A Tool for Evaluating the Early-Stage Design of Corvettes

by

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Submitted to the Department of Mechanical Engineering
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Abstract

In naval architecture terminology, the term "corvette" refers to a class of ships that are shorter than frigates and longer than patrol boats. Corvettes have always been the centerpiece of the navies whose mission requirements are based on littoral combat such as Anti-Submarine Warfare, Mine Warfare, and Anti-Surface Warfare. Numerous studies have focused on frigates and patrol boats in the history of naval architecture. However, few studies applied to corvettes.

There is a trend in the ship building industry to design new ships as corvettes [1] since they can operate both independently and in joint missions. However, it is difficult for a naval architect to manage all the information flow throughout the corvette design process. When the displacement of the ship gets larger, this design process also becomes more complicated. The management of this process becomes more efficient by using computer programs. However, programs for use in the design of corvettes do not exist. This thesis explains how early-stage estimations are made for corvettes. In order to cover this future trend in marine transportation, a Matlab™ model for the estimation of the main characteristics of corvettes in the early-stage design is also developed.

This Matlab™ model is based on a statistical analysis of existing ships that are classified as corvettes. The database used in this study is created by using the public information that is available to the author. For this study, design lanes are created, trend lines are drawn and relationships between the desired values are graphed. For the validation of the code, the *Kral J Petar Kresimir, Eilat (SAAR 5)* and *Robinson* are used as reference ships in this study. The customer requirements of these ships are entered into the model. The results show that the data of these ships fall within the design lanes.

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Biographical Note and Acknowledgements

Mustafa Yasin Kara is a Lieutenant Jr. G. in the Turkish Navy. He received his B.S. from Turkish Naval Academy in Naval Architecture and Marine Engineering in 2006 and was commissioned as an Ensign in the Turkish Navy. Mustafa Yasin Kara is qualified on Amphibious Ships and served for one year aboard the TCG ERTUGRUL (L-401). Now he is transferred to Engineering Community where he will design, maintain and acquire surface ships for the Turkish Navy.

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"Hayatta en hakiki mursit ilimdir."
"Our true mentor in life is science."
MUSTAFA KEMAL ATATURK

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Table 1 Nomenclature

(Source; Lamb[2])

A_M	submerged hull section area amidships (m^2)
AP	after perpendicular, often at the center of the rudder post
A_W	area of design waterplane (m^2)
A_X	maximum submerged hull section area (m^2)
AAW	Anti-Air Warfare
ASSET	Advanced Surface Ship Evaluation Tool
ASW	Anti-Submarine Warfare
ASuW	Anti-Surface Warfare
B	molded beam of the submerged hull (m)
BM_T	transverse metacenteric radius (m)
BM_L	longitudinal metacenteric radius (m)
C_B	block coefficient = Δ/LBT
C_{BD}	block coefficient to molded depth D
C_B	block coefficient at 80% D
C_{DWT}	total deadweight coefficient = DWT_T/Δ
C_I	transverse waterplane inertia coefficient
C_{IL}	longitudinal waterplane inertia coefficient
C_M	midship coefficient = A_M/BT
C_m	coefficient in non prime mover machinery weight equation
C_P	longitudinal prismatic coefficient = Δ/A_XL
C_Δ	volumetric coefficient = Δ/L^3
C_{VP}	vertical prismatic coefficient = Δ/A_WT
C_{WP}	waterplane coefficient = A_W/LB
C_X	maximum transverse section coefficient = A_X/BT
D	molded depth (m)

FF	Frigate
F/C	Fire and Control Systems
F_n	Froude number = $V/\sqrt{(gL)}$, nondimensional
FP	forward perpendicular, typically at the stem at the design waterline
FS	free surface margin as % KG
F_Δ	volumetric Froude number = $V/\sqrt{(g^{\Delta^{1/3}})}$
g	acceleration of gravity (m/s^2); 9.81 m/s^2
GM_T	transverse metacentric height (m)
GM_L	longitudinal metacentric height (m)
ISR	Intelligence, Surveillance and Reconnaissance
KB	vertical center of buoyancy above baseline (m)
KG	vertical center of gravity above baseline (m)
LBP	length between perpendiculars (m)
LCB	longitudinal center of buoyancy (m aft FP or %L, + fwd amidships)
LCF	longitudinal center of flotation (m aft FP or %L, +fwd amidships)
LCG	longitudinal center of gravity (m aft FP or %L, +fwd amidships)
LOA	length overall (m)
LWL	length on the design waterline (m)
MIW	Mine Warfare
PCAT	Patrol Craft Assessment Tool
SAWE	Society of Allied Weight Engineers
T	design molded draft (m)
V	ship speed (m/s) = 0.5144 V_k
V_k	ship speed (knots)
w	average longitudinal wake fraction
$W_{C\&E}$	weight of crew and their effects (t)

W_{FL}	weight of fuel oil (t)
W_{FW}	weight of fresh water (t)
W_{LS}	Lightship weight (t)
W_M	propulsion machinery weight (t)
W_{ME}	weight of main engine(s) (t)
W_o	outfit and hull engineering weight (t)
W_S	structural weight (t)
γ	water weight density; 1.025 t/m^3 SW at 15°C; 1.000 t/m^3 FW at 15°C
Δ	displacement at the design waterline (t)
∇	molded volume to the design waterline (m^3)

CHAPTER 1

1 Introduction

There has been a growing interest in building corvettes [1] because these warships are key to navy combat operations. However, while there are many computer programs that are applied to frigates and patrol boats, there is not an efficient tool to specifically analyze the early-stage design of corvettes.

The development of the early-stage estimation tool in this thesis is based on four studies that have various methodologies. The first study (completed in 1976 by M.R. Reed [3]), which is called the "Ship Synthesis Model", is based on the design spiral that is central to most computer based designs. Reed's study is focused on frigate-sized ships, and his model uses parametric relationships to analyze surface combatants. Parametric relationships are solely the focus of the second study, called "A Comparative Analysis of Small Combatant Ships" completed in 1980 by P.E. Sullivan [4]. Sullivan's study focused on deriving parametric relationships for the small surface combatants with a range of 200 to 800 tons. Neither Reed's study nor Sullivan's study was focused on corvettes. However, they both present a method to derive parametric relationships for the naval combatants.

Szatkowski's study [5], which is written in MathCAD™, evaluates naval combat ships ,specifically USN frigates, using Reed's ship synthesis model [3]. In 2008, Gillespy developed an early-stage design tool [6] in Matlab™ for patrol boats using the design spiral. However, none of these studies presented any parametric relationships for corvettes or focused on developing a program to analyze the early-stage design of corvettes.

Therefore, a tool for early-stage evaluation using both comparative naval architecture and the ship synthesis model is needed. This thesis focuses on developing an early-stage design tool for corvettes. The new model is written in Matlab™. The program is designed to be user friendly, that is, to help customers understand and use the program without receiving any support from naval architects. This thesis presents the theory together with the analysis of the model developed. Therefore, this thesis is not simply a manual for the Matlab™ program, but a combination of the theory and application intended to help the reader to understand the design process of corvettes.

