant using aircraft-derivative engines for the base power plant with a simple cycle gas turbine for boost. The Bureau planned to install a shaft's worth of equipment at NBTL by 1966 [6-37]. This was a two-year slip from initial Bureau planning for the CODAG power plant. Having participated in development planning this time in contrast to the situation two years earlier, the ASN (R&D) endorsed the Bureau's plan and forwarded it DDR&E.

Evidently, DDR&E had not been informed of the Navy's efforts during the SEAHAWK Program and the long awaited DDR&E endorsement did not come. On February 23, 1965, DDR&E responded by releasing $3.5 million, not for the purpose the Navy intended, but for the continuation of the Pratt and Whitney FT4A gas turbine engine tests, additional preliminary design work on the more promising alternative new machinery plant systems for ASW surface ships, additional work on recycling the design of the selected machinery system, and the task of developing better cost estimates for the alternative systems considered.

so that four of their engineers could witness part of the CODAG power plant engineering effort, testing and design work. The Coast Guard quickly adopted the concept for their new class of cutter, while the Navy continued to experiment and study. This situation is almost identical to one that occurred in the late 1950's, at that time with the COSAG power plant when the British came to observe a U.S. Navy experiment and quickly adopted the concept for a class of eight of their destroyers. This emphasis on research and lack of an integrated development policy contrasts sharply with the U.S. Coast Guard's adoption of the CODAG innovation.
Before granting approval to new propulsion system development for use in a large number of ships, DDR&E requested a statement of all RDT&E costs, related SCN and at-sea test costs, initial machinery plant costs for the intended application(s), 20-year fuel and lube oil costs, and maintenance and operating costs. DDR&E considered the proposed development schedule and costs submitted by the Navy to be questionable. It did not appear to DDR&E that enough work had been accomplished to identify the more promising naval propulsion system. Though the Navy had clearly addressed in detail the issues of manning reduction, noise reduction and reliability [6-60], it had failed to integrate DDR&E into this program.

Further, DDR&E considered R&D funds better spent in other than propulsion development areas; every dollar not spent on propulsion research would be available for other SEAHAWK allotted research, such as sonars. Evidence also points to the fact that some DDR&E staff members felt that a 6,000-ton destroyer should not be conventionally propelled; diffusion of R&D funds into ASW items appeared to be a convenient way of stopping conventional naval propulsion plant developments. Regardless of DDR&E’s motives, had they been integrated into the decision process two to three years earlier, the chances of incorporating gas turbine propulsion technology into a U.S. destroyer would have been significantly increased.

Just as DDR&E and the Navy’s R&D community questioned (after four years of work) the basic assumptions for the Bureau’s selected SEAHAWK propulsion plant, they also questioned whether a surface ship was best suited for the ASW job. They broadened the SEAHAWK study to
examine the basic allocation of resources to study airplanes, either
carrier or land based, or submarines as the best answer to the ASW
problem.

By that time, the Navy Material (NAVMAT) organization had been
established with responsibility over the Bureaus of Ships, Weapons and
Air for all Navy procurements. The SEAHAWK Project was transferred from
the Bureau of Ships into the NAVMAT organization under the program manager
for ASW. The majority of funds were invested in other than propulsion
system development. The issue of adopting gas turbines as prime movers
in U.S. warships was left behind, without doubt in great part because of
the consequences of the hypothesis under discussion.

The second case study also lends support to the hypothesis that
the existence of separate chains of command for R&D and design organiza-
tions, spatially separated and lacking effective integration mechanisms,
hinders innovation adoption. The poor motion qualities of the 10,000-ton
class cruisers built in the early 1930's under the Washington Treaty prompted
an investigation lasting several years. The investigation was conducted
onboard full-scale ships and with models at a naval laboratory. Bilge keels
and passive anti-roll tanks were installed in two cruisers on an experimental
basis, but the results did not lead to policy-making conclusions. The
Bureau, still faced with poor rolling qualities in many of its ships, was
besieged by offers of devices which might solve the problem. Accordingly,
in 1935, a special committee of ship stabilization was established by the
National Academy of Sciences at the request of the Navy [6-45].
The committee recommended the installation of an active-tank type stabilizer in a full-scale ship. This was achieved by 1940 in the 1,200-ton destroyer HAMILTON. Again, the results were inconclusive. The HAMILTON experiments never awakened any real enthusiasm in the Bureau of Ships because the engineers in charge of work at the Bureau were appalled by the lack of concern over considerations of weight and space shown by the chief researcher who evidently did not establish good communication with the Bureau.

Practical application of the active-tank method appeared remote after the HAMILTON experiments because of the problems associated with tank control, which appeared more and more formidable as they were better understood. Time lags inherent in the use of activated tanks made a control system based on roll acceleration necessary. The Bureau's engineers at the time were concerned about the possible consequences; substitution of activation for passive damping meant that any error in phasing could result in a component of the "stabilizing moment" acting to increase the rolling of the ship. Also, the Bureau did not directly participate in the design and execution of the HAMILTON experiments; the laboratory had operated on its own.

The outright failure of the HAMILTON experiment in 1940, as well as the subsequent lack of enthusiasm for active tank stabilizers among ship designers in the Bureau, did not deter R&D management in the organization from convincing the Navy in 1946 to fund another ill-fated experiment on the minesweeper PEREGRINE [6-63].
Meanwhile, by 1950, over 100 Royal Navy ships had been fitted with Denny-Brown stabilizers. Though the U.S. Navy was cognizant of the British experience, it made no effort to adopt fins, since the laboratory was preoccupied with active tank experiments and the Bureau was not directly involved in the full-scale experimentation.

After the PEREGRINE failure, the Bureau of Ships sent an inquiry to Denny-Brown in November 1948, 10 years after the first British warship had incorporated the concept and 20 years after it was patented by Motora in Japan. However, the evident success of the British with fin stabilizers had little impact on the U.S. Navy, where research continued to pursue an independent path.

One of the first undertakings of the Hull and Hydrodynamics Panel in 1952 was the investigation of roll stabilizers. The panel noted the failures of the past, as well as the successes of the British and debated which course of action the Navy should take regarding roll stabilization [6-41].

In spite of the evident success of the British and past failures by U.S. naval laboratories, the laboratory proposed to continue experimenting. Specifically, the laboratory proposed to experiment with stabilizing a 40-foot model before a full-scale installation was made. The issue was a practical one; putting a stabilizer on a U.S. Navy ship to uncover the operating unknowns in the technology. Lack of positive integrating mechanisms between the laboratories and the Bureau was evident since
all the laboratory was interested in was to gain more knowledge regarding prediction and scaling techniques while the Bureau attempted to incorporate existing British technology (which was working at the time) into a full-scale destroyer.

After a year of deliberation, the Hull and Hydrodynamics Panel recommended that a program be instituted and vigourously prosecuted to develop roll stabilization systems for naval ships in general and to initiate a specific program to install active fins on the TIMMERMAN. The Panel felt that the program should include: "The assignment of a project manager who will assure strong and enthusiastic leadership and persistence," specifically requesting that the Chief of the Bureau not repeat the error made twice before (in the case of the HAMILTON and the PEREGRINE) by assigning the project leadership to a laboratory researcher. This advise was not heeded; the Chief of the Bureau again assigned management of the development project to the laboratory.

The stabilizers designed and ordered for the TIMMERMAN were eventually installed in the GYATT in 1959. The GYATT was the U.S. Navy's first active fleet warship to have an active fin roll stabilization system. Following the success of the GYATT test, the DE 1037 became the Navy's first new design class to have active fin roll stabilization. After the DE 1037 design, roll stabilization was considered for nearly every new design of destroyer-type ships, but it was only adopted for destroyer escorts which were evolutions of the DE 1037 class. The story on each new ship design was almost identical. First, the need for roll stabilization on the new design was highlighted. A study was initiated during
which a contractor evaluated characteristics such as tanks, fins, and moving weights, (as if no one had ever done so before), and $50-75 thousand later, invariably recommended that fins of a certain size be incorporated. By this time several months had passed, giving proponents of various combat systems an opportunity to propose their latest developments, some of which sold. A few new requirements were also made in the same time period. The SCB realized that the ship was larger and more expensive than initially conceived and searched for something to remove. Among the first items to go were the roll stabilizers.

This now familiar history has still not deterred further research. The most recent laboratory report, published in 1976 [6-96], notes that:

"Additional work is needed in a number of areas. These include roll motions, predictions in quartering seas, minimum acceptable model size and correlation of the ship data, model data and theoretical predictions."

Meanwhile, the proper functioning of the new stabilizers which the Navy has in today's fleet is hampered, not by lack of theory, but by lack of attention to practical operational and maintenance problems. Since inadequate attention was given in their design to operational problems, these fin stabilizers typically had an unsuitable location on the ship (i.e., with high humidity and poor access for maintenance). This problem has further obstructed the adoption process, since the Navy had considerable difficulty and expense in keeping its few existing stabilizers functioning properly.
The historical perspective provided by the preceding summary reveals a differentiated organization without sufficient mechanisms for integrating its laboratories, (which deal with basic and applied research), with its design engineering organization (which designs new Navy ships and is supposed to be well tuned to "user need"). All in all, the past events strongly support the hypothesis that separate chains of command for R&D and design organizations, spatially separated and lacking effective integration mechanisms, hinder innovation adoption.
6.4 The Effect of Policies and Regulations on Innovation Adoption

6.4.1 Hypothesis C-1. Quantity of R&D funding is not necessarily the
decisive factor in innovation adoption.

The sixth hypothesis (C-1 of Table 3-1) addresses the fairly
common fallacy that R&D dollars expended are synonymous with innovation.
This fallacy is so pervasive that certain industries' innovative image is
judged on the percentage of sales contributed to R&D, assuming that the
higher the percentage, the more innovative the firm [6-97, 6-98, 6-99, 6-100].
The same factor is frequently used by analysts in comparing the innovativeness
of world military powers [6-101]. It is also used during congressional hearings
to defend DOD's annual R&D budget, e.g., the Soviets have surpassed the
U.S. in their defense R&D investment.

As discussed in a preceding section of this thesis, 8 of the 10
most significant systems (Table 3-2) were not products of original Navy
research and development but were adoptions of commercial or foreign naval
research and development. The case studies substantiate this hypothesis.

The gas turbine was invented in 1791 by John Barber, an Englishman
[4-2] and was refined by John Dunbell (also English) in 1808 [6-113], by
Bresson in Paris in 1837 [6-113], by Boulton in 1864 in England [4-4], by
Sir Charles Parsons in 1884 [4-5], and by a number of others from countries
such as Hungary [4-10] and Switzerland [6-114]. In the 1930's, the work that
led to some practical applications was accomplished entirely in Europe.
The aircraft-derivative gas turbine, eventually adopted for marine use in
the DD 963, was conceived, developed and applied to aircraft propulsion in
Germany and England in the 1930's and early 1940's [6-102]. The U.S. Army
Air Force first adopted this innovation near the end of World War II,
when Lockheed built a jet plane using a British gas turbine engine. The
U.S. Navy did nothing about aircraft-derivative engines for marine propulsion
until the early 1950's. The "free piston" gas turbine engine was also a
foreign development. Patented by Pescara in the 1930's [6-19], it was
introduced into several French minesweepers [6-56] after the war. In contrast,
the U.S. Navy's development efforts from 1943-1957, did not result in the
installation of this innovation into U.S. Navy ships [6-49], in spite of
the cost of many millions of dollars invested by the Navy in its gas turbine
program.

The U.S. Navy sponsored various gas turbine developments [6-49]
over a period of 20 years starting in 1940. None of these turbines were
adopted as a prime mover in naval ships, other than on an experimental
basis. The first gas turbine used as a main propulsion prime mover was
introduced by the British in 1947; it was installed in a motor gun boat [6-49].
The U.S. Navy began design of a COSAG power plant for a DD 931 class
destroyer in 1953 [6-35]. The prototype was operational by 1957 but the
Navy never adopted the plant for a ship. The British observed the COSAG
experiment at NBTL and promptly adopted the concept into a destroyer class
of eight ships, the first of which was in service by 1962 [6-35]. In the
early 1960's, in connection with the U.S. Navy's SEAHAWK Program, CODAG
power plant was tested at NBTL. This time the Coast Guard requested
permission to observe the test [6-37] and promptly designed a number of Coast Guard cutters (the HAMILTON class) with CODAG propulsion, the first was in service by 1967. The U.S. Navy did not adopt either of these power plants.

The first gas turbine adopted as the main propulsion prime mover for a U.S. Navy warship was G.E.'s LM 2500 engine (marine designation), not a product of the Navy's R&D. It was used in the DD 963 class (30 ships); the first was in service by 1975. It will also be used in the FFG 7 class (50 ships), with the first ship expected to be in service by early 1978. This engine is the marinized version of the engine used in the C5A aircraft and the engine used in the DC-9 (sponsored by the commercial world).

The only Navy R&D investment into the LM 2500 occurred after the decision to adopt if for the DD 963. The investment consisted of testing an engine in the marine environment aboard a military sea lift command ship, CALLAGHAN, side-by-side with another gas turbine, a Pratt and Whitney engine; several other tests were conducted at NBTL to ascertain the engine's response to a destroyer duty cycle. Other testing not sponsored by R&D funding included a shore-based test of a half ship set of the DD 963 propulsion plant, a full ship set of the FFG 7 propulsion plant and an engine test on the Navy's shock barge to assure that the engine could withstand the wartime environment. The engine passed all of these verification tests.

This investment can hardly be called true research and development since it occurred after the engine was already developed and the decision
to adopt had already been made. Thus, the innovation adoption of gas turbines as main propulsion prime movers for U.S. Navy warships did not occur because of Navy R&D funding; it occurred because of other military and commercial developments, although some Navy R&D funds were expended. Between 1940 and 1970, the Navy invested tens of millions in engine development, experimental installations or full-scale testing at NBTL but, eventually, adopted a development funded and sponsored by others.