1.1 Rationale for Ship Selection

This research covers ship designs that span a range of time, size and nationality. In particular, a range of 372 to 1850 tonnes has been selected, and current designs are included from all over the world. The selected ships are classified as corvettes in Jane's Fighting Ships[7]. These ships' basic characteristics are tabulated in an Excel™ sheet and the missing coefficients are calculated using the parametric relationships presented in Lamb [2]. Table 2 contains all of the ships considered in this study. A more complete study would include more ships. However, such an undertaking is limited by lack of available data.

Table 2 Selected Ships for the Historical Database

No	Ship Class	Ship No	Country	Builder	Year
1	Stockholm	K11	Sweden	Karlskronavarvet	1984
2	Goteborg	K21	Sweden	Karlskronavarvet	1989
3	KralJ Petar Kresimir 4	RTOP 11	Crotia	Kraljevica SY	1992
4	Victory	P 88	Singapore	Lürssen-Werft	1988
5	Visby	K31	Sweden	Karlskronavarvet	2000
6	Kharomsin	531	Thailand	Ithal Thai Marine	1988
7	Roussen	P-67	Greece	Elefsis Shipyard	2002
8	Eleftheria	P-64	Greece	Rolandwerft	1962
9	HTMS Rattanakosin	FS 441	Thailand	Tacoma Boatbuilders	1986
10	Parchim	MPK-99	Russia	Wolgast	1985
11	Dong Hae	PCC-751	South Korea	KSEC Pusan	1982
12	PF 103(Bayandor)	81	Iran	Levingstone Ship Building. TX	1963
13	Serviola	P-71	Spain	Bazan, Ferrol	1990
14	Lutsk	U 200	Ukraine	Leninskaya Kuznitsa	1993
15	Kaszub	240	Poland	Northern Shipyard,Gdansk	1986
16	Pohang	PCC-756	South Korea	Korea SEC,Pusan	1985
17	Minerva	F551	Italy	Fincantieri	1986
18	Eilat (Saar 5)	501	Israel	Northrop Grumman	1993
19	Niels Juel	F 354	Denmark	Aalborg Vaerft A/S	1978
20	Vosper Mk5(Alvand)	F-71	Iran	Vosper Thornycroft,Woolston	1968
21	Baptisda De Andrade Class	F 486	Portugal	Empresa National Bazan	1973
22	Joao Coutinho	F 475	Portugal	Blohm Voss	1969
23	Khukri	P49	India	Mazagon Dock Ltd	1986
24	Fatahillah	FTH-361	Indonesia	Wilton Fijenoord	1977
25	Ishikari	DE 226	Japan	Mitsui,Tamano	1980
26	Cassiopea	P 401	Italy	Fincantieri	1988
27	Magdeburg	F 261	Germany	Lürssen- Vegesak	2006
28	Descubierta	P-75	Spain	Bazan, Ferrol & Cartagena	1975
29	Robinson(Meko 140)	P-45	Argentine	Blohm Voss	1985
30	Kasturi	F25	Malaysia	Howaldtswerke,Kiel	1983

1.2 Goals of the Study

This study analyzed the parametric relationships of the ships and developed an evaluation tool for corvettes in the early-stage design. Lamb [2] shows how these parametric studies have been carried out throughout the history of naval architecture for most of the surface combatants.

The first goal of this thesis was to develop and present the parametric relationships using graphs and trend lines. An Excel™ sheet was used to store the characteristics of ships. This sheet also presented the graphs and trend lines. Results were used in the development of the model. Equations in the following sections are based on these parametric relationships.

The second goal of this thesis was to develop a Matlab™ model that is able to evaluate the early-stage design of corvettes. This developed model is called *Early-Stage Corvette Evaluation Tool*, which is written in this thesis as ESCET. It uses equations from the parametric relationships derived from the results of the historical database. ESCET was written to be user friendly and used the GUIDE function in Matlab™, which helps the code writer to survey his program user by providing new windows as customers continue to enter their requirements.

1.3 Thesis Outline

The thesis is organized as follows;

Chapter 1 defines the problem and presents the goal of this research.

Chapter 2 presents the historical database and figures displaying the equations, which are used in ESCET. This chapter also provides the historical database graphs, charts and derived equations from trend lines.

Chapter 3 describes the customer requirements and shows the steps to gather these requirements from the customers using the Matlab™ GUIDE function.

Chapter 4 describes the development of the each module in ESCET and presents the initial validation of these modules.

Chapter 5 presents the validation of ESCET. In this chapter, the validation of the model is carried out by using Kral J Peter Kresimir, Eilat (SAAR 5) and Robinson as reference ships. This chapter presents the assessment of results for each ship as well.

Chapter 6 presents the summary of the results and shows the recommendations for the follow-on work for future developments/improvements.

CHAPTER 2

2 Review of Historical Database

The database is the centerpiece of this thesis and described in this section. Table 3 presents the main dimensions of the selected ships and the geometric ratios. ESCET uses these values to calculate the parameters for the hull module, and it is explained in section 4.2.

Table 3 Selected Ships' Main Dimensions and Their Geometric Ratios

Ship Class	LOA	LWL	B	D	T	L/B	B/T	L/T	B/D	L/D
Stockholm	50.00	48.00	7.50	6.60	3.30	6.40	2.27	14.55	1.14	7.27
Goteborg	57.00	54.72	8.00	4.00	2.00	6.84	4.00	27.36	2.00	13.68
KralJ Petar Kresimir 4	53.60	51.46	8.50	4.60	2.30	6.05	3.70	22.37	1.85	11.19
Victory	62.40	58.00	8.50	6.20	3.10	6.82	2.74	18.71	1.37	9.35
Visby	72.00	69.12	10.40	5.00	2.50	6.65	4.16	27.65	2.08	13.82
Khamronsin	62.00	56.70	8.20	5.00	2.50	6.91	3.28	22.68	1.64	11.34
Roussen	61.90	59.42	9.50	5.20	2.60	6.26	3.65	22.86	1.83	11.43
Eleftheria	70.00	67.20	8.20	5.40	2.70	8.20	3.04	24.89	1.52	12.44
HTMS Rattanakosin	80.00	76.80	9.60	4.80	2.40	8.00	4.00	32.00	2.00	16.00
Parchim	75.20	69.70	9.80	8.80	4.40	7.11	2.23	15.84	1.11	7.92
Dong Hae	78.10	74.30	9.60	5.20	2.60	7.74	3.69	28.58	1.85	14.29
PF 103(Bayandor)	84.00	79.00	10.10	6.20	3.10	7.82	3.26	25.48	1.63	12.74
Serviola	68.70	63.00	10.40	6.80	3.40	6.06	3.06	18.53	1.53	9.26
Lutsk	74.17	71.20	9.80	7.40	3.70	7.27	2.65	19.24	1.32	9.62
Kaszub	82.30	79.01	10.00	6.20	3.10	7.90	3.23	25.49	1.61	12.74
Pohang	88.30	82.40	10.00	5.80	2.90	8.24	3.45	28.41	1.72	14.21
Minerva	86.00	82.56	10.50	6.40	3.20	7.86	3.28	25.80	1.64	12.90
Eilat (Saar 5)	85.00	81.60	11.90	6.40	3.20	6.86	3.72	25.50	1.86	12.75
Niels Juel	84.00	80.64	10.30	7.30	3.10	7.83	3.32	26.01	1.41	11.05
Vosper Mk5(Alvand)	94.50	88.00	11.10	6.50	3.25	7.93	3.42	27.08	1.71	13.54
Baptisda De Andrade Class	84.60	81.22	10.30	6.20	3.10	7.89	3.32	26.20	1.66	13.10
Joao Coutinho	84.60	81.22	10.30	6.60	3.30	7.89	3.12	24.61	1.56	12.31
Khukri	91.10	84.20	10.50	8.00	4.00	8.02	2.63	21.05	1.31	10.53
Fatahillah	84.00	80.20	11.10	6.60	3.30	7.23	3.36	24.30	1.68	12.15
Ishikari	91.00	85.00	10.80	7.20	3.60	7.87	3.00	23.61	1.50	11.81
Cassiopea	80.00	72.60	11.80	7.00	3.50	6.15	3.37	20.74	1.69	10.37
Magdeburg	88.30	84.77	13.20	9.60	4.80	6.42	2.75	17.66	1.38	8.83
Descubierta	88.80	85.25	10.40	7.60	3.80	8.20	2.74	22.43	1.37	11.22
Robinson(Meko 140)	91.20	86.60	11.10	6.80	3.40	7.80	3.26	25.47	1.63	12.74
Kasturi	97.30	89.60	11.30	7.00	3.50	7.93	3.23	25.60	1.61	12.80