The situation in the roll stabilization case is no different. The facts described in the roll stabilization study of this thesis support this hypothesis. The Navy did invest heavily in roll stabilization research and development. Over the 60 years of experimentation, countless millions were invested in this endeavor; however, when partial adoption took place in the early 1960's, the device that was adopted had not been developed by the Navy with its R&D funds. Fin stabilizers which the Navy first installed on an experimental basis in the destroyer GYATT in 1957 [6-63] and, subsequently, in 65 more destroyers by the mid-1960's were all products of either British naval development or commercial U.S. development. Roll stabilization experimentation by the U.S. Navy dates back to the early 1910's, but was all based on stabilization by large gyroscopes or by active or passive tanks.

In the late 1950's, Sperry-Rand Corporation developed fin stabilizers for the first commercial U.S. ships which were to have fin roll stabilization, the MARIPOSA and MONTEREY [6-63]. This commercially-supported development was the first fin roll stabilization system designed in the U.S.; it was not a product of the U.S. Navy's development but a commercially
funded one. The 65 pairs of fin roll stabilizers which were installed in U.S. Navy destroyers in the 1960's were procured partly from Sperry and partly from Denny-Brown. (The Denny-Brown design was sold under the Lidgerwood and Canadian Vickers labels.) Thus, the fin roll stabilization system that have been installed in the U.S. naval ships were products of foreign naval and/or foreign or U.S. commerical development, not products of U.S. Navy R&D.

Thus, both case studies have provided significant support to the hypothesis that the quantity of R&D funding is not necessarily the decisive factor in innovation adoption.
6.4.2 Hypothesis C-2. Personnel policies which create anti-risk taking incentives for the Washington military executive tend to retard innovation adoption.

The seventh and last hypothesis to be discussed (Table 3-1) concerns the effects of military personnel such as promotion and job rotation of the Washington military executives on innovation adoption. Innovation adoption constitutes a departure from the usual organizational procedures and is always disruptive, especially in a large, well-established organization. The attention required by the organizational leadership to accomplish the broad mission typical of a large organization can easily result in innovation adoption being given low priority.

Managerial resistance restricts the innovative process for various reasons. Most people tend to be risk-averse. Drucker [6-103] describes the strategy for innovation as based on the clear acceptance of the risk, i.e., potential for failure. Innovation is strongly influenced by the attitudes and practices which exist in an organization, especially at top management levels. Risk aversion on the part of management takes many forms. One such form is the method commonly used to select new projects. Rigorous operations research (OR) techniques are used in an attempt to ensure that the potential benefits of a new project justify its anticipated cost. Risks are analyzed and traded off against those of other candidate projects which is a rational approach to the management of innovation. Schon, [6-64] believes that this method is a mistake because it makes innovation
very difficult if not impossible. To assume any responsibility for implementa-
tion is a high-risk action and the effects of failure can be painful [6-67].
Management generally takes a broad perspective on the potential implications
of new technological innovations and tends to exercise its power to minimize
the "total damage" resulting from failures.

Woodward [2-32], Burns and Stalker [6-87], and Harvey [6-104] have
all investigated the relationship of organizational structure to technology
and have put forward important explanatory and predictive propositions about
variations in organizational structure and technology. A distinction is
made between "mechanistic" and "organic" management systems. In stable
task environments, firms employ "mechanistic" systems which have a sharply-
defined hierarchy with formal rules and procedures. "Organic" systems,
with contrasting characteristics, prevail in environments of rapid change.
When firms with "mechanistic" organizations try to exploit more rapidly
changing technologies and enter new, more dynamic markets, they are
generally unable to make the necessary organizational adjustments.
Abernathy and Utterback [2-4] went even further and developed a model
which they contend predicts the structure of a firm as a function of the
evolution of the firm and predicts that barriers to innovation and probable
patterns of innovation success and failure will also vary as the structure
of the firm evolves.

The military organization with its reward and promotion policies
is primarily a "mechanistic" management system, characterized by the rigid
work breakdown of jobs into functional specialties with precisely-defined duties and a well-developed command hierarchy along which communication takes the form of orders rather than consultation. Such "mechanistic" organizations hinder innovation adoption because of:

a. Heavy reliance on extrinsic rewards (e.g., promotion in the military) which generates predictable and directable responses, as opposed to a more balanced reliance on both extrinsic and intrinsic rewards associated with the act of innovation itself. (The extrinsic system is hierarchically controlled and implemented, generating a climate of conservatism and conformity rather than one of novelty, change and innovation.)

b. Absence of a legitimate, institutional appeal system with its repercussions. Generally, the power to veto innovative or risky ideas rests in the administrative hierarchy. The threat of having one's ideas vetoed by a superior, coupled with the hierarchically-controlled extrinsic reward system, reinforces conservatism, especially among middle rank military managers.

c. Explicit or tacit discouragement of presenting alternative solutions.
Thus, "mechanistic" management systems produce risk-averse organizations.

Small new enterprises and large firms entering a new business introduce a disproportionate share of major product innovation [2-43]. Young entrepreneurs often leave large, well-established firms to create successful spin-off enterprises because they were unable to pursue innovation within the large organization. A number of studies were conducted relative to the inability of well-established corporations to match the
number of product innovations achieved by small and new enterprises. One such investigation, performed by Roberts and Frohman [6-105], developed the concept of "internal entrepreneuring" and enumerated five business practices of large corporations which hinder innovation:

a. Remoteness of upper-management key decision making for innovations

b. Short-term oriented criteria for resource allocation

c. Obstacles labeled "organizational fictions"

d. Reward and penalty systems which discourage risk taking

e. Personnel selection practices for key positions which rely on personal qualifications not likely to characterize entrepreneurs.

There is a striking similarity between the retarding features of "mechanistic" management systems mentioned earlier and those listed by Roberts and Frohman as innovation-retarding corporate business practices.

Conservatism is synonymous with an anti-risk taking attitude. Organizational conservatism in the Navy, particularly in the Bureau of Ships, and the absence of an appropriate incentive structure for decision makers (specifically, the engineering duty officers serving as heads of the Ship Design Division in the Machinery branch and Hull Design branch) were extremely influential in retarding adoption in both cases studied, but especially for gas turbines. Decision makers favored incremental improvements in existing power plants over the more risky gas turbine.
In a lecture on military conservatism, Rear Admiral W.S. Sims offered a point of view which is difficult to implement in the organizational environment just described [6-106]:

"Our objective must not be 'safety first' in the sense of adherence to already tested practices and implements, but safety first in being the first to recognize, the first to experiment with, and the first to adopt improvements of distinct military value."

One of the primary determinants of a climate conducive to innovation adoption is the degree to which executives are willing to commit to risky decisions. The degree to which conservative bias implicit in "mechanistic" models of organization can be counterbalanced is determined by the extent to which such a condition exists in the leadership of an organization.

The two case studies provide several examples which exemplify the non-risk taking characteristics of the military executive, such as unwillingness to place their personal reputation and professional image on the line by advocating an action or decision with unknown or uncertain consequences, thereby reducing the chances for innovation adoption. These examples provide strong support for this hypothesis.

Frequent changes in the military leadership (another military personnel policy) further contribute to the Navy's difficulty in adopting innovations. The turnover of key people [6-107] can severely impede technological innovation. It was mentioned earlier that key people (e.g., product champions, advocates, entrepreneurs) are crucial in guiding a
specific innovation through the development maze. Loss of such key people results in resistance to innovation simply because advocates are not easily found. The most recent recognition of the detrimental effects of the frequent rotation of the military came from the Secretary of Defense, Dr. Harold G. Brown. In an interview with the Washington Post [6-108], he stated that the Army, Navy and Air Force switch officers as well as enlisted personnel from one job to another far too often.

Dr. Brown argued against the principle that frequent changes are required in the military because it is often necessary to move personnel from one job to another during wartime:

"I don't see how it can be universally applied anymore. A certain amount of flexibility is necessary, but not everybody is going to be CNO (Chief of Naval Operations) so I don't see why everybody should be trained to be CNO, and I don't think getting to be CNO means spending six months in each of 20 jobs."

He stated that frequent changes in assignments are doubly expensive because of the cost of moving a man and his family from one station to another as well as the decreased efficiency that he had often observed "as a consequence of people not staying on the job long enough to finish it."

Brown did not specifically address the impact of this phenomenon on innovation, but, having previously served as Director of Research and Engineering, he was well aware that decreased efficiency resulting from duty tours not "long enough to finish the job" could have a significant effect on the innovation process.
The mechanism by which frequent changes in the military management in Washington work against innovation adoption is as follows:

a. An innovation is proposed
b. Resistance from various segments of the organization surfaces
c. A fight ensues
d. A winner emerges

The opposing forces (assume they are the anti-innovators) do not give up the war just because they lost a battle. They examine the duty schedules of the key military management personnel and bounce it against the schedule of the development program on which they lost the battle. If it is a normal ship design, chances are that the development program is of longer duration than the key military executives' tenure on the job.

e. New military executives arrive
f. The opposition forces reopen the case
g. A rematch of the earlier fight is on
h. A winner emerges again (not necessarily the same winner as earlier, this time it might very well be the innovation retarder)
i. Innovation adoption fails.

The detrimental effect of frequent rotation of the military personnel on innovation adoption is shown in the development of the winch for the UNREP system on the fleet oiler A0 177 (the contract for ship detail design and construction was awarded to Avondale Shipyard in the fall of 1976). The Navy's design organization decided to incorporate electrically-
driven winches in this ship rather than hydraulically-driven winches (currently in the fleet and presenting maintenance problems). The SHAPM favored this choice but his staff was opposed to the innovation. The SHAPM was transferred prior to the contract award. With the support of NSWSES (a naval engineering field activity) and private contactors, the SHAPM staff convinced the new SHAPM to revert to hydraulically-driven winches, against the advice of the Navy's central design and engineering activity.

One may argue that rotation of the military leadership is helpful for innovation adoption because it forces conservative military leaders out of positions in which they may be holding up progress. This would most often occur in a case when the particular military leader was an innovation champion himself at the beginning of his tenure and, having successfully achieved adoption, did not want to spoil his image as an innovator by risking championing another innovation which might fail.

This hypothesis was not intended to suggest no rotation at all such that the military leader would stay in one position for 10 to 20 years, but to suggest that 2 years is too short and more like 4 – 5 years would allow sufficient time to recognize the value of some significant innovations and then see them through the adoption phase. It takes two years or so to get familiar with all the ramifications of the available technologies, the R&D budget cycle, past history, the organizational structure, the innovation retarding personalities, etc. If a particular military leader is inclined to then champion some innovations it will take him at least
another two to three years to see through one or two significant innovation
to the stage beyond which its potential demise on the road toward adoption
is reduced to a minimum.

The preceding discussion indicates that some, although spotty,
recognition has been given in the literature to management risk aversity
and the current rotation policy for military personnel as factors which
may influence innovation adoption. The two case studies do offer support
for both the issue of lack of incentives as well as that of the frequency
of rotation as influencing innovation adoption. Several times during the
design of the Navy's post-World War warships a risk-averse management in
the Navy caused setbacks. Fortunately, in most cases, either the ship
was never built or the decision was reversed by subsequent decisions (at
times forced by pressures from outside the decision-making system for U.S.
naval ship design, such as from the Secretary of the Navy), By 1951, the
Navy felt that a new prototype destroyer design was needed which would
would permit the new ships to be built in quantity in the case of an
emergency. The DL-2 (ex-DD 927) configuration was considered unsuitable
as the prototype because it was too large and intricate. The DD 692 design
was obsolete and also had rather unsatisfactory seakeeping characteristics.
Since large sums of money would eventually be expended if these new
destroyers were built in quantity, it was considered important that the
design be excellent in all respects [6-35].
The Navy felt that the design should be modern, but not experimental. Knowledge gained from the DD 828 design, the TIMMERMAN, was to be applied where it was considered to be sound practice.

As a result of such considerations and in spite of the introduction of 1,200-psi steam in the preceding destroyer design (the DD 927 class in 1948), the design of the DD 931 class was completed on the basis of a 600 psi, 850°F steam cycle. According to the Bureau, the 600-psi plant was selected because [6-35]:

a. The ship was a prototype for a large quantity buy,

b. All major shipbuilders were experienced in problems associated with 600 psi, 850°F plants,

c. Many designs were available in the 600 psi range,

d. The 600 psi plant required less critical material than higher temperature cycles.

As the design progressed, there was a growing conviction that the 600 psi, 850°F plant was obsolete and that the selection of a 600 psi, 850°F cycle should be reexamined. Shipbuilders engaged in the production of 1,200 psi, 950°F plants were questioned about production problems; no major problems were reported. The higher steam conditions also offered an improvement in fuel rates. Near the end of the contract design phase, steam conditions were changed to 1,200 psi, 950°F, after more than 18 months of ship design work using an obsolete power plant design. Risk aversity and lack of incentives for innovation were the basic reasons for originally reverting to the 600 psi plant design.
Another case of a backward step occurred 14 years later. The ship characteristics development for the FY 1967 DDG started in January 1965. Guidance provided by the Chairman of the SCB initiated studies to meet the CNO-directed goal for a ship displacement under 6,000 tons and a follow ship cost less than $69 million. Various propulsion plants were considered during these studies, including steam, combined steam and gas turbine, and an all gas turbine plant. Steam plant studies were based on 1,200 psi boilers. The Chief of Bureau of Ships [6-38] recommended eliminating the combined steam and gas turbine plant from consideration since it incorporated the disadvantages of the steam plant while requiring specially trained personnel to operate the gas turbine plant.