The minimum and maximum geometric ratios (L/B, B/T, L/T, B/D and L/D) are presented in Figure 1. These geometric ratios are also used in the hull module by ESCET. The L/B ratio of corvettes is close to frigates' L/B ratio. However, the other geometric ratios are not in the same range.

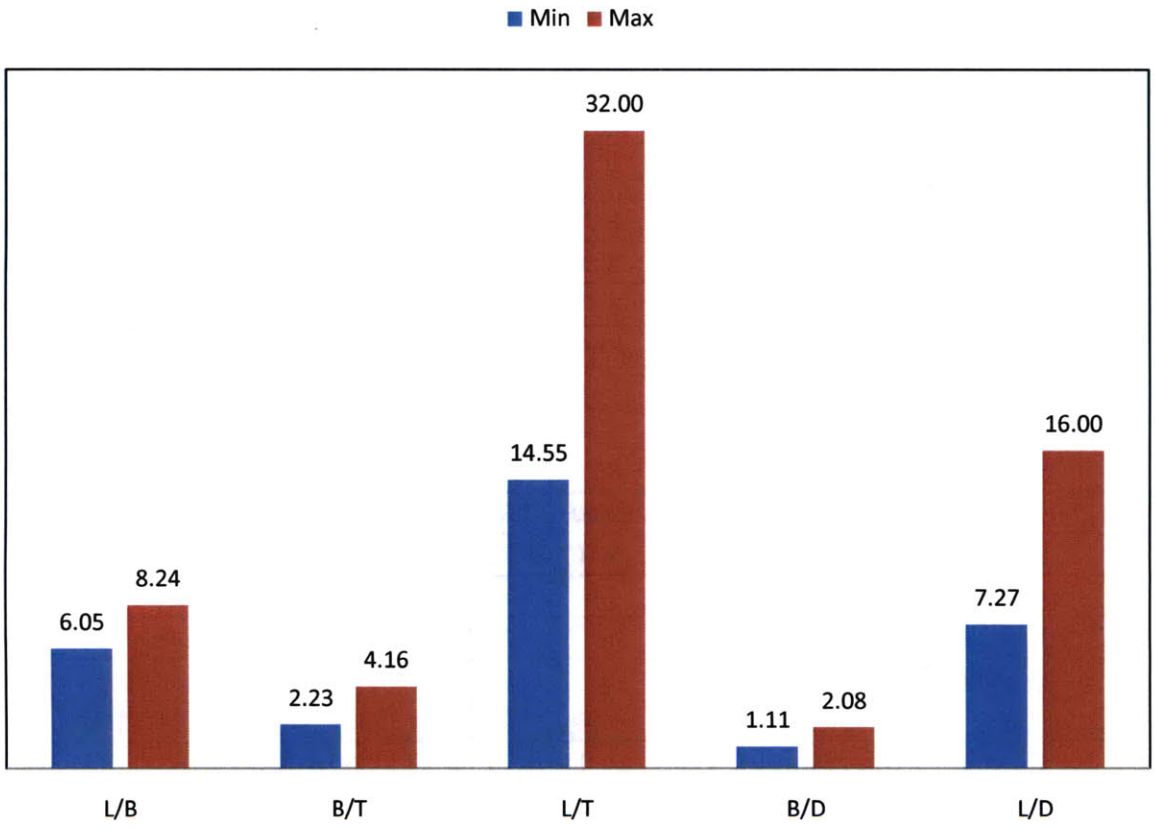


Figure 1 Minimum and Maximum Values for Corvettes' Geometric Ratios.

Watson [8] presents the summary of warship geometric ratios for corvettes. However, he does not provide the minimum and maximum values for these geometric ratios. Figure 1 explicitly shows these geometric ratios. In Watson's [8], these geometric ratios for corvettes are:

- L/B=7-8
- L/D=11
- B/D=1.5
- B/T=3.5

In this thesis, corvettes were searched and their coefficients were calculated. The selected ships' coefficients and characteristics are used by the ESCET's hull module in order to generate

new values to design a new corvette for the customers. Lamb [2] shows most types of warships' characteristics and parametric relationships. However, there is no data on corvettes. In this section, the database is reviewed and the parametric relationships are described. Selected ships' coefficients and characteristics are shown in Table 4.