Characteristics development for the steam plant and all gas turbine propulsion plant options proceeded until the SCB recommended a gas turbine propulsion plant for the FY 1967 DDG. Nevertheless, the CNO chose the steam propulsion option for the FY 1967 DDG. Because of this decision and the maintenance problems with 1,200 psi plants present in the fleet at that time, the Chief of the Bureau decided to revert to 600 psi boilers in lieu of 1,200 psi boilers. This decision to revert to the World War II state-of-the-art in ship propulsion came almost 20 years after the decision to install a 1,200 psi plant in the DD 927 class and subsequent destroyer designs.

The Secretary of the Navy requested a briefing on the power plant selected for the DDG FY 1967, including an analysis of alternatives. On the basis of this review, the Secretary directed the Bureau to adopt gas turbines. This action overruled the risk-averse Bureau and CNO decisions.
Risk-aversive management also hindered the DE 1052 class design in the early 1960's. Contract design had been completed and bids were being accepted for detail design and construction when the Bureau Chief changed the propulsion plant boiler from the pressure-fired boiler design of the previous class (the DE 1040) back to unloaded 1,200 psi boiler. This decision caused a substantial delay and necessitated redesigning the ship to accommodate the unloaded 1,200 psi boiler power plant.

Management risk aversity was the primary reason for the change; however, in this case, the second half of the hypothesis, i.e., frequently changing military executives in Washington, was also a contributing cause. The Chief of Bureau retired just as the original DE 1052 contract design was completed. The new Chief came from a naval shipyard command on the West Coast; it had been several years since he had had duty in Washington. In his prior Washington tour of duty, he was head of the Machinery Design Division when the initial tests of the pressure-fired boilers were made in 1957; thus, he was well aware of the early development problems.

The people in the machinery design organization knew the new Chief well, and some of them were unhappy with the pressure-fired boilers but had lost out on the first round at the time that pressure-fired boilers were incorporated into the DE 1040 design. As the new Chief arrived on the scene, they saw another chance to win. The in-house concern over the pressure-fired boiler, along with a phone call from W.F. Gibbs of
Gibbs & Cox suggesting the change back to the 1,200 psi boiler (for his own business reasons), happened to fall on receptive ears, and a backward step was taken. This time both the risk aversity factor and the frequent changes in military management played a role in blocking innovation adoption.

Further support of this hypothesis is afforded by the Chief's decision to proceed with two-casing series-parallel turbine designs rather than incorporating the conventional cruise turbine. This basic two-casing series-parallel design had been operational in the German Navy 10 years prior to the Bureau's decision (in sizes up to 50,000 shp per shaft and with comparable steam conditions). Available records indicated no appreciable difficulties except with middle and end packing glands (because of rigid mounting and close clearances as a result of an attempt to obtain maximum efficiency). This information was verified by a NBTL employee from Germany who had shipyard experience with these installations. Investigation revealed that packing gland difficulties experienced by the Germans with their series-parallel turbines had already been corrected by features incorporated in both General Electric Company and Westinghouse Electric Corporation designs.

In addition to the results of these studies, the Chief of the Bureau cited consultations with the following sources regarding the advisability of this innovation: representatives of Westinghouse and G.E., experienced officers and civilians at the Bureau of Ships, the Main Propulsion Panel, the David Taylor Model Basin, the Engineering Experiment Station at Annapolis and NBTL.
The Chief further justified his decision in a memorandum stating:
"In view of the unanimous opinion of BUSHIPS experts that the design has every promise to be successful, we must accept some risk in order to take this important step of progress." In the memorandum the Chief claimed as little responsibility for his decision as possible (further evidence of risk-aversive management).

One of the reports of the Main Propulsion Panel touched on the subject of frequent changes in the military. The panel discussed the problem that formal evaluations, final reports or comprehensive lists of objectives did not exist for many of the previous propulsion development projects. The panel was concerned that the TMMERMAN project might suffer the same fate, even though a private firm was under contract for overall analysis of results and preparation of reports.

The panel attributed many problems to "changing personnel in both the Bureau and OPNAV injecting changed requirements and views into un-finished projects without too thorough analysis of causes and effects".

The Main Propulsion Panel referred to the risk aversity within the Bureau's "executive suite" when it stated [6-35]:

"During the Committee's discussions it was apparent that the general atmosphere extant in the Bureau is one of undue conservatism. The Committee understands that it is the current practice to avoid the incorporation of developmental installations in new construction ships. This attitude may well result from the policy of the CNO's directive (OPNAV INSTRUCTION 4470.1 of 28 May 1953),
only for production items and that the ship is the laboratory for the service evaluation of hull designs and new propulsion plants. It is believed that the time is now ripe to reconsider this practice. In order to obtain maximum engineering progress while the current opportunity exists, the Committee feels that shipboard installations of new developments should be made as early as possible. This is the period when engineering judgement indicates a promise of improved performance coupled with reliability."

The Committee thought that changing the existing practice could result in some construction delays; however, the accelerated engineering progress more than justified this risk. The Committee urged the adoption of such a policy to consolidate engineering gains to the maximum extent. The Panel's recommendation was ignored.

Risk aversity could have very well stopped the development of nuclear propulsion had it not been for its strong advocate, Admiral Rickover. In October 1953, the Chief of Naval Operations informed the Chief of the Bureau of Ships that there was no longer an operational requirement for closed-cycle power plants of Wolverine, Ellis, and Alton types for submarine propulsion. The CNO instructed the Bureau of Ships to review the 1955 research budget and to recommend diversion of research funds from submarine closed-cycle projects to submarine nuclear propulsion or other important projects.

The Chief of the Bureau replied [6-35]:

"The Bureau feels that while progress to date has been most encouraging, the history of all power plant developments has been that there is a considerable period of elapsed
time in the development phase before such plants should be considered for general adoption. In spite of the remarkable success which has attended the development of the atomic plant up to this point, it is believed only prudent to assume that it will be some time before the technical difficulties which must be anticipated have been sufficiently countered to make the general adoption of atomic power for submarine propulsion advisable."

Less than a year later, the NAUTILUS performed well and all subsequent submarine designs were committed to nuclear power. Again risk aversity in the Bureau management is evident.

About a decade later, at the time of the FY 1967 design, risk aversity was demonstrated by the Chairman of the SCB (the most important post in the U.S. Navy relative to the characteristics of new Navy ships). In a memorandum to the CNO he stated [6-38]:

"In the past few years, we have had many problems in convincing OSD of our need to build major fleet escorts. Some of these problems may have been brought on by some of our own activities. For example, various proposals for the use of gas turbine propulsion have been the cause of division of opinion within the Navy itself. I am by no means hereby saying that new ideas are no longer welcome in ship propulsion; rather, I am saying that our need to proceed with building numbers of escorts must not be impeded by consideration of untried and unproven propulsion schemes."

This statement was made at a time when British and Soviet navies had been using gas turbine-propelled ships for five years in their fleets, the U.S. Coast Guard had commissioned a class of CODAG-propelled cutters, and numerous navies and commercial shippers had operational gas turbine-propelled ships [6-38].
Although risk aversity was not a major factor in delaying adoption of roll stabilization, frequent rotation in the military had a definite impact in this case. Experiences of OPNAV officials and SCB members with ship equipment had had a very significant influence on their decisions regarding features of the Navy's new ships. Favorable impressions of a particular ship feature makes its adoption more likely. Frequent personnel rotation brings people with different experiences into decision-making positions at various stages of ship design. Corresponding decision changes are, therefore, predictable. This situation has profoundly influenced the adoption of roll stabilization.

Many OPNAV decision makers who were formerly ship operators have had no experience on small ships and are unaware of the difficulties in operating a small destroyer without roll stabilizers in adverse weather conditions. Further, many former ship operators holding positions in OPNAV do not have experience with roll stabilized ships, making a comparative analysis impossible. Those decision makers having direct experience with roll stabilized ships may have been on ships equipped with tanks rather than fins. If the latter were poorly located or too small, roll stabilization would be ineffective and their perception of roll stabilization in general would be strongly negative. Fin maintenance/reliability problems on the few destroyer escorts which had them created similarly negative impressions on their commanding officers. Much imagination is not required to see that changing military executives in Washington responsible for the selection of new ship characteristics would likely result in changed decisions relative to the incorporation of fin roll stabilizers.
Thus, it appears that the two case studies provide strong evidence that personnel policies such as frequent rotation among Washington military executives, or risk-aversive attitude which develops as a result of policies regarding promotion in the military are major impediments to innovation adoption.
6.5 Concluding Note

It is interesting to note as a parting ancedote of this chapter that both the gas turbine and fin stabilizer innovations share even the fact that, when they were finally adopted, it was for the wrong reasons.

The gas turbine was finally adopted because it won an economic trade-off based on life-cycle cost which it had previously always lost. It was not adopted for many other sensible reasons, more difficult to quantify but much more important, as discussed in previous sections of this chapter.

During the ship design in which adoption eventually took place, (the DD 963), life-cycle costs were calculated for three engines per ship which were electrically cross-connected in order to allow the propulsion of both shafts with any one of the three gas turbines. By cruising on one engine operating at a higher load, a much lower fuel consumption rate was achieved than if one engine per shaft were used.

Also, the gas turbine acquisition cost and spare and repair parts, strongly influencing costs, were depressed at the time of the trade-offs because of at least two factors:

a. Competition between General Electric and Pratt and Whitney
b. Excess gas turbine units at G.E. due to the cancellation of procurement of a number of C5-A aircraft which used the aircraft version of the LM 2500.
However, subsequent events changed the whole picture to the extent that the predicted marginal differences in the life-cycle costs of the gas turbine and steam ship options would have been further narrowed or reversed. These events were:

a. The Navy, during the technical infusion phase prior to contract award of the DD 963, insisted that a fourth engine be introduced, thus adding to both acquisition and logistic support costs.

b. G.E., having cornered the market by having the Navy's logistic support system committed to its second generation engine, by having no more left over C5-A engines, and by having won an additional contract for engines for 50 destroyer engines (FFG-7 class), raised its price from $1,090,000 per engine for the DD 963 to $1,800,000 for the FFG-7's in 1974 (a 75 percent increase in four years).

c. Once the fourth engine was introduced, it provided the basis for Litton, the winner of the contract, to submit a value engineering proposal to save the acquisition cost of the cross-connect motor/generators. This proposal was accepted by the Navy and the cross-connect feature was eliminated from the DD 963, thus increasing fuel consumption and further deteriorating the gas turbine's life-cycle cost position relative to steam.

d. Navy Distillate fuel prices skyrocketed from $5.00 per barrel in 1970 to $20.00 per barrel in 1977. This change, coupled with the change in (c.) above, caused a dramatic shift in the standing of fuel cost relative to the other cost elements which make up total life-cycle cost, e.g., acquisition, maintenance, and Manning further penalizing the gas turbine option.
The result was the compounding impact on life-cycle cost by an additional engine costing 75 percent more, increased fuel consumption due to the lack of the electrical cross-connect, and quadrupled fuel prices. This impact solely on a life-cycle cost comparison basis, probably reversed the initially estimated relative standing of steam versus gas turbines for the DD 963.

Therefore, even though eventually, after years of struggle, the gas turbine innovation was adopted because it won the usual economic trade-off, it appears that it may not have won in the light of changed circumstances. This is not to imply that the decision to adopt the gas turbine for the DD 963 was wrong, but simply that the adoption was for the wrong reason. It was correct for numerous reasons other than those which lend themselves to being easily incorporated into the life-cycle costing methodology such as: good availability, reduced operating crew, rapid starting capability, light weight, maintenance by quick replacement, etc.

In the case of roll stabilization, as the case study showed, the primary reason for the adoption of the fins for the DE 1037 was their predicted benefits for the new SQS-26 sonar performance. Subsequent studies assessing the benefits of roll stabilization on U.S. destroyers, including the DD 963, do not cite sonar performance as a reason at all but rather, helicopter landing in rough seas, crew comfort, weapons reloads, and replenishment at sea are given as the reasons for the need for roll stabilization. Yet, there have been no adoptions for these reasonably well quantifiable
reasons; all of the destroyer escort classes which have roll stabilization today have them because of their sonars. Again, ironically, it appears that the adoption was accomplished for the wrong reason. Interestingly, this phenomenon of adoption of sensible innovations for the wrong reason is not unique to naval ship design. Albert Horshman [6-109] documented a few years ago a number of similar cases for development projects in Latin America, Asia, and Africa.

Both of these innovations are sensible and should have been adopted sooner for many good reasons. However, they were not adopted for the proper reasons, further substantiating two of the hypotheses:

a. that the innovation adoption process is not a rational, orderly process but rather a political one, i.e., innovation adoptions are achieved by bargaining, deception and other means of resolution of the conflicts present in a large, complex organization such as the U.S. Navy.

b. that overemphasis of cost considerations during design development, to the detriment of other sensible factors more difficult to quantify, retards innovation adoption.
CHAPTER 7

CONCLUSIONS

The two-part research question posed at the outset of this study was:

a. Are there similarities in the factors influencing innovation adoption for these two technologies which differ in their engineering features, their operational use, the organizations responsible for their development and eventual adoption, the industries that manufacture them, the policies regulating their procurement and other differences.

b. Do the study results indicate the existence of certain conditions conducive to innovation adoption; if so, can fundamental changes be realized to create conditions enhancing innovation adoption for future naval ship designs?

To investigate the first part of the research question, seven hypotheses (Table 3-1) were developed. The two case studies focused on entirely different systems, in terms of functional performance, perceived essentiality for a warship, their producers, potential markets stemming from their adoption, and the character of the Navy organizations concerned with the two systems. Inspite of these substantial differences, both case studies lend strong support to all seven hypotheses as demonstrated by the preceding analysis. Thus, there is clearly a great deal of commonality among the factors influencing their adoption.
Although the relative importance of the factors affecting the Navy's adoption of the two different innovations (gas turbines and roll stabilization fins) varies, the factors themselves are common to both. For this reason, it is likely that the seven hypotheses are more generally applicable, particularly for naval ship design.

The second part of the research question asks whether analysis of the two case studies indicates any realistic actions which the Navy could take to enhance the adoption of innovations; the answer is yes.

Although no simple solutions exist, a number of possibilities did emerge. First, it is clear that, while there are changes in organizational structure which might promote innovation adoption, the complexity of the vast Navy organization cannot be simplified enough to radically impact the innovation adoption process. The multiple missions of the Navy, the sheer size of its organization, and the technological complexity of its equipments will be present no matter how the organizational structure is changed. While it is possible to create conditions conducive to innovation advocacy through appropriate environmental changes, no clear-cut formula emerges to foster innovation champions. In addition, without incentives for innovative individuals and/or organizations and with no penalties for the organization which fails to innovate, the innovation adoption rate will probably remain small.

In spite of these fundamental limitations (which appear to be inherent organizational constraints), the following changes would enhance the adoption of innovations into new naval ships:
a. Establish conditions within the Navy which will foster high level engineering policy decisions for the introduction of significant ship systems or transfer the ship design function from the diverse organization of the Navy to the private sector (thereby creating incentives to introduce innovation).

b. Create stronger integrating mechanisms between the Navy's R&D and design communities.

c. Introduce both organizational and environmental changes that would encourage the emergence of innovation advocates.

d. Diminish the increasing emphasis on schedule and cost considerations during the ship design phase by reducing the importance of ship acquisition management and by strengthening the central design and engineering organization.

Each of these recommendations will be discussed in turn.
Establish Conditions Which Will Foster Policy-Based Decisions
For Innovation Adoption Or Transfer The Design Function To The
Private Sector

One technique to foster early adoption of innovative systems, used by the Royal and Soviet navies in both the roll stabilization and gas turbine cases, was the formulation of top level policy as opposed to ship-by-ship trade-offs.

The British observed the U.S. Navy's COSAG experiment in the mid-1950's and promptly initiated the design and construction of the COUNTY class destroyers incorporating COSAG; the first of eight ships in this class was commissioned in 1962. The British adopted the COSAG plant inspite of COSAG's many disadvantages because they did not restrict their trade-off analyses to conditions relating only to the particular ship class being designed. Instead, the Royal Navy instituted top level policy to deliberately introduce gas turbines into the fleet via a step-by-step approach. As a result, they started to accumulate operational experience with gas turbines more than ten years before the U.S. Navy's first gas turbine installation.

In addition to the British, the Soviets, Canadians, Danes, and Germans adopted gas turbines for their destroyers (initially in combined plant configurations), while the U.S. Navy kept experimenting with different types of power plants. The U.S. Coast Guard, having observed the Navy's CODAG power plant design for its SEAHAWK destroyer program in the
early 1960's, promptly adopted it for a number of new Coast Guard cutters. The U.S. Navy never progressed beyond the design and experimental stage with either the COSAG or CODAG power plants.

An innovation adoption process featuring combined power plant types has been traditional for the introduction of virtually every new mode of naval ship propulsion since oars. Many centuries ago, when oars were slowly replaced by sails, both were employed on the same ship. Similarly, in the 1800's, the U.S. Navy combined sails with engines prior to abandoning sails in favor of engines. In 1912, the U.S. Navy adopted a combined plant for nine destroyers in which steam turbines were used as a boost for a base plant with reciprocating steam engines. Until the recent delivery of the SPRUANCE which introduced the gas turbine as the sole propulsion prime mover, the combined plant was repeatedly selected each time a new prime mover was introduced. This sudden introduction of the gas turbine into the 80 new ships of the SPRUANCE class and the PERRY class (FFG 7) (nearly half of the Navy's destroyer fleet) without the traditional fall-back option to a tried and true prime mover, was a drastic departure from the established method of introducing a new prime mover, and can be attributed to the failure of Navy's top management to establish timely design policy.

Without a sound policy, power plant selection will have to be reenacted for each ship design. Various system advocates and manufacturers will continue to exert influence, and economic analyses will still show marginal advantages for a particular plant type. These factors, combined
with changing ground rules for power plant trade-offs (e.g., life cycle cost, acquisition cost or "design to some other cost") will prevent the Navy from adopting innovations unless a farsighted policy, benefiting the fleet as a whole, is established and enforced.

As demonstrated in the gas turbine case study, when cost was used as the primary trade-off criterion for each new ship design, only marginal differences were indicated among alternative power plant types and worked to the advantage of the gas turbine opponents. Risk, R&D costs, and all the unknowns accompanying an untried system were against the innovation.

Without policy derived through careful consideration at the highest Navy management level, adoption decisions are:

a. Influenced by the experiences and personalities of transient decision makers in OPNAV

b. Made by individual engineers who lack a comprehensive view extending beyond the single subsystem for the ship being designed or

c. Relegated to DOD or Congress by default (e.g., in the case of Title VIII)* without complete knowledge of past experience or full consideration of all pertinent factors.

* Congressional decision to require all major warships to be nuclear propelled.
However, policy decisions must be made sparingly and with utmost care. When sufficient information on which to base a decision is available, a policy decision can obviate the need for repetitive decisions, thereby allowing the ship designer and the R&D community to concentrate on the unsolved problems. This approach is not meant to downgrade the value of day-to-day engineering trade-offs and decisions which may result in the adoption of an innovative idea; these are the foundations of effective ship design. However, without the overview afforded but to the highest management level of the Navy, both personnel and financial resources may be wasted by repeatedly studying and testing innovative ideas which (perhaps because of their scope or revolutionary nature) do not get adopted.

In both cases, the diversity of the Navy's organization played a key role in retarding innovation adoption. A large number of proposals were brought forth by the organization and investigated, sometimes for decades. The Navy pioneered the study of industrial gas turbines and invested fourteen years studying the so-called "free piston" gas turbine. Combined plants using gas turbines in combination with steam, nuclear and diesel base power plants were evaluated, some reached the full-scale experimental stage, but none were adopted by the Navy. Gas turbines were not adopted until the ship design was removed from the confines of the Navy's organization and given to private industry. When design teams were formed for the express purpose of developing a single ship (i.e., the DD 963) in competition with each other using practically the entire country's ship design/shipbuilding industry, for very high stakes (the
contract was on a total package procurement basis), the organizational diversity factor was eliminated, and the gas turbine innovation was adopted.

Thus if it becomes impossible (organizationally or otherwise) to assure that high level engineering policy is made within the Navy, an alternative would be to transfer the design phase to outside the reach of the diverse organization of the Navy to the competitive environment of the private sector.

Although the history of the roll stabilization case was radically different from that of gas turbines, the diversity of the Navy organization hampered its adoption as well. The Navy has been experimenting with a variety of stabilizers since 1915, at great cost to the government, but has failed to diffuse this innovation into the fleet despite their 1960 adoption in one destroyer escort class and its subsequent evolutions. Again, as soon as the innovation was examined by private industry, it was promptly adopted. Unfortunately, the combination of insufficient safeguards against the influence of the Navy's organization on this adoption decision and the wrong hardware choice again resulted in its rejection during the Navy's in-house technical review of the SPRUANCE design preceding the production contract award.

The Soviets, in a non-capitalistic society, have attempted to deal with the innovation adoption problem for weapon systems design and procurement. For example, the Soviet military has competing design bureaus
for procurement of its military aircraft. Those which innovate are successful; those that do not, either disappear as an organization or are relegated to doing engineering tasks other than new design [7-1]. When this practice was adopted by the U.S. Navy (i.e., for the design and procurement of the SPRUANCE) innovation adoption flourished.

If the design of new warships is to be retained within the Navy and innovative ships are to be the outcome, then in-house Navy policy decisions will have to be made regarding the adoption of new major systems, rather than having them relegated to lower levels in the organization or abdicated altogether to DOD or Congress.
7.2 Provide Stronger Integration Between The R&D And Design Communities

The two cases studied in this thesis indicate that the Navy, whether by design or by default, overemphasized research, even in the development phase of R&D. This concentration on research resulted in a low ratio of innovations adopted compared to the large sums invested for study and experimentation. Of course, not everything that is studied should be adopted; however, this value decision should be made sooner than these two cases indicate. If further study of sound concepts appears justified, management should be able to overcome obstacles hindering the introduction of the innovation. Instead, the Navy continued making substantial investments in system/equipment research without adopting them into fleet use. Many projects which were not worthwhile were abandoned much too late. Other innovations failed due to the inability to overcome organizational resistance to their adoption resulting from an inadequate understanding of the innovation adoption process. At times, our allies, other U.S. government agencies, or adversaries who observed the Navy's research and development work took advantage of its R&D investments, promptly adopting some of the innovations that the Navy rejected or subsequently adopted only years later.

Neither roll stabilizers nor gas turbines were developed through the Navy's R&D programs but were products of foreign (naval or commercial) or U.S. commercial development efforts. The U.S. Navy made significant R&D investments in both of these fields. However, because of
poor assessments as to which avenue would lead to a payoff and orga-
nizational inertia fostering a tendency to retain poor initial choices, the
particular systems in which the U.S. Navy did invest did not yield suc-
cessful hardware and, consequently, were not adopted.

Based on the facts presented by the two case studies, this situation is partly attributable to the relative autonomy gained within the last 20 years by the R&D community from the engineering and design community. Such autonomy, without adequate integrating mechanisms with the design/engineering community (which deals with the application of technology to new ship concepts), promotes:

a. Development of technologies and concepts without sufficient "user need" input.

b. An opportunistic attitude in the R&D/laboratory community relative to its portion of resource allocations (which could possibly be avoided by creating a leaner in-house community and establishing better integration with the design/engineering community).

The last 30 years have witnessed a shift to centralized manage-
ment of Navy R&D (see Appendix A). At the same time, there has been a change in laboratory reporting relationships to the design and engineering organizations responsible for new warship systems. Recently, the practice of "block funding" laboratories for new technological developments has further removed the interplay between system "user" and "producer."

Analysis of the two case studies of this thesis indicates that this trend could be reversed by:
a. Returning management control of the laboratories to the "users" of the new technology.

b. Establishing a mechanism which will force a face-to-face communication between researchers and engineers/designers in deciding laboratory programs.

c. Connecting the highest position in the R&D command chain, i.e., ASN (R&D), with the engineering community by establishing an organizational bond with the engineering side of the Navy. (Currently, ASN (R&D) is organizationally linked only to the R&D side.)

These organizational changes would more directly relate the "D" portion of R&D activities to near-term fleet needs, discourage inordinate study (vice application) of promising ideas and consequently improve the rate of innovation adoption.
7.3 Make Organizational/Environmental Changes To Encourage The Emergence Of Innovation Advocates

A major determinant of a climate conducive to innovation adoption is the degree to which executives are willing to commit themselves to risky decisions. The conservative bias implicit in "mechanistic" organizational models (which reflect the military organization) tends to be counterbalanced by the number of its executives that are willing to make such decisions.

The two case studies exemplify the non-risk taking attitude of military executives as evidenced by their unwillingness to jeopardize personal reputation and professional image by advocating an action or decision with uncertain consequences. This situation substantially reduces chances for innovation adoption.

Several times during design of the Navy's post-World War II warships, the risk-aversive management in the Bureau of Ships caused a setback (e.g., the Bureau decision to revert to 600-psi steam World War II technology for a destroyer scheduled for delivery to the fleet in the 1970's). Fortunately, in most cases, either the ship was never built or the setback was reversed by subsequent decisions (at times from outside the normal decision-making system for U.S. naval ship design, e.g., the Secretary of the Navy).*

* The case studies document several instances in which forces or authorities outside the Navy effected an innovation adoption.
The absence of penalties for an anti-innovation attitude, together with obvious negative consequences associated with an unsuccessful innovation, fosters a non-risk taking attitude which hinders innovation adoption. For example, an engineering duty naval officer in charge of the machinery design organization or one of its components would advance in his profession to higher and higher rank if his organization "stayed out of trouble." Championing a new concept which succeeds, offers potential recognition (e.g., Admiral Rickover, champion for nuclear propulsion) and increases chances for promotion, but these incentives are weak relative to the potential punishment for advocating an "unsuccessful" innovation. Unlike private industry, where the existence of a viable business entity may depend on successful innovation adoption, in the Navy there are no repercussions whatsoever for those who fail to adopt worthwhile innovations.

Since the introduction of gas turbines was an incremental improvement as opposed to the introduction of nuclear propulsion, the operator side of the Navy viewed it strictly as an engineering trade-off among alternative options, not worth the risk associated with championing it. In the case of roll stabilization, even though the advocates of alternative systems to fin roll stabilizers couldn't offer anything equivalent to the kind of alternative that nuclear power offered to gas turbines, the stabilizer also suffered from an "incremental improvement syndrome" rather than a technological breakthrough.

Roll stabilization by active fins is a relatively expensive item. Without an advocate, it was easily eliminated in favor of some
other device that performed a different function judged more important than stabilization.

Fleet operators do have a stake in roll stabilization since it provides more comfort, extends operating ability and decreases wear and tear on the ship. In view of this, it is interesting that the decision makers in OPNAV, all of whom come from the fleet, don't emerge as roll stabilization advocates. The explanation is that the fleet representative/decision makers in the Pentagon have two conflicting tasks:

a. Assuring that fleet requirements are considered for every new ship design and

b. Responsibility for the annual budget submission to Congress.