Table 4 Selected Ships' Coefficients, BHP and Number of Shafts

Ship Class	C_B	BHP	C_P	C_{vol}	C_m	C_{wp}	C_{vp}	Shafts
Stockholm	0.3055	5440	0.3209	3.2817	0.9520	0.5219	0.5853	3
Goteborg	0.4446	8700	0.4613	2.3758	0.9638	0.6357	0.6994	3
KralJ Petar Kresimir 4	0.3889	12500	0.4055	2.8715	0.9591	0.5905	0.6586	3
Victory	0.3798	15020	0.3964	2.9752	0.9583	0.5831	0.6514	4
Visby	0.3366	21760	0.3526	1.8317	0.9546	0.5476	0.6147	2
Kharomsin	0.5288	9980	0.5446	3.3718	0.9709	0.7031	0.7520	2
Roussen	0.4387	23170	0.4554	3.0686	0.9633	0.6309	0.6954	4
Eleftheria	0.4800	6800	0.4965	2.3533	0.9668	0.6642	0.7227	2
HTMS Rattanakosin	0.5293	14730	0.5451	2.0676	0.9710	0.7035	0.7523	2
Parchim	0.3214	14250	0.3371	2.8524	0.9533	0.5351	0.6006	3
Dong Hae	0.5661	26820	0.5811	2.5593	0.9741	0.7327	0.7726	2
PF 103(Bayandor)	0.4477	5250	0.4644	2.2459	0.9641	0.6381	0.7015	2
Serviola	0.5023	7500	0.5186	4.4753	0.9687	0.6820	0.7365	2
Lutsk	0.4346	31000	0.4513	3.1084	0.9629	0.6276	0.6925	3
Kaszub	0.4712	16900	0.4878	2.3402	0.9661	0.6571	0.7171	2
Pohang	0.4981	26820	0.5144	2.1274	0.9683	0.6786	0.7339	2
Minerva	0.4519	11000	0.4686	2.2278	0.9644	0.6416	0.7044	2
Eilat (Saar 5)	0.4066	30000	0.4233	2.3253	0.9606	0.6049	0.6722	2
Niels Juel	0.5002	24600	0.5164	2.4558	0.9685	0.6803	0.7352	2
Vosper Mk5(Alvand)	0.4149	40000	0.4316	1.9327	0.9613	0.6116	0.6784	2
Baptisda De Andrade Class	0.5192	12000	0.5352	2.5132	0.9701	0.6955	0.7465	2
Joao Coutinho	0.4877	12000	0.5041	2.5132	0.9675	0.6703	0.7276	2
Khukri	0.3926	14400	0.4092	2.3257	0.9594	0.5935	0.6615	2
Fatahillah	0.4815	25440	0.4980	2.7423	0.9669	0.6654	0.7237	2
Ishikari	0.4281	24700	0.4448	2.3035	0.9624	0.6223	0.6879	2
Cassiopea	0.4799	7940	0.4964	3.7606	0.9668	0.6641	0.7227	2
Magdeburg	0.3019	19850	0.3172	2.6620	0.9517	0.5190	0.5817	2
Descubierta	0.4824	15000	0.4989	2.6236	0.9670	0.6661	0.7243	2
Robinson(Meko 140)	0.5481	20400	0.5635	2.7580	0.9726	0.7184	0.7628	2
Kasturi	0.5093	23400	0.5255	2.5091	0.9693	0.6876	0.7407	2

In Table 4, the missing coefficients are calculated using the equations in Introduction to Naval Architecture [9] and Lamb [2]. C_B is calculated using (1) and C_{vol} is calculated using (2). The midship and the maximum section coefficients (C_m~C_x) can be estimated using generalizations developed from existing hull forms. C_m is calculated using (3) and C_p was calculated using (4), while C_{wp} was calculated using (5) and C_{vp} is calculated using (6). The data on BHP and the number of shafts are gathered from Jane's Fighting Ships [7].

$$C_B = \frac{\Delta}{(LWL * B * T) * \gamma_{Salt\ Water}} \quad (1)$$

$$C_{vol} = \frac{\nabla}{\left(\frac{LWL}{10}\right)^3} \quad (2)$$

$$C_m = 0.977 + 0.085 * (C_B - 0.6) \quad (3)$$

$$C_p = \frac{C_B}{C_m} \quad (4)$$

$$C_{wp} = 0.262 + 0.81 * C_p \quad (5)$$

$$C_{vp} = \frac{C_B}{C_{wp}} \quad (6)$$

Equation (3) is presented in Lamb [2], which is developed by Benford from Series 60 data. Equation (5) is presented as an estimation method to find C_{wp} in Lamb [2] for twin screw, transom stern ships. Figure 2 (source; Lamb [2]) shows the graph of this estimation method. As it is presented in Figure 2, there is significant difference between Benford Series 60 and Eames Small Sterns. In this thesis, C_{wp} values are found more proper as if they are calculated by Benford Series 60. Figure 3 (source; Lamb[2]) shows the recommended values for C_m and Table 5 shows the minimum, maximum, standard deviation and average values of the coefficients in the historical database.

Table 5 Min, Max, Standard Deviation and Average Values of the Coefficients and Ratios

	L/B	B/T	L/T	B/D	L/D	Δ_{Stan}	Δ_{Full}	C_B	BHP	C_p	C_{vol}	C_m	C_{wp}	C_{vp}
Min.	6.05	2.23	14.55	1.11	7.27	300	372	0.0708	5250	0.0708	0.5545	0.0060	0.0573	0.0514
Max.	8.24	4.16	32.00	2.08	16.00	1500	1850	0.5661	40000	0.5811	4.4753	0.9741	0.7327	0.7726
Avg.	7.34	3.23	23.69	1.61	11.78	937	1136.4	0.4486	18729	0.4643	2.6116	0.9322	0.6290	0.6845
STD	0.73	0.47	4.00	0.24	1.99	376	420	0.1004	10062	0.1025	0.7552	0.1782	0.1234	0.1316