Inflationary pressures and new construction requirements make budgetary considerations the dominant concern of this group, at times overshadowing requirements issues for ship components which lack sufficiently strong advocates. The same individuals cannot simultaneously be system advocates and compromisers; responsibility for schedule and cost should not be assigned to the decision makers who must determine requirements for new warship characteristics. Advocacy positions independent of other tasks encroaching on the advocacy task should exist in order to enhance innovation adoption.

The absence of an appropriate incentive structure for leaders/decision makers (specifically, the engineering duty officers serving as
heads of the Ship Design, Machinery Design and Hull Design Divisions) was extremely influential in retarding adoption in both cases studied, especially for gas turbines. Over the last two decades, the importance of the design phase has been deemphasized, further reducing any potential incentives for engineering duty officers to want to be even involved in ship design. For example, during the first fifteen years following World War II, five out of nine captains who headed the preliminary ship design organization achieved flag rank; since 1963, none have. Since 1966, six captains have been directors of the Ship Design and Engineering Department, none of whom became admiral; four of them retired directly from the job. Prior to 1963, this assignment was a prime route to attaining the rank of admiral in the EDO community. Instead, the field has narrowed to three positions from which an EDO captain has the best chance to become an admiral: SHAPM, shipyard commander, and, less frequently, a major-laboratory commander. The Navy must provide incentives within the design community if an environment conducive to innovation advocacy is to be created.

Frequent changes in military leadership further contribute to the Navy's difficulty in fostering innovation champions. Key people, e.g., product champions, advocates, entrepreneurs, are critical in guiding a specific innovation through the development maze. Loss of such key people results in resistance to innovation, simply because advocates are not easily replaced.

As shown in the case studies, frequent rotation of the officers responsible for determining requirements for new warships hinders innovation adoption. Furthermore, officers occupying these key positions lack
adequate training in requirements definition because they have not had previous tours of duty in either the requirement determination or the design organization at junior levels. This inexperience and a high rate of personnel rotation in an environment which rewards risk aversive behavior, discourages the emergence of innovation champions. Innovation advocacy by the military could be enhanced by: (1) separating the two conflicting roles in which senior officers find themselves in OPNAV, i.e., advocates of fleet requirements as well as budget defenders, at the same time; (2) slower turnover of officers; (3) promotion incentives for those who occupy senior design/engineering positions not only from shipyard commands and business management positions; and (4) more experience for those who occupy senior positions earlier in their careers in the subjects of requirements definition/design of new warships.
7.4 Reduce The Emphasis On Cost And Schedule During Design

Analysis of the emphasis on business aspects (schedule and cost) during design development showed its detrimental effect on innovation adoption.

Schedule urgency was used to prevent the introduction of gas turbines as boost power plants for nuclear base power plants during the 1950's. During the SEAHAWK Program in the early 1960's, schedule constraints were again used to delay the adoption of gas turbines. It was also schedule considerations which caused the termination of the FY 1967 DDG design, which would have introduced gas turbines years before their eventual introduction into the DD 963 class destroyer.

Navy proponents of all-nuclear propulsion almost succeeded in stopping the adoption of gas turbines for the DD 963 on the basis of schedule after the design and production proposals were submitted to the Navy. They argued that the Navy should not design the ship while still testing its propulsion plant and recommended reverting to a tested propulsion plant, like steam or nuclear power, since the Navy needed these ships urgently.

Overemphasis on cost was another dominant factor preventing early adoption of gas turbines and roll stabilizers. In propulsion plant trade-offs, consideration of only acquisition or life cycle cost tended to show marginal differences among various propulsion plant alternatives.
This worked to the advantage of those opposed to the change, since risk, R&D costs and all the unknowns accompanying a new, untried system could be stacked as additional cost of an unknown magnitude against the innovation. Chances are that basic errors made in early attempts to introduce gas turbines were not in the cost comparisons of competing power plants, but in the failure to consider other important factors which are difficult to quantify yet, in the long run, have a major impact on the cost effectiveness of the fleet, such as: good availability, reduced operating crew, rapid starting ability, small weight, maintenance by quick replacement, etc.

During the last two decades, the growing emphasis on ship acquisition management has been manifested in the shifting of personnel resources away from ship design and the reduction of promotion potential for those naval officers and young civilian engineers who choose design as their area of interest. The SHAPM's have been staffed at the expense of the centralized engineering organization of the Navy.

With the strong project orientation of engineering and the weakening of the functional organization for design (the organization which by its nature has a stake in defending innovation), the scale has been tilted in a direction which hampers innovation adoption. As a result, the SHAPM acquires yesterday's technology because his job is to manage a successful procurement judged mostly by business success (schedule and cost), not innovation adoption.
On 24 October 1974, in an address to a meeting of the National Society of Former FBI Agents in Seattle, Admiral Rickover discussed this subject. He stated that the Navy's present organization keeps knowledgeable men out of the decision-making process and puts the Navy in the hands of managers who, in turn, depend heavily on private contractors. Rickover faulted former Defense Secretary Robert S. McNamara for emphasizing project management over technical considerations [7-2]:

"The changes McNamara made were in the wrong direction. He took the advice of analysts and management experts rather than seeking the advice of people with technical expertise."

Rickover asserted that because of its reorganizing and increased reliance on managers rather than on "the hewers of wood and drawers of water," the Navy "no longer has adequate in-house technical capability. We cannot depend on industry to develop and maintain a technical organization capable of handling the design of complex ships without the Navy itself having a strong technical organization." He also addressed the loss of professionalism among the remaining engineers which, he said, has resulted in ships of questionable design.

Project orientation toward engineering, weakens the functional organization for design, one of the few organizations which exist to defend innovation adoption.

To correct this situation, and thus improve the chances of innovation adoption, DOD and Navy policies which have tended increasingly
to overemphasize the acquisition management function during the last two decades should be reversed to create a better balance between the importance of schedule and cost and that of innovation adoption.

While the findings and conclusions of this entire thesis will certainly not resolve completely the problem of improving the rate of innovation adoption within the Navy, they are bound to improve its chances.
CHAPTER 8

LIST OF REFERENCES


LIST OF REFERENCES (Continued)


LIST OF REFERENCES (Continued)


LIST OF REFERENCES (Continued)


LIST OF REFERENCES (Continued)

There are no references in Chapter 3.


LIST OF REFERENCES (Continued)


[4-17] Chief of the Bureau of Ships, "Large Destroyers Proposed Characteristics", to the Chairman, General Board, March 30, 1942.


[4-21] Boatwright, J., "Interview with the Author", October 25, 1976.


LIST OF REFERENCES (Continued)


654
LIST OF REFERENCES (Continued)


[4-54] Sylvester, E.W., RADM (Code 400), "BUSHIPS Instruction No. 5420.1; Reports from the SDCC and Associated Panels", March 20, 1953.


LIST OF REFERENCES (Continued)


[4-64] , "Minutes of the Seventh Meeting of the SDCC", September 15-17, 1953.

[4-65] , "Enclosure 7 to the Promulgation of the Minutes of the Seventh Meeting of the SDCC", BUSHIPS Ser. 107-0126, October 5, 1953.


LIST OF REFERENCES (Continued)


LIST OF REFERENCES (Continued)


658
LIST OF REFERENCES (Continued)


LIST OF REFERENCES (Continued)


[4-120] Secretary of the Navy, "Termination of the DDG FY 67' Design", memorandum to the Chief of Naval Operations, June 28, 1967.


LIST OF REFERENCES (Continued)


LIST OF REFERENCES (Continued)


[5-23] Durand, W.F., Chairman, Special Committee on Ship Stabilization, "Third Progress Report to SECNAV", May 9, 1938.


[5-29] Commanding Officer, USS UTAH, "Inspection of Corvettes of Canadian Navy" to CNO, AG16/S3-1(65), Long Beach, California, March 22, 1941.


LIST OF REFERENCES (Continued)


LIST OF REFERENCES (Continued)


LIST OF REFERENCES (Continued)


[5-79] Request by the Chairman of SCB to BUSHIPS at Meeting Held May 6, 1958.


LIST OF REFERENCES (Continued)


LIST OF REFERENCES (Continued)


[5-102] Section 5-1 of This Thesis.


LIST OF REFERENCES (Continued)


LIST OF REFERENCES (Continued)


LIST OF REFERENCES (Continued)


[6-33] Section 4-1; Gas Turbine Case Study.
LIST OF REFERENCES (Continued)

[6-34] Section 4-3; Gas Turbine Case Study.

[6-35] Section 4-5; Gas Turbine Case Study.

[6-36] Section 4-7; Gas Turbine Case Study.

[6-37] Section 4-8; Gas Turbine Case Study.

[6-38] Section 4-9; Gas Turbine Case Study.


[6-41] Section 5-4; Roll Stabilization Case Study.

[6-42] Section 5-6; Roll Stabilization Case Study.

[6-43] Section 5-1; Roll Stabilization Case Study.


[6-45] Section 5-3; Roll Stabilization Case Study.


[6-47] Section 5-8; Roll Stabilization Case Study.


[6-49] Section 4-4; Gas Turbine Case Study.


LIST OF REFERENCES (Continued)


[6-54] Section 5-9; Roll Stabilization Case Study.


[6-57] Section 4-6; Gas Turbine Case Study.


[6-61] Section 4-10; Gas Turbine Case Study.

[6-62] Section 5-2; Roll Stabilization Case Study.

[6-63] Section 5-5; Roll Stabilization Case Study.


LIST OF REFERENCES (Continued)


LIST OF REFERENCES (Continued)


LIST OF REFERENCES (Continued)


676
LIST OF REFERENCES (Continued)


### Abbreviations and Glossary of Selected Military Terms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAW</td>
<td>Anti Air Warfare</td>
</tr>
<tr>
<td>ABL</td>
<td>Allocated Baseline</td>
</tr>
<tr>
<td>AC</td>
<td>Approved Characteristics</td>
</tr>
<tr>
<td>ACNO</td>
<td>Assistant Chief of Naval Operations</td>
</tr>
<tr>
<td>ADO</td>
<td>Advanced Development Objective</td>
</tr>
<tr>
<td>AE</td>
<td>Applications Engineering</td>
</tr>
<tr>
<td>ASD</td>
<td>Assistant Secretary of Defense</td>
</tr>
<tr>
<td>ASN</td>
<td>Assistant Secretary of the Navy</td>
</tr>
<tr>
<td>ASPR</td>
<td>Armed Services Procurement Regulations</td>
</tr>
<tr>
<td>ASW</td>
<td>Antisubmarine Warfare</td>
</tr>
<tr>
<td>BuAer</td>
<td>Bureau of Aeronautics</td>
</tr>
<tr>
<td>BuBud</td>
<td>Bureau of the Budget</td>
</tr>
<tr>
<td>BuOrd</td>
<td>Bureau of Ordnance</td>
</tr>
<tr>
<td>BuShips</td>
<td>Bureau of Ships</td>
</tr>
<tr>
<td>BuWeps</td>
<td>Bureau of Naval Weapons</td>
</tr>
<tr>
<td>CF/CD</td>
<td>Concept Formulation/Contract Definition</td>
</tr>
<tr>
<td>CNA</td>
<td>Center for Naval Analysis</td>
</tr>
<tr>
<td>CND</td>
<td>Chief of Naval Development</td>
</tr>
<tr>
<td>CNM</td>
<td>Chief of Naval Material</td>
</tr>
<tr>
<td>CNO</td>
<td>Chief of Naval Operations</td>
</tr>
<tr>
<td>CNR</td>
<td>Chief of Naval Research</td>
</tr>
<tr>
<td>CSC</td>
<td>Civil Service Commission</td>
</tr>
<tr>
<td>DCNM</td>
<td>Deputy Chief of Naval Material</td>
</tr>
<tr>
<td>DCNO</td>
<td>Deputy Chief of Naval Operations</td>
</tr>
<tr>
<td>DCP</td>
<td>Development Concept Paper</td>
</tr>
<tr>
<td>DD</td>
<td>Destroyer</td>
</tr>
<tr>
<td>DDG</td>
<td>Guided Missile Destroyer</td>
</tr>
<tr>
<td>DDR&amp;E</td>
<td>Director of Defense Research and Engineering</td>
</tr>
<tr>
<td>DL</td>
<td>Frigate</td>
</tr>
<tr>
<td>DLF</td>
<td>Direct Laboratory Fundings</td>
</tr>
<tr>
<td>DLG</td>
<td>Guided Missile Frigate</td>
</tr>
<tr>
<td>DLP</td>
<td>Director of Laboratory Programs</td>
</tr>
<tr>
<td>DNL</td>
<td>Director of Navy Laboratories</td>
</tr>
<tr>
<td>DOD</td>
<td>Department of Defense</td>
</tr>
<tr>
<td>DSNARC</td>
<td>Defense Systems Acquisition Review Council</td>
</tr>
<tr>
<td>DSB</td>
<td>Defense Science Board</td>
</tr>
<tr>
<td>DTC</td>
<td>Design-to-Cost</td>
</tr>
<tr>
<td>EDG</td>
<td>Exploratory Development Goal</td>
</tr>
<tr>
<td>EDR</td>
<td>Exploratory Development Requirement</td>
</tr>
<tr>
<td>FBL</td>
<td>Functional Baseline</td>
</tr>
<tr>
<td>FY</td>
<td>Fiscal Year</td>
</tr>
<tr>
<td>GAO</td>
<td>General Accounting Office</td>
</tr>
<tr>
<td>GOR</td>
<td>General Operational Requirement</td>
</tr>
<tr>
<td>IED</td>
<td>Independent Exploratory Development</td>
</tr>
<tr>
<td>JAC</td>
<td>Joint Advisory Committee</td>
</tr>
</tbody>
</table>
JCS  Joint Chief of Staff
JRDB  Joint Research and Development Board
NAVELEX  Naval Electronic Command
NAVMAT  Naval Material Command
NAVORD  Naval Ordnance Command
NAVSEA  Naval Sea Systems Command
NAVSEC  Naval Ship Engineering Center
NAVSHIPS  Naval Ship Systems Command
NIF  Navy Industrial Funding
NMC  Naval Material Command
NMSE  Naval Material Support Establishment
NRL  Naval Research Laboratory
NRR  Naval Research Requirement
NSA  National Security Act
ODDR&E  Office of the Director of Defense Research and Engineering
ONR  Office of Naval Research
OPDEVFOR  Operational Development Force
OPNAV  Operations Navy
OPTEVFOR  Operational Test and Evaluation Force
OSD  Office of the Secretary of Defense
OT&E  Operational Test and Evaluation
PCD  Program Change Decision
PCP  Program Change Proposal
PDA  Principal Development Activity
PERT  Program Evaluation and Review Technique
PF  Patrol Frigate
PM  Program Manager, Project Manager
PPBS  Planning, Programming, and Budgeting System
PTA  Proposed Technical Approach
R&D  Research and Development
R&E  Research and Technology
RDB  Research and Development Board
RDT&E  Research, Development, Test and Evaluation
RMS  Resource Management Systems
SCB  Ship Characteristics Board
SCN  Shipbuilding and Conversion, Navy
SCS  Sea Control Ship
SECDEF  Secretary of Defense
SECNAV  Secretary of the Navy
SHAPM  Ship Acquisition Program Manager
SLM  Ship Logistic Manager
SOR  Specific Operational Requirement
SSC  Single Sheet Characteristics
SSD  Ship System Design
SSDS  Ship System Design Support
SWBS  Ship Work Breakdown Structure
SYSCOM  System Command
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>T&amp;EE</td>
<td>Test and Evaluation</td>
<td>TLS</td>
<td>Top Level Specification</td>
</tr>
<tr>
<td>TDP</td>
<td>Technical Development Plan</td>
<td>TPP</td>
<td>Total Package PROCUREMENT</td>
</tr>
<tr>
<td>TLR</td>
<td>Top Level Requirement</td>
<td>TSOR</td>
<td>Tentative Specific Operational Requirement</td>
</tr>
</tbody>
</table>
APPENDIX A

THE ORGANIZATION OF THE U.S. NAVY

This appendix is intended to provide an overview of the Navy's organization with particular attention to its R&D and ship design divisions. It is not a comprehensive statement on the complexity of the Navy's organizational structure, its functioning or the deep-rooted issues which shaped it (especially in view of the frequent changes the Navy's organization has undergone in the last forty years). Rather, the appendix is directed toward familiarizing the reader with those aspects of the organization most closely involved with the innovation adoption study undertaken in this thesis.*

The Navy contains both the creators and users of its technological developments. For this thesis, it is important to understand the Navy's design and R&D organizational structure and how it functions from the standpoint of authority flow, money flow, end products generation, and lateral interfaces within and among the structural elements involved. This appendix is limited to a discussion of the Navy organizations responsible for:

* The Navy is an entire society, containing people with a wide range of divergent tasks, interests, education and occupations. Not only is its organization large, complex and changing, but it must be analyzed from the viewpoints of the different communities which it encompasses before it can be completely understood. A ship commander would use the Navy's organization as having different structural functions than would the director of a naval laboratory or the director of ship/submarine design, since each would deal with different day-to-day operating procedures and organizational elements.
a. Requirements definition and the subsequent design of new ships

b. R&D activities, including equipment development.

The evolution of these organizations is first described, followed by an overview of the ship design process and R&D planning and execution in these organizations.
The Evolution of the Organizational Structure

The Act of 1842 established two bureaus within the Navy Department:

a. The Bureau of Construction, Equipment and Repair with responsibility for design, construction and outfitting (except for ordnance) of Navy ships and

b. The Bureau of Steam Engineering, redesignated the Bureau of Engineering in 1862.

For some time after the creation of the Bureau of Steam Engineering, the Bureau of Construction and Repair dominated the shipbuilding picture. The complex relations between engine, hull, machinery, and ordnance had not yet developed.

New designs and improvements in technical knowledge soon made the straightforward relationships between the Bureaus of Engineering and Construction and Repair more involved.

As new questions of cognizance began to arise, decisions had to be made assigning responsibility to one bureau or the other. With little experience upon which to base these decisions, the authorities assigned functional jurisdictions which, in some instances, were controversial and not wholly definable. Inter-bureau discord developed from some of these assignments. Gradually, the Bureau of Construction and Repair's control over shipbuilding was shared with the Bureau of Engineering.
By enactment of Public Law 644 on June 20, 1940, the 76th Congress abolished both the Bureau of Construction and Repair and the Bureau of Engineering, centralizing their functions in the Bureau of Ships. The establishment of the Bureau of Ships stands with the creation of the Office of the Chief of Naval Operations (OPNAV) in 1915 as one of the most important changes in the Navy Department since the bureau system was initiated in 1842. Admiral Bowen outlined the issues and events surrounding the foundation of the Bureau of Ships in his book "Ships, Machinery and Mossbacks."

The Bureau of Ships, under the direction of the Secretary of the Navy, was charged with responsibility for the design, construction, and maintenance of all Navy ships (except aircraft and craft assigned to the Bureau of Yards and Docks). Providing for this reorganization of the Navy Department, the 76th Congress stated that:

"The duties of the Bureau of Ships shall be assigned by the Secretary of the Navy and performed under his authority and the orders of the Chief of the Bureau of Ships shall be considered as emanating from the Secretary of the Navy, and shall have full force and effect as such."

The Bureau of Ships was one of seven bureaus. Figure A-1 shows the Navy's organization circa 1950. The basic management approach of the bureaus was one common to engineering organizations. Personnel were grouped according to technical disciplines and end products (often subsystems or components) for which they had engineering responsibility.
FIGURE A-1  THE NAVY'S ORGANIZATION FROM WORLD WAR II THROUGH THE MID-SIXTIES
Project offices assigned to coordinate these groups frequently had no direct administrative authority over the engineering specialists working on their projects.

In the 1950's, fundamental organizational problems emerged within and among the bureaus. Interfaces between respective product areas became more troublesome as evidenced by the dispute between the Bureaus of Ordnance and Aeronautics over cognizance of guided missiles. Furthermore, the centralization of authority in the Office of the Secretary of Defense (OSD), OPNAV, and the Secretary of the Navy (SECNAV) conflicted with the independence traditionally exercised by bureau chiefs.

In 1959, the Franke Board recommended merging the Bureau of Ordnance and Aeronautics into a Bureau of Naval Weapons. The Board reasoned that placing two-thirds of the material organization under a single "producer" would eliminate cognizance disputes in weapons system development. The merger was accomplished shortly thereafter.

As establishment of the Bureau of Naval Weapons did not produce all the anticipated benefits, another management study of the bureau organization was undertaken. The Dillon Board found that the lead bureau system failed to resolve interface problems and that an office was needed to reconcile differences among co-equal bureau chiefs. It proposed federating the material bureaus under the coordinating authority of a single flag officer.
In 1963, the Secretary of the Navy created the Naval Material Support Establishment (NMSE) and assigned overall responsibility for coordinating the material bureaus to the Chief of Naval Material (CNM). Experience with the NMSE led the CNM to undertake further organizational studies which resulted in the creation of the Naval Material Command in 1966. The Bureau of Ships and Naval Weapons were split into separate systems commands for electronics, ordnance, ships, and aircraft. The Chief of Naval Material was given command authority over the systems commands but now reported directly to the CNO rather than to the Secretary of the Navy.

While the 1966 reorganization strengthened the CNM's program management authority, it also placed the CNO in a line position between the material organization and the Secretary of the Navy, thereby erasing the Navy's traditional bilinear structure.
A.2 The Changing Design Organization

The organization of the Bureau of Ships is shown on Figure A-2, and consisted of five major subdivisions. This organization remained static as it related to the design function from 1940 to 1966 with the exception of the relative position of the naval reactor organization as shown on Figure A-3 as composed using Reference A-1.

The Design Division comprised little more than half the personnel of the entire Bureau of Ships during the war years. The design organization, Code 410 (see Figure A-4) was responsible for designing, planning, and supervising construction of Navy ships and their subsystems, except those under cognizance of the Bureau of Aeronautics and the Bureau of Ordnance, e.g., the payload for warships.

The Preliminary Design Branch determined the initial feasibility of new ship concepts as derived from the military requirements defined by the General Board of the Navy (through 1950) and the Ship Characteristics Board (which succeeded the General Board). After selection of a feasible concept by the above mentioned Boards, the Preliminary Design Branch prepared a preliminary design. In this initial portion of the ship design phase, engineering characteristics of the selected alternatives are established and delineated. Trade-offs and other analyses conducted to optimize performance while remaining within design, cost, and logistic constraints predominate in the preliminary design effort.
FIGURE A-2  ORGANIZATION OF THE BUREAU OF SHIPS (1940)
FIGURE A-3  RELATIVE POSITION OF THE NAVAL REACTOR ORGANIZATION

690
ORGANIZATION OF BUREAU OF SHIPS DESIGN DIVISION

FIGURE A-4
Contract design was the next phase of ship design. The Hull Design Branch project coordinator provided administrative coordination for the branches and sections providing inputs on characteristics such as weights, machinery design, and arrangements. During contract design, drawings and specifications were developed to a level at which a qualified shipbuilder could bid on prototype or lead ship detail design and construction. Trade-off studies were continued at the subsystem and component level. Products of contract design included ship specifications and approximately 150 contract drawings and contract guidance drawings. Until 1966, the Bureau of Ships developed the preliminary and contract designs for all naval ships "in-house," in some cases with the support of contractors.

Toward the end of Robert McNamara's first term as Secretary of Defense, he initiated the so-called total package procurement (TPP) concept for major weapon systems, including naval ships. This entailed a concept formulation/contract definition (CF/CD) process which led to the development of a design through competition in industry prior to the contract for procurement of new ships built to that design. This process was sponsored by the Department of Defense.

Three ship acquisition programs were defined and developed by the CF/CD process: the FDL, the LHA, and the DD 963. The FDL program was cancelled after the completion of CF/CD but before the award of a detail development and construction contract. The progress of the other two contracts has been well publicized.
The TPP concept and the CF/CD process were not inseparable; one could have been employed without the other. However, the two techniques were combined for the three ship acquisition projects of that era.

Concept formulation by the Navy was intended to verify performance requirement compatibility. Its results were not made known to the competing contractors. At the outset of the contract definition phase, the Navy transmitted its requirements for a new ship design to prospective contractors defining ranges of performance characteristics. The contractors were to provide a balanced design solution considering performance criteria, design standards, and production techniques. This process emphasized industry's responsibility for satisfactory ship performance. The Navy's role during this phase was to monitor and guide the builder.

The end product of contract definition was a proposal from each would-be contractor for total package procurement, including a set of ship drawings and specifications to meet Navy requirements, together with detailed management, facility, logistic support and other plans for detail development and ship production. After an intensive proposal review process, the Navy chose the contractor providing the most cost effective ship design and construction plans. The successful firm was awarded a single contract for the entire production run of the ship class. This approach to ship acquisition and design took the design function away from the Navy for about five years. The Navy's organization during this period (which lasted until 1971) is shown on Figure A-5.
FIGURE A-5  A MAJOR CHANGE WHICH AFFECTED BOTH REQUIREMENT DEFINER'S (USER'S) AND SHIP DESIGNER'S (DEVELOPER'S) ORGANIZATIONS
In 1971, DOD cancelled the McNamara directive for total package procurement and the ship design function reverted to in-house Navy execution. However, the ship design function was no longer performed by the Naval Ship Systems Command (NAVSIPS) or later, the Naval Sea Systems Command (NAVSEA), the successors to the Bureau of Ships but by the Naval Ship Engineering Center (NAVSEC, created in 1966) which reports to NAVSEA. There are two layers of management between NAVSEA and the Secretary of the Navy: the Navy Material Command (NAVMAT) and OPNAV. Major system components of the ship, weapons, and electronics system became the responsibility of separate commands and numerous project managers within these commands.

By 1971, it was clear that the ship design process had to be aligned with the ship acquisition method. In that year, DOD instituted structural modifications to the Navy organizations involved in requirements derivation and design execution. The DOD policy changes dictated stronger control by both the Navy and DOD over the design evolution of Navy ships and pointed out the deficiencies of the highest level organization in the Navy, OPNAV, as follows:

a. There was no single organization to establish ship characteristics for all ship types. By 1950, the General Board had been disbanded and the scope of its successor, the Ship Characteristics Board (SCB), was narrowed. The SCB did not handle carriers or submarines; as part of OP-03, the Office of the Deputy Chief of Naval Operations (DCNO) for surface warfare, it was co-equal with DCNO for submarine warfare and
DCNO for air warfare. The process of defining new ship characteristics was consequently lengthened by frequent delays, while the cognizant offices debated the specific requirements for each ship. Further, by shifting this function from office to office, no single organization had sufficient competence to handle the task effectively.

b. There was no standard procedure for requirements derivation; thus the effort had to be duplicated for each new program and those assigned to establish the requirements were usually unfamiliar with what they were to do.

These organizational inadequacies led to the selection of participants who could be spared from the organization rather than those best qualified for the job. The situation had a negative impact on the end product, i.e., the ship characteristics, which were often inconsistent with available equipment or technology. This lack of coordination often proved to be an obstacle to approval by reviewing authorities in DOD and also led to inefficient use of personnel resources.