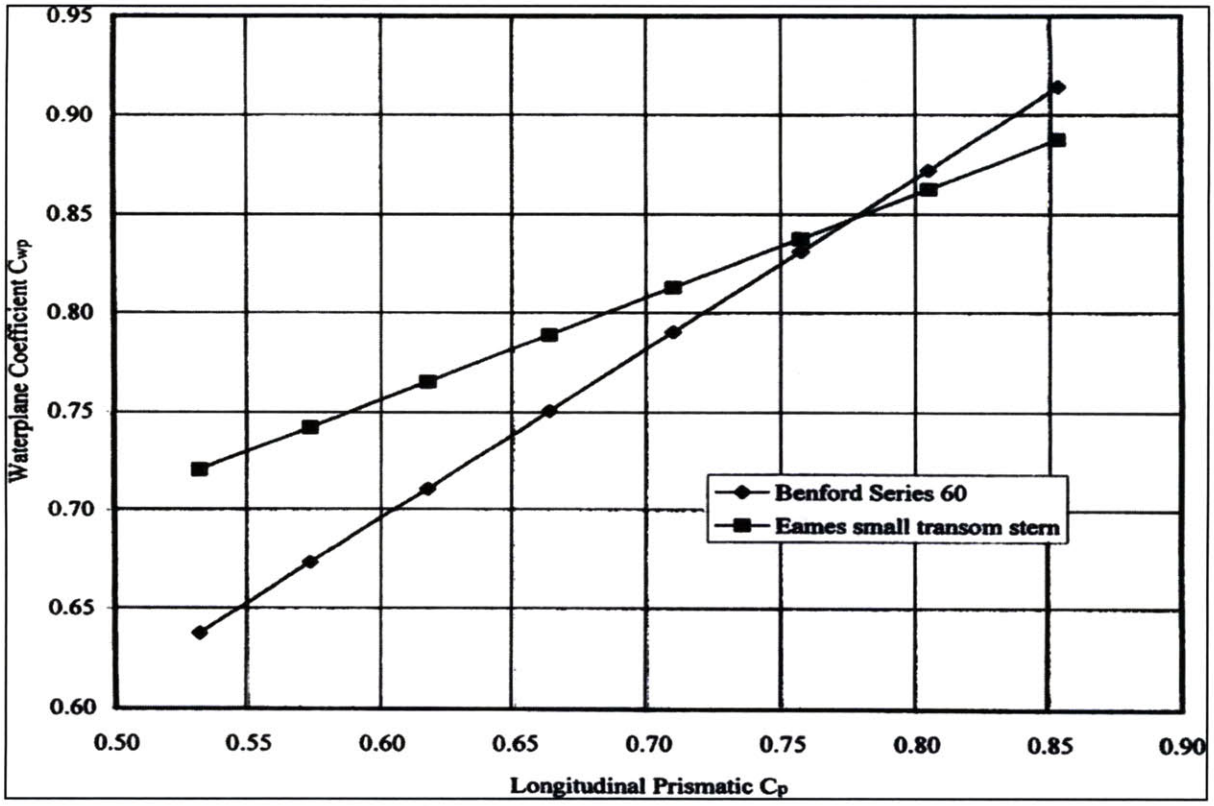


Figure 2 Estimates of C_{wp} Based on the Stern Type

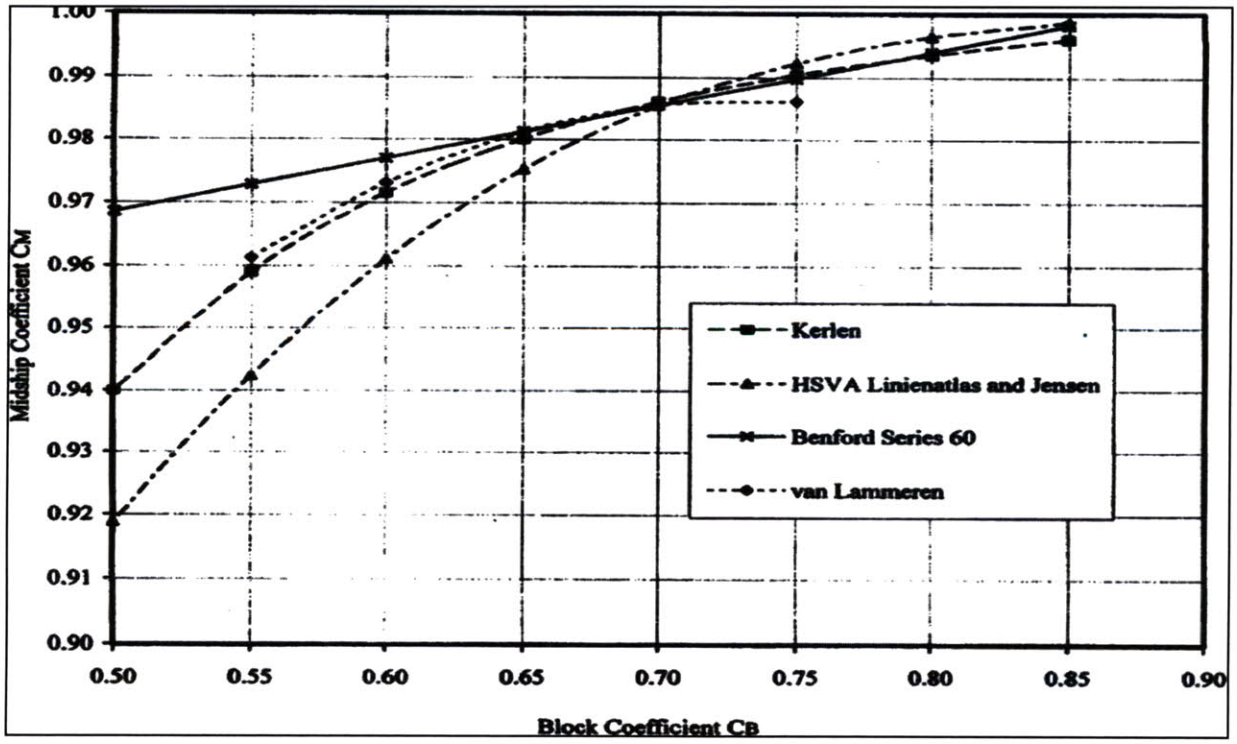


Figure 3 Recommended Values for C_m

The range of the coefficients is used in the Matlab™ model to restrict the outputs of the hull module in ESCET. The range of these coefficients is presented in Figure 4. Figure 5 shows the linear relationship between C_p and C_{wp} for corvettes.

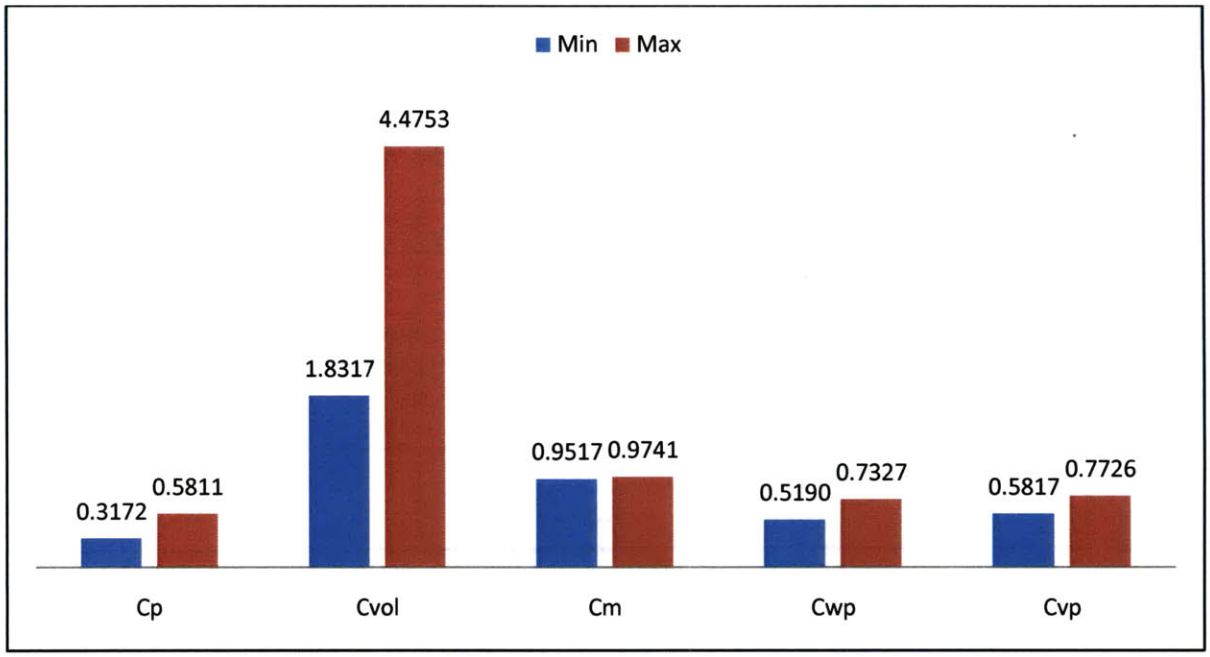


Figure 4 Minimum and Maximum Values for C_p, C_{vol}, C_m, C_{wp}, C_{vp} Coefficients