A number of studies conducted in 1971 and early 1972 recommended establishment of the Office of Ship Acquisition and Improvement (OP-97) within OPNAV (see Figure A-6a). When established, OP-97 was assigned management responsibility for requirements formulation and compatibility with the evolving design. The OP-97 function was essential in dealing with increasingly severe fiscal constraints and the rapid technological advances being made in response to changing military threats.
FIGURE A-6 (a)(b) ORGANIZATION OF OPNAV
Correspondingly, other offices in OPNAV which had previously defined ship characteristics relinquished that function. For example, OP-36, the Ship Characteristics Board, was eliminated. Additionally, personnel in OP-05 selecting new air systems and OP-02 selecting submarine systems were transferred to, or had additional duties in OP-97.

The basic organizations within the DCNO remained (OP-02, OP-03, and OP-05 as sponsors, OP-098 as R&D budget manager, and OP-096 for systems analysis). After two years of successfully managing the Navy's design requirements formulation, OP-97 was disbanded in August 1974. (See Figure A-6b.)

The 1974 organizational change returned characteristics selection for new carriers to OP-05 and submarines to OP-02. OP-37 was established to perform the functions of the Ship Characteristics Board regarding surface ships (excluding carriers).
A.3 The Changing R&D Organization

At the time the Bureau of Ships was founded, the research organization was a subset of the Ship Design and Shipbuilding Division (see Figure A-2). Research Branch activities were officially confined to administration of practical research problems. In practice, these activities affected the entire naval establishment.

The Naval Research Laboratory has always been under the jurisdiction of the Secretary of the Navy. For technical matters and the allotment of funds, the Bureau of Ships and the Research Branch had authority over the Engineering Experimental Station (Annapolis), the David W. Taylor Model Basin (Carderock), the Naval Boiler Laboratory (Philadelphia), and the Materials Laboratory (New York Navy Yard), and other laboratories. (See complete listing on Table A-1.) Although administered either as independent commands or as activities under the Commandant of Naval Districts or Navy Yards, each laboratory was placed under the cognizance of the bureau most closely concerned with its principle output.

The Technical Investigations Section of the Research Branch was concerned with the bureau's basic applied research projects. The Standards and Tests Station and its five subsections administered and furnished directives for laboratory testing of all materials and equipment used by the bureau. By 1947, the Office of the Director of Research, while still under the Assistant for Ship Design and Shipbuilding in the bureaus, grew
TABLE A-1

LABORATORIES UNDER THE COGNIZANCE OF THE BUREAU OF SHIPS DURING THE WAR*

Naval Research Laboratory,
Anacostia, Washington, D.C.
Naval Engineering Experiment Station,
Annapolis, Maryland
Naval Boiler and Turbine Laboratory,
Navy Yard, Philadelphia, Pennsylvania
Industrial Test Laboratory,
Navy Yard, Philadelphia, Pennsylvania
Materials Laboratory,
Navy Yard, New York, New York
Industrial Laboratory,
Navy Yard, Mare Island, California
Radio and Sound Laboratory,
San Diego, California
Naval Mine Warfare Testing Station,
Solomons, Maryland
Paint Laboratories at Navy Yards,
Mare Island, California and Norfolk, Virginia
Rubber Research,
Mare Island, California
Metals Laboratory,
Munhall, Pennsylvania
Rope Laboratory,
Boston, Massachusetts
Petroleum Laboratory,
Houston, Texas
Experimental Diving Unit,
Navy Yard, Washington, D.C.
Industrial Laboratory,
Navy Yard, Puget Sound, Washington

* These laboratories have undertaken, in addition to their work on Bureau of Ships projects, research and testing for any naval bureau and any other governmental activity as their facilities and workloads permitted. The character of the work done in the laboratories has varied from fundamental research and investigation leading to major inventions or modifications of practices to the routine testing necessary.
into a much more elaborate organization and shortly thereafter was placed on the same level as the Assistant for Ship Design and Shipbuilding in BUSHIPS 300. By November 1965, the organization of the Assistant Chief of R&D was structured as shown on Figure A-7.

With the establishment of the Material Command and the change from the bureau system to the system commands (SYSCOM's) in 1966, the successor organization to the Bureau of Ships, NAVSHIPS, lost control over its laboratories. Figure A-8 depicts the NAVSHIPS 03 organization (successor to BUSHIPS 300). The chain of command for RDT&E activities in the Navy (not just the Naval Sea Systems Command) from 1966 through today is shown on Figure A-9.

The chronological events leading to the present RDT&E organization are summarized in a recent Booze-Allen report [A-2]:

"The passage of the National Security Act of 1947 created the Office of the Secretary of Defense and gave him a mandate to eliminate 'unnecessary duplication' in military R&D. Under the provisions of the Act, Secretary of Defense Forrestal established the Research and Development Board (RDB). The Board, which consisted of representatives from the three military departments (Army, Navy, and Air Force) plus a nonvoting chairman, had the responsibility of preparing and coordinating an integrated R&D program.

"In 1949, amendments to the National Security Act substantially increased the authority of the Secretary of Defense and gave the chairman of the RDB power of decision in Board matters.

"In 1953, a major reorganization of the Department of Defense disestablished the RDB
FIGURE A-7  BUREAU OF SHIPS R&D ORGANIZATION (1965)
Figure A-9  Chain of Command for RDT&E Field Activities (1966)
"and split the research and development role between two Assistant Secretaries. The Assistant Secretary (R&D) assumed responsibility for preparing an integrated R&D program for the Department of Defense and had cognizance over basic research and exploratory development. The Assistant Secretary (Applications Engineering) was made responsible for the production engineering phase of the R&D process.

"In 1957, the two Assistant Secretaries were merged into a single office of the Assistant Secretary of Defense for Research and Engineering, the former division of R&D responsibilities having proved unworkable.

"In 1958, another major DOD organization upgraded the R&D function from the level of Assistant Secretary of Defense to that of Director, and significantly expanded its powers.

"Service R&D programs were subjected to a comprehensive and formal management review and justification process prior to final approval of major developments.

"Detailed R&D reviews by DDR&E were accomplished by greater demands for program information and formal documentation.

"Through the use of the Advanced Research Projects Agency, the Defense Emergency Fund and by withholding previously appropriated funds, DDR&E was able to directly control a growing share of the defense RDT&E budget."

In an attempt to insure the integrity of the Navy R&D organization as separate from the organizations with responsibility for integrating ship systems, DOD and the Navy created an autonomous R&D organization which at times has been unresponsive to user's needs. There are several excellent documents providing detailed descriptions of the Navy's R&D organization (in particular, references [A-2] and [A-3]).
The Ship Design Process in the U.S. Navy

Before design work can take place, the new ship requirements must be established. OPNAV identifies the Navy's need for a new class of ships in one of several ways:

a. Through inputs from OP-03 and OP-05 (for surface ships and carriers) and OP-02 (for submarines) specifying the need to replace old ships or that a major new shipborne weapon system is ready to go to sea and conversion of an existing ship type would be more costly than designing a new one.

b. Through OP-96, which translates its threat analyses into new mission objectives, possibly requiring new hardware.

c. Through a directive from the Chief of Naval Operations (CNO) on the advice of the CNO Executive Board, cognizant admirals or others.

Regardless of which source describes the need for a new ship, the requirement must be translated into a specific hardware definition. The relationship between the CNO and the Chief of Naval Material (CNM) approaches that of customer to contractor. The responsibility of the former is to state the requirements for ship systems and the responsibility of the latter is to produce the required ships, weapons, and equipment.
From 1930 through 1970, the CNO's requirements were first stated as "single sheet characteristics." Following review of the preliminary ship design, these requirements were confirmed as "approved characteristics."

This process was fairly efficient until the design execution function was returned to the Navy in 1971 and DOD imposed the "design-to-cost" concept on all major acquisition programs. This action removed the contractual barrier existing during CF/CD (i.e., a change in a requirement necessitated a contract change), again enabling OPNAV to change requirements during the design period, as seen in both case studies of this thesis. The design-to-cost concept presented the following problems [A-4]:

"The 'single sheet characteristics' and 'approved characteristics' did not define adequately the required ship system performance. The definitions ranged from a mixture of detailed hardware specifications for radars, weapons, and electronics to the most extreme generalities such as, for example, 'best obtainable seakeeping qualities.'"

"The requirements for performance as required by OPNAV and the characteristics in the resulting design were unbalanced to the extent that, while certain functions of the ships were discussed at great length, others were only mentioned casually and many were not even discussed."

The primary reasons for this situation were [A-4]:

"A lack of early disciplined progressive derivation of the requirements and characteristics and the lack of a documented dialogue among budget managers, the ship operators, and the ship designers."
Figure A-10 outlines the process involved between the time when the need for a ship is recognized and the beginning of its preliminary design, as viewed from the multitude of documents required to put the undesigned ship into the budgetary cycle and the various organizations which review and approve the program. The document titles and numbers are continuously changing, but the general process depicted in Figure A-10 is fairly standard.

To overcome the problems of the design-to-cost concept and to achieve an orderly derivation of feasible ship requirements to meet initial cost constraints, the Navy initiated a top level requirements/top level specifications (TLR/TLS) process in early 1974. TLR/TLS documents are developed during the three design phases conducted by the Navy (conceptual design, preliminary design, and contract design) and are compatible with DOD milestones for major weapon procurement. The TLR is under the cognizance of the Chief of Naval Operations and the Chief of Naval Material is responsible for the TLS.

The TLR deals with the concerns of the "operating" Navy, such as:

a. Mission requirements
b. Mission derived operational requirements
c. Information projecting the ship environment (plan for use, maintenance concept, logistics concept)
d. Selected design guidance and design constraints (for example, whether life cost or acquisition cost should be used as the criterion in the various engineering trade-offs).

Thus, the TLR addresses operational considerations, not the specific technical solutions for stated operational needs.

The TLS describes in specification format the ship system concept selected as the one which best provides the performance characteristics specified in the TLR. The four basic sections of the TLS include:

a. A brief summary of primary ship system and major component characteristics
b. Design direction to meet performance requirements ("across-the-board" items)
c. A description of major ship functions
d. A performance description by ship subsystems, i.e., groups of specific hardware elements.

The development of these documents in relation to the various design phases is shown on Figure A-11:

The design of a naval combatant ship can extend over four years (or longer), starting with the examination of alternative concepts responsive to pre-established requirements and culminating in 2,500 to 5,000 multisheet detail drawings used to construct the ship in the yard. This
figure is exclusive of the drawings necessary to produce the thousands of equipments on the ship. The process is traditionally divided into concept exploration, preliminary design, contract design, and detail design phases.

Prior to contracting, the Navy accomplishes the first three design phases which cover approximately 40-50 percent of the total design period. (See Figure A-11.) During this time, all major design decisions are made and all functional characteristics (including most equipment requirements) are established.

If no major functional design requirement or feature is found infeasible during physical detailing of production drawings, the system design phase is considered successfully accomplished.
For each new ship design, NAVSEC organizes a design team headed by a design manager and staffed by representatives from functional elements of the NAVSEA organization. The design team, as shown on Figure A-12, functions as the ship system design agent for the Ship Acquisition Program Manager (SHAPM). The SHAPM is within the NAVSEA organization and has overall responsibility for design and construction of the ships assigned to him.

FIGURE A-12 NAVSEC/NAVSEA SHIP DESIGN PROJECT ORGANIZATION

The Ship Design Manager (SDM) is linked to the functional elements of NAVSEC/NAVSEA through Task Group Managers (TGM's) assigned from these elements. The TGM's usually operate on a full-time basis for major ship designs; in cooperation with the project office, they form the
project team. Thus, the NAVSEC/NAVSEA functional elements participate directly in day-to-day design evolution through the TGM interface.

As team members responsible for one or more major systems, the TGM's provide the project team with an interdisciplinary character. They are responsible for managerial and technical decisions made in their area. As representatives of specific functional entities within NAVSEC/NAVSEA, they effect direct involvement of the functional organization in program decision making.

The TGM's have the full authority of their functional code directors for their specific project assignments and are responsible for their division's input to the design effort. Within their areas of responsibility, task group managers implement the ship design manager's authority to allocate and control project resources, initiate, review and control tasks, and resolve technical issues. In this way, the TGM's are the critical link between the SDM and the NAVSEC line/functional organization.

Other systems commands (SYSCOM) and the Bureau of Medicine and Surgery are invited to assign representatives to each ship design team. These SYSCOM design representatives participate in the day-to-day evolution of the design, including its planning phases.

The joint efforts of the ship design manager and other NAVSEC/NAVSEA functional units are required for design completion. Since the
Navy is a matrix-type organization, all elements involved have mutual responsibility to assure that issues requiring resolution by higher levels are identified as early as possible.

The design manager has the authority to make unilateral decisions in time-constrained situations. However, this prerogative is exercised with discretion and the functional organization can later rescind such decisions through normal channels.

If recommendations of a branch or section within a functional division office have an adverse impact on the ship system design or program, the cognizant TGM is responsible for resolving the problem within the division office concerned. If such resolution cannot be obtained, the matter is referred to the design manager.

Prior to the total package procurement approach which transferred the entire design effort to private industry, the practice in the Bureau of Ships was not completely different from current methods. The primary differences were:

a. The design was passed on from one organization to the other as the design evolved from a preliminary to contract design.

b. There was very little participation in a new ship design prior to completion of preliminary design by any organization outside the Preliminary Design Branch,
c. Financial control and planning of the design were not emphasized.

This brief overview provides the basic features of the naval ship design process. More detailed descriptions can be found in the reference material [A-5], [A-6], [A-7] and [A-8].
A host of organizations outside its own organizational boundaries derive their existence from the Navy. More than 50 percent (over $1 billion per year) of the R&D dollars allocated to the Navy's laboratories flow into privately owned concerns which supply items ranging from janitorial service to special test instrumentation to the "renting" of sophisticated research personnel. The remaining R&D funds support other Navy organizations, including parts of the so-called system commands engaged in development, procurement, and maintenance for this highly technologically oriented service, as well as the system commands' own contractors.

The Navy's R&D budget is almost $4 billion annually. Operating such a budget to achieve multiple objectives requires considerable planning and negotiating; the requirements of a large R&D organization and its laboratories are always more demanding than available funds. As the budget increased during the postwar years, planning and budgeting became more involved (to the extent that it sometimes takes three years to incorporate a new R&D line item into the budget). The complexity of the Navy's R&D organization is in great part attributable to its planning and budgeting activities, rather than to its R&D execution function alone. Accordingly, this section describes these activities as well as the actual execution of R&D.

The 1940's mark the beginning of the era of substantial planned R&D in the Navy. Prior to that time, R&D planning procedures were
relatively informal and unstructured. Requirements statements were generated in OPNAV by warfare groups and the Operational Readiness Division based on intelligence estimates and contacts with fleet personnel and the technical community. These requirements were transmitted via internal memorandums to the office of the DCNO for logistics who then assigned R&D projects to the appropriate bureaus and offices responsible for program planning.

The creation of the Office of the Director of Defense Research and Engineering (DDR&E), the Assistant Secretary of the Navy for Research and Development, and the Deputy Chief of Naval Operations for Development set the stage for radical changes in R&D program planning and justification.

A quick succession of changes (see Table A-2) established a complete set of planning procedures. The "user-producer" dialogue, with OPNAV representing the "user," evolved into a highly formalized documentation system as part of the accelerated trend toward centralized control of R&D programs.

The R&D program was broken into six elements within which line items for specific projects were introduced. DDR&E required justification for each program, involving extensive analysis to show program cost effectiveness. As a result, similar procedures were adopted within the services. Thus, a proposed project must be approved by at least a dozen different organizations. If approved, two or three years may pass before
TABLE A-2

CHANGES IN THE R&D PLANNING PROCEDURES 1959 - 1962

- In 1959, the Navy established a separate program category for Exploratory Development and subsequently issued Exploratory Development Requirements.

- In 1961, OSD introduced a new system for planning, programming and budgeting (PPBS) and further compartmentalized the RDT&E program into six categories: Research, Exploratory Development, Advanced Development, Engineering Development, Management & Support, and Operational Systems Development.

- In 1960 and 1962, DDR&E imposed new reporting requirements on the military departments which included OSD requirements for TDP's, periodic submission of project listings, and revised reports for projects not covered by TDPs.

- In 1962, DCNO (Development) issued a comprehensive revision to the Navy's RDT&E program planning system which further formalized the process and brought it into line with the six-part program structure.
it can be introduced as a legitimate line item for funding. Because of finite resources and existing programs, a decision to stop a funded program may have to be made so the newly approved project can be funded.

In the early postwar years, the entire process of R&D budget formulation and execution was bureau-oriented. Research and development was funded with the bureau's overall programs; it was not identifiable as a separate entity either in the budget or in the appropriation acts approved by Congress. The only exception was the appropriation category "Research, Navy" established by Congress to support the newly created ONR and its Navy-wide research mission. The bureau chiefs had responsibility and authority for preparing and justifying R&D budget estimates in addition to broad reprogramming authority within their blanket appropriations. While obtaining and allocating R&D funds varied slightly among the material bureaus, the basic process and its participants were similar in most respects; it was time consuming, relatively informal and highly iterative, and involved most participants in the R&D process at one stage or another. Between the bureaus and Congress, the Office of the Secretary of the Navy, and the Office of the President exercised approval authority for the budget and apportionment of appropriated funds.

The developments of the 1950's and 1960's brought major changes to the budget submission process [A-2]:

"Provided a financial information base essential to centralized review and control over R&D funding.
"Further subordinated the identity of individual bureaus in the budgeting and appropriations processes."

"Promoted more direct competition for R&D funds among bureaus and the military departments."

"Led to more complex and voluminous R&D budget submissions."

The planning, programming, and budgeting systems (PPBS) initiated by Secretary of Defense McNamara in 1962 proved a powerful mechanism for DOD control over the bureaus' R&D efforts. This visible centralization led to increased assertion of congressional authority over R&D, making it even more difficult for an innovation champion to obtain funds for development. Between 1946 and 1976, the R&D budget increased from $250 million to over 15 times that sum. Inspite of this growth, R&D managers in the system commands find their resources diminishing, because of proliferation of programs and loss of control by those who design and engineer the systems which are introduced in the fleet.

R&D program execution involves assigning work to in-house laboratories or to private industry, institutions and universities through contracts and grants. Almost half the funds allocated to laboratories also end up in the private sector.

Until the late 1950's, the bureaus and their laboratories executed R&D programs with little or no outside interference. Guided by only the most general requirements, bureau personnel relied on official correspondence, discussions with OPNAV, fleet and laboratory personnel,
as well as the experience of their own officers and engineers, to identify existing and projected Navy problems.

Ideas for solving fleet problems and exploiting technological opportunities were converted into exploratory projects with relative ease. Project plans, task assignments, and monitoring procedures were flexible and tailored to the needs of the individual manager. Some projects ultimately paid off; some did not. Managers attempted to screen out potential failures and find projects likely to succeed. The key to this complex, relatively unstructured process was the responsibility and authority assumed by the bureau chiefs in meeting the material requirements of the fleet and the emphasis on the "cradle-to-grave" engineering responsibility by technical personnel involved. In fact, the Navy's R&D function during the early 1940's was performed by a design division branch within the Bureau of Ships.

Following the shift to centralized management over the last 15 years, the change in laboratory reporting relationships has had a great impact on the execution of R&D relative to near-term fleet needs.

A comprehensive review of Navy R&D management over the last 25 years summarized the trend which led to the situation today as follows [A-2]:

"a. Centralization and shift of authority upward

b. Augmentation of the organization at all levels with staffs and offices having R&D responsibilities"
c. Frequent reorganization and reformulation of the Navy R&D management framework

d. Proliferation of controls, restrictions, and procedures."

This brief description has presented some of the issues relating to R&D management and execution in the Navy. (For a more indepth review, see [A-2] and [A-3].)
LIST OF REFERENCES


APPENDIX B

Devices for Ship Roll Stabilization

Since the devices that have been invented to counter the problem of roll stabilization are central to this study, they will be briefly described in this section. For further reference, see [B-1] and [B-2].

An effective roll-quencher should provide at each instant, a restoring moment of a magnitude equal (ideal case) or close to the exciting or roll-producing moment of each wave as it approaches and acts on the ship. The restoring moment should be generated by an energy source that is independent of the roll and at a rate corresponding to the varying rates of encounter of the often irregular waves of the sea. This means that active types of roll-quenching equipment can be more effective than the passive types. Although anti-rolling tanks are intended to produce a restoring rather than a resisting moment, as do bilge keels, they are considered as passive devices because the time and phase of the restoring moment are not under control. (Also, their primary mechanism is the provision of added damping.)

It should be emphasized that the restoring moment must not only be close in magnitude to the exciting moment and opposite in sign, but also be properly phased in time, especially in irregular waves. This timing is a function of the system which controls the activity of the roll-quenching device. The restoring moment or stabilizing force is produced by one of several well-known methods of mechanics:
a. Pushing or pulling against a heavy rotatable mass, like a huge flywheel mounted on a fore-and-aft axis, in a direction opposite of that of the impressed roll. The solid mass may be replaced by liquid in a doughnut-shaped tank, circulated in one direction or the other within the tank by one or more impellers.

b. Forced precession of one or more large gyros, spinning in a direction at right angles to the plane of the roll-quenching moment desired.

c. Transferring a movable mass toward one side or other of the vessel. This may be a solid mass, like a weight mounted at the end of an arm pivoted on a vertical axis, a large mass on a wheeled carriage running on an athwartship track, or a mass of liquid which is shifted from a wing tank on one side of the vessel to a wing tank on the other through an interconnecting duct.

d. Squirtling large jets of water outward and downward to produce an upward reaction suitable for the restoring moment.

e. Generating lift forces about the rolling axis, with the vessel underway, by one or more tilting hydrofoils, projecting transversely on each side of the ship and thereby generating torques about the roll axis of the ship in opposition to the rolling motion.

Table B-1 lists the various devices which have been used to control the rolling motion of ships. The simplest and most common of these are fixed bilge keels. Other, more elaborate schemes have been tried with varying degrees of success. Table 5-1 shows a chronological list of significant installations of the various devices. The list does not show specific
commercial installations for the last 15 years. During the last 15 years, hundreds of ships have been fitted with passive tanks (mostly commercial) and active fin stabilizers (both naval and commercial), and the Soviets as well as the British Navies have adopted a policy to fit all their destroyers with fin stabilizers.

**TABLE B-1**

**STABILIZING SYSTEMS TO QUENCH ROLLING MOTION**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
</table>
| a. BILGE KEELS | SOLID  
|   | SERRATED |
| b. SOLID WEIGHT | ACTIVE  
|   | PASSIVE |
| c. ANTI-ROLLING TANKS | ACTIVE  
|   | PASSIVE  
|   | (a) FREE SURFACE  
|   | (b) U TUBE  
|   | (c) OPEN TO SEA  
| d. GYROSCOPE |   |
| e. EXTERNAL FINS | RETRACTABLE  
|   | NON-RETRACTABLE |

The two major categories of roll stabilizers which are in current use, in commercial and naval ships, are of the internal tank type and the external fin type.

The internal tank type stabilizers can be passive or active, which refers to whether the water movement is from the ship motion alone (passive) or is enhanced by power input via a pump which is controlled (active).
There are also variations with respect to the geometry of the tanks. The so-called U-tube tank and the flume tank both have water flow inside the ship from one side to the other (Figure B-1). In another type, each wing tank communicates with water outside of the ship (see Figure B-2). The water in the tank acts together with the ship as a double pendulum and it can be set to oscillate in two natural resultant periods, one on each side of the natural period of the ship. Synchronism effects with sea conditions are thus removed from the period of the ship to two new resultant periods, at neither of which the amplitude is as great as the resonant amplitude without tanks (see Figure B-3).

As shown in Figure B-3, by properly designing the tank for a specific ship, the accentuated peaks can be easily reduced to Curve 2. For passive operation, effective stabilization is obtained near the ship's resonant frequency, but above and below resonance the ship rolls more heavily than when it is unstabilized. This is typical of passive systems depending on the resonance phenomena. The residual rolling of the ship with active stabilization is shown by Curve 3. An accelerometer is the only roll-sensing element assumed in this case. Note that the rolling increases at the higher frequencies, because of uncompensated time lags in the controls. Adding compensation results in Curve 4.

Passive fixed fins projecting on each side of the ship can generate lifting forces and torques in opposition to the roll when the ship is underway. Because the generated lift force is proportional to the angle of attack of the fin, the passive fins are very inefficient
a. FREE SURFACE TANK

b. U-TUBE TANK

FIGURE B-1  SKETCHES OF PASSIVE ANTI-ROLL TANK STABILIZERS

SOURCE: REF [B-3]
FIGURE B-2  PASSIVE-TANK STABILIZERS, USS PENSACOLA AND USS NORTHAMPTON

SOURCE: REF [B-4]
1. UNSTABILIZED SHIP
2. DAMPED MOTION WITH RESONANT PEAKS
3. PASSIVE STABILIZED SHIP
4. ACTIVE STABILIZED SHIP

FIGURE B-3 PERFORMANCE CURVES OF TANK STABILIZED SHIP

730
because the angle of attack of the fin is generated only by the transverse component of the flow velocity due to roll. They are not used in practice.

Active fins have particularly attractive performance characteristics. Depending on the type of controls used, it is possible to make them very effective over a wide range of wave frequencies (over-all frequencies encountered in practice). Unlike the passive fins, the active fins can have their angle of attack varied in accordance with and in opposition to the ship's roll motion. A pair of fins, one on each side, produces a torque about the ship's axis of roll which is essentially proportional to the fin angle of attack, and acts in opposition to the wave-excited roll moment. Because this torque is also proportional to the square of the ship's speed, fins are not very effective at low speeds. In fact, for installations of practical size, they are essentially useless below five knots, and are really effective only above ten knots. This, however, is within the range of the usual operating speeds of naval vessels. Fins have an advantage over tanks in that they require a minimum of weight and space.

Figure B-4 shows typical frequency-response curves for a ship with an activated fin stabilizer. Curve 1 shows the response of the unstabilized ship. Curve 2 shows the effect of controlling fin angle by roll-velocity signal alone. This simply increases the apparent damping. Curve 3 shows the expected stabilization using all three roll signals - angle, velocity and acceleration, to control the fin angle. It might
1. UNSTABILIZED SHIP
2. VELOCITY CONTROL OF FIN ANGLE
3. ACCELERATION, VELOCITY AND POSITION CONTROL OF FIN ANGLE

FIGURE B-4 PERFORMANCE CURVES OF FIN STABILIZED SHIP
seem that one could make the stabilization as complete as desired by simply increasing the gain of the control system ad infinitum. However, small but inevitable time lags in actual control system put a finite limit on this control gain. Curve 3 represents a degree of stabilization which can in fact be achieved.

Whatever the type of stabilizing system, its success, in large measure, depends on the controls used. Unfortunately, in the early development period, most people working on ship stabilization were primarily concerned with stabilizing devices, rather than with the controls for these devices. In the early days of ship stabilization, a formal science of control simply did not exist, and even as elegant and powerful theories were developed, they somehow failed to be carried over soon enough into the ship-stabilization field. Many of the difficulties that designers of active ship-stabilization systems have had in the past can be attributed to a lack of attention to controls.

This brief review of options for roll stabilization should suffice as a basis for understanding the issues of the case study.
LIST OF REFERENCES