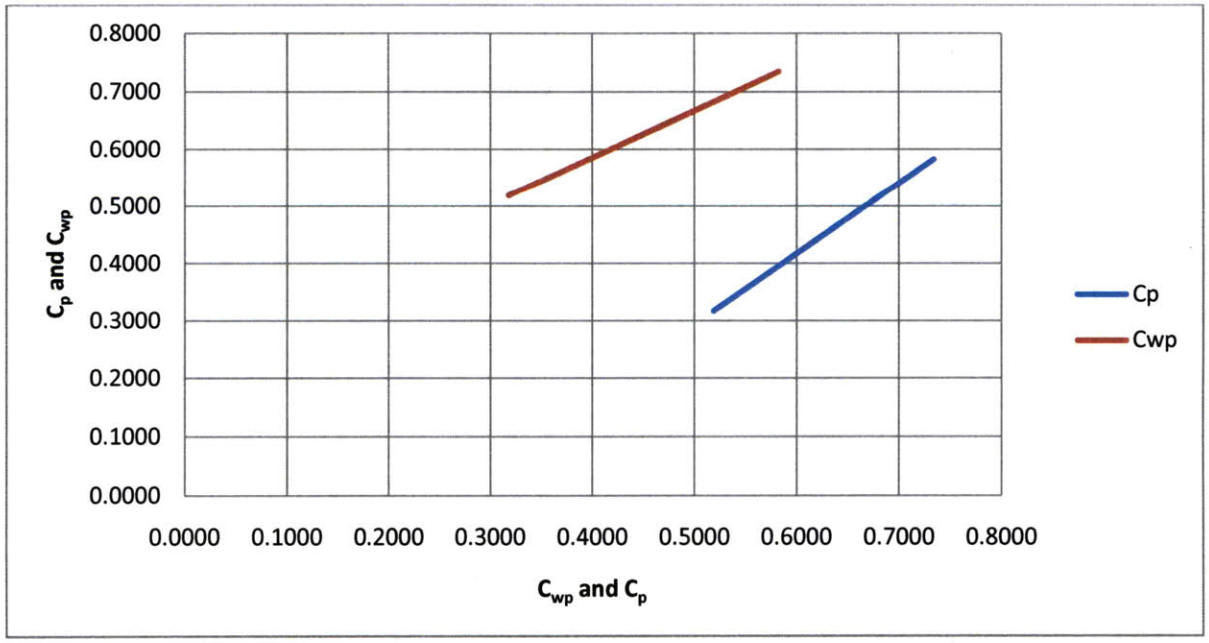


Figure 5 Relationship between C_p and C_{wp} Coefficients

Selected ships' characteristics are shown in Table 6. As mentioned before, the full load displacement of the ships varies from 372 to 1850 tonnes. Crew is the total number of the personnel on board, and speed is the maximum speed, which varies from 19 to 39 Knots. The list of the ships that have helicopter platform is tabulated in Table 6. There are four power plant types in the historical database:

- Combined Diesel and Gas Turbine (CODAG)
- Combined Diesel or Gas Turbine (CODOG)
- Combined Diesel and Diesel (CODAD)
- Diesel

None of the ships in the historical database has a Combined Gas Turbine or Gas Turbine (COGOG) or Combined Gas Turbine and Gas Turbine (COGAG). Propulsion plant data is used in the machinery module by ESCET. The machinery module is explained in section 4.3. Figure 6 shows the relationship between speed and BHP. In this graph, every power plant in historical database is plotted. In Figure 6, BHP varies from 5250 to 40000 hp and speed varies from 19 to 39 Knots. ESCET uses this figure to find a suitable power plant for the customer. The other evaluation tools ask their customer for the type of the power plant. However, in this study the power plant is defined without asking for specific engines. The use of this graph is explained in section 4.3 as well. All ships' machinery specifications and the historical database are tabulated in the appendices. Machinery area, machinery volume, BHP and machinery weight are gathered using Jane's Marine Propulsion [10] and available data, which is on the internet.

Figure 7 shows the number of shafts vs. the maximum speed. This graph is used by Machinery Module in ESCET. There are two ships in the historical database (Victory, Roussen) that have four shafts. These ships have diesel power plant and four diesel engines. They do not represent common power plant for corvettes. Therefore, these two ships are excluded from some of the graphs for diesel power plant. These graphs are presented in section 4.3.

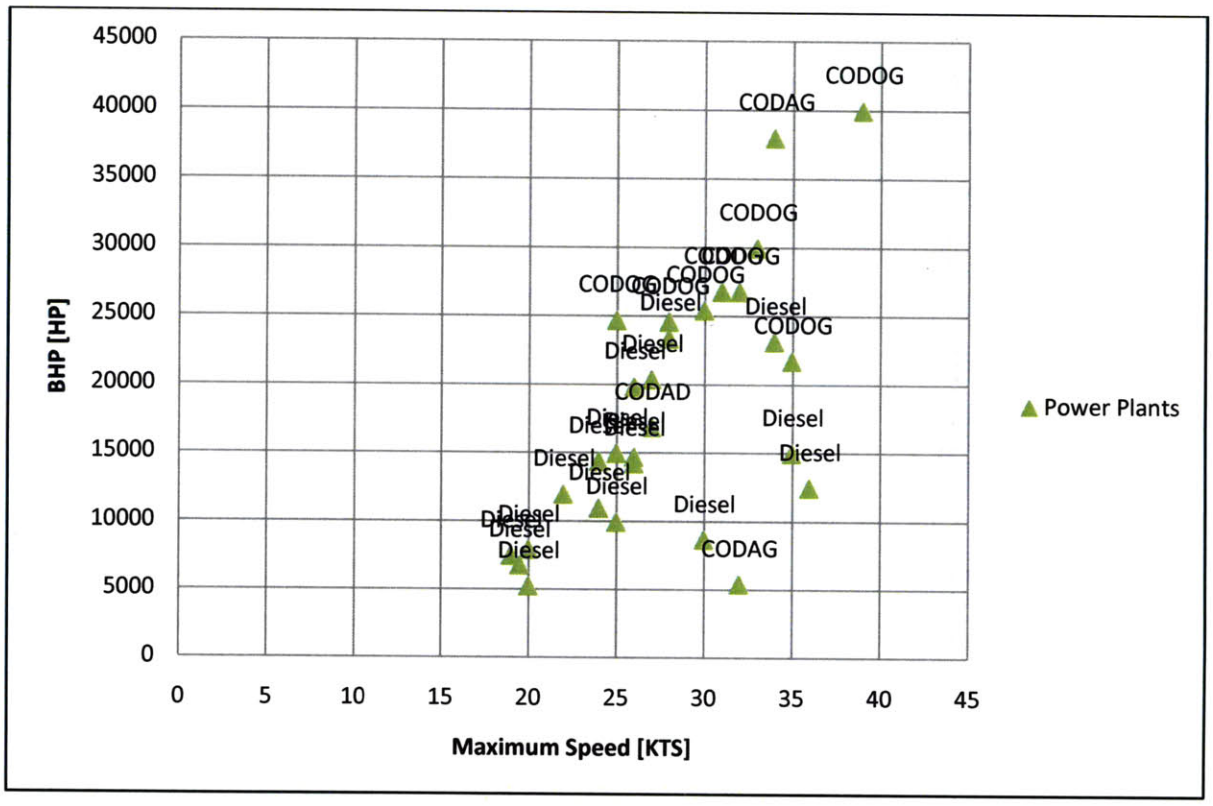


Figure 6 Max. Speed vs. BHP Relationship for Each Power Plant

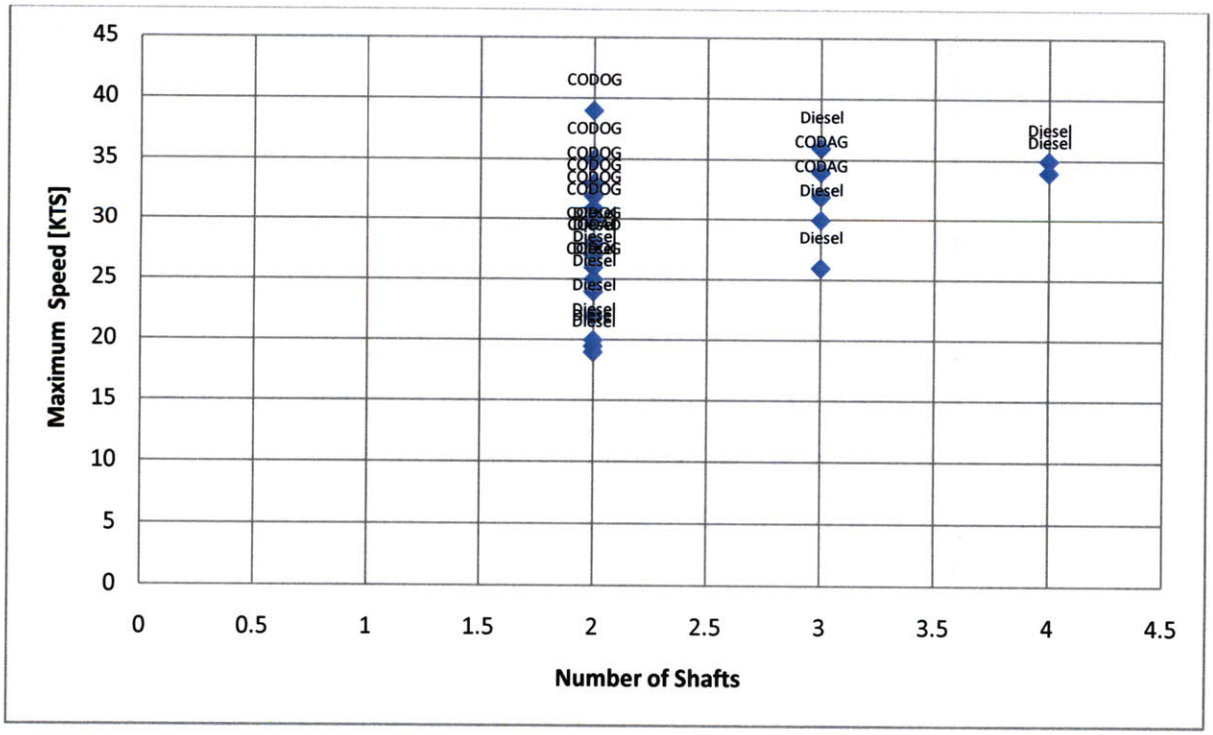


Figure 7 Number of Shaft vs. Maximum Speed for Each Power Plant

Table 6 Selected Ships' Characteristics

Ship Class	Δ_{Full}	Crew	Speed	Power Plant	Helo Platform	F_n	F_n @ V_{Range}
Stockholm	372	33	32	CODAG	No	0.759	N/A
Goteborg	399	36	30	Diesel	No	0.666	N/A
KralJ Petar Kresimir 4	401	29	36	Diesel	No	0.824	0.412
Victory	595	49	35	Diesel	No	0.755	0.388
Visby	620	43	35	CODOG	Yes	0.692	N/A
Khamronsin	630	57	25	Diesel	No	0.545	0.327
Roussen	660	45	34	Diesel	No	0.725	0.256
Eleftheria	732	48	20	Diesel	No	0.391	0.301
HTMS Rattanakosin	960	87	26	Diesel	No	0.487	0.300
Parchim	990	70	26	Diesel	No	0.512	0.236
Dong Hae	1076	95	31	CODOG	No	0.591	0.286
PF 103(Bayandor)	1135	140	20	Diesel	No	0.370	0.333
Serviola	1147	42	19	Diesel	Yes	0.393	0.248
Lutsk	1150	70	30	CODAG	No	0.584	0.273
Kaszub	1183	82	27	CODAD	No	0.499	0.259
Pohang	1220	95	32	CODOG	No	0.579	0.271
Minerva	1285	106	24	Diesel	No	0.434	0.325
Eilat (Saar 5)	1295	64	33	CODOG	Yes	0.600	0.309
Niels Juel	1320	94	28	CODOG	No	0.512	0.329
Vosper Mk5(Alvand)	1350	135	39	CODOG	No	0.683	0.315
Baptisda De Andrade Class	1380	71	22	Diesel	Yes	0.401	0.328
Joao Coutinho	1380	70	22	Diesel	Yes	0.401	0.328
Khukri	1423	112	24	Diesel	Yes	0.430	0.286
Fatahillah	1450	89	30	CODOG	No	0.550	0.293
Ishikari	1450	95	25	CODOG	No	0.445	N/A
Cassiopea	1475	65	20	Diesel	Yes	0.386	0.328
Magdeburg	1662	65	26	Diesel	Yes	0.464	0.268
Descubierta	1666	118	25	Diesel	No	0.445	0.320
Robinson(Meko 140)	1836	93	27	Diesel	Yes	0.477	0.318
Kasturi	1850	124	28	Diesel	Yes	0.486	0.312

Table 7 presents the breakdown of the SWBS groups for the FF (Frigate). In the SWBS system, each component is assigned a five-digit number. The first three digits identify individual ship systems in a major one-digit category. For example, in the SWBS element 622, the 6 identifies the item as part of an outfitting category, the first 2 identifies the component as being part of the hull compartmentation system and the second 2 identifies the item as being floor plating and gratings. These SWBS groups are also used by cost module, which is explained in section 4.7. Table 8 shows the estimated SWBS weight groups for selected corvettes in the historical database. The estimation of these weight groups are based on the ratiocination method, which is explained in SAWE (Marine Vehicle Weight Engineering, Society of Allied Weight Engineers) [11]. Weight groups are estimated using FF values that are presented in SAWE [11]. FF is the closest design to corvettes that is presented in this text. Therefore, estimations on SWBS groups are made based on these FF weight percentages. These ratios (the displacement to weight groups) are presented below. SAWE [11] also presents the VCG/D ratios for FF. These VCGG/D ratios are used by machinery module in ESCET. The calculations are explained in section 4.3.

Table 7 SWBS Groups Breakdown

SWBS Group	Description	Estimation
W_{100}	Hull Structure	$0.31*\Delta_{Full}$
W_{200}	Propulsion Plant	$0.11*\Delta_{Full}$
W_{300}	Electric Plant	$0.03*\Delta_{Full}$
W_{400}	Command & Surveillance	$0.04*\Delta_{Full}$
W_{500}	Auxiliary Systems	$0.09*\Delta_{Full}$
W_{600}	Outfitting Systems	$0.06*\Delta_{Full}$
W_{700}	Armament	$0.02*\Delta_{Full}$
$W_{Payload}$	Payload	$W_{400}+W_{700}$
W_{Margin}	Margins, Acquisition	$0.05*\Delta_{Full}$
$W_{Light\ Ship}$	Light Ship Weight	$Sum(W_{100}...W_{700})$
$W_{Full\ Loads}$	Loads, Departure	$0.29*\Delta_{Full}$

Table 8 Estimated Weights for Selected Ships in the Historical Database

Ship Class	W_{100}	W_{200}	W_{300}	W_{400}	W_{500}	W_{600}	W_{700}	$W_{Payload}$	$W_{Light\ Ship}$	W_{Margin}	$W_{Full\ Loads}$
Stockholm	115.32	40.92	11.16	14.88	33.48	22.32	7.44	22.3	245.5	18.6	107.8
Goteborg	123.69	43.89	11.97	15.96	35.91	23.94	7.98	23.9	263.3	19.95	115.7
KralJ Petar Kresimir 4	124.31	44.11	12.03	16.04	36.09	24.06	8.02	24.0	264.6	20.05	116.2
Victory	184.45	65.45	17.85	23.8	53.55	35.7	11.9	35.7	392.7	29.75	172.5
Visby	192.2	68.2	18.6	24.8	55.8	37.2	12.4	37.2	409.2	31	179.8
Khamronsin	195.3	69.3	18.9	25.2	56.7	37.8	12.6	37.8	415.8	31.5	182.7
Roussen	204.6	72.6	19.8	26.4	59.4	39.6	13.2	39.6	435.6	33	191.4
Eleftheria	226.92	80.52	21.96	29.28	65.88	43.92	14.64	43.9	483.1	36.6	212.2
HTMS Rattanakosin	297.6	105.6	28.8	38.4	86.4	57.6	19.2	57.6	633.6	48	278.4
Parchim	306.9	108.9	29.7	39.6	89.1	59.4	19.8	59.4	653.4	49.5	287.1
Dong Hae	333.56	118.36	32.28	43.04	96.84	64.56	21.52	64.5	710.1	53.8	312.0
PF 103(Bayandor)	351.85	124.85	34.05	45.4	102.15	68.1	22.7	68.1	749.1	56.75	329.1
Serviola	355.57	126.17	34.41	45.88	103.23	68.82	22.94	68.8	757.0	57.35	332.6
Lutsk	356.5	126.5	34.5	46	103.5	69	23	69	759	57.5	333.5
Kaszub	366.73	130.13	35.49	47.32	106.47	70.98	23.66	70.9	780.7	59.15	343.0
Pohang	378.2	134.2	36.6	48.8	109.8	73.2	24.4	73.2	805.2	61	353.8
Minerva	398.35	141.35	38.55	51.4	115.65	77.1	25.7	77.1	848.1	64.25	372.6
Eilat (Saar 5)	401.45	142.45	38.85	51.8	116.55	77.7	25.9	77.7	854.7	64.75	375.5
Niels Juel	409.2	145.2	39.6	52.8	118.8	79.2	26.4	79.2	871.2	66	382.8
Vosper Mk5 (Alvand)	418.5	148.5	40.5	54	121.5	81	27	81	891	67.5	391.5
Baptisda De Andrade Class	427.8	151.8	41.4	55.2	124.2	82.8	27.6	82.8	910.8	69	400.2
Joao Coutinho	427.8	151.8	41.4	55.2	124.2	82.8	27.6	82.8	910.8	69	400.2
Khukri	441.13	156.53	42.69	56.92	128.07	85.38	28.46	85.3	939.1	71.15	412.6
Fatahillah	449.5	159.5	43.5	58	130.5	87	29	87	957	72.5	420.5
Ishikari	449.5	159.5	43.5	58	130.5	87	29	87	957	72.5	420.5
Cassiopea	457.25	162.25	44.25	59	132.75	88.5	29.5	88.5	973.5	73.75	427.7
Magdeburg	515.22	182.82	49.86	66.48	149.58	99.72	33.24	99.7	1096	83.1	481.9
Descubierta	516.46	183.26	49.98	66.64	149.94	99.96	33.32	99.9	1099	83.3	483.1
Robinson(Meko140)	569.16	201.96	55.08	73.44	165.24	110.1	36.72	110.	1211	91.8	532.4
Kasturi	573.5	203.5	55.5	74	166.5	111	37	111	1221	92.5	536.5

CHAPTER 3

3 Gathering Customer Requirements

Customer requirements are the key inputs of the developed model. Figure 8 shows the customer requirements page from ESCET and the abilities of the ship. Customers usually state several requirements on board. Here are some of these requirements:

- Combat Capability; this requirement consists of the capability of conducting several warfare. Mostly corvettes take part in littoral operations and they can conduct ASW, ASuW, AAW and ISR.
- Manning; is the number of the crew that most of the navies around the world request from the naval architects to maintain the ship secure and operable under any emergency situation.
- Survivability; "Survivability; is a measure of the capability of the ship and crew to perform assigned warfare missions and the protection provided to the crew to prevent serious injury or death while operating in combat or accident (e.g., groundings) environments. The principle subsets of survivability are susceptibility, vulnerability, and recoverability." [12]
- Endurance; is the ability of the ship to conduct the assigned missions without any logistics for either the storage on board or the fuel needed by the ship.
- Acquisition cost; "is the procurement cost (the system cost plus the cost of the initial spares) of the ship and the cost of RDT&E (Research, Development, Test and Evaluation) and facility construction." [13]
- Mobility; is the quality of state of being mobile while conducting the missions and also be able to reach the maximum speed when it is needed. It is the ability of being mobile when the ship receives any damage from hostile ships as well.
- Maintainability; is a characteristic of the ship, expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time, when the maintenance is performed in accordance with prescribed procedures and resources.
- Affordability; is the extent to which ship is affordable to customer, as measured by its cost relative to the amount that the customer is able to pay.

- Operability; is the ability to keep the ship in a safe and reliable functioning condition under any circumstances, according to pre-defined operational customer requirements.
- Reliability; "is the ability of the ship and its systems to perform mission without failure, squalor, or demand on the support system." [14]
- Interoperability; is the capability of the ship -- whose interfaces are fully disclosed -- to interact and function with other allied units, without any access or implementation restrictions.

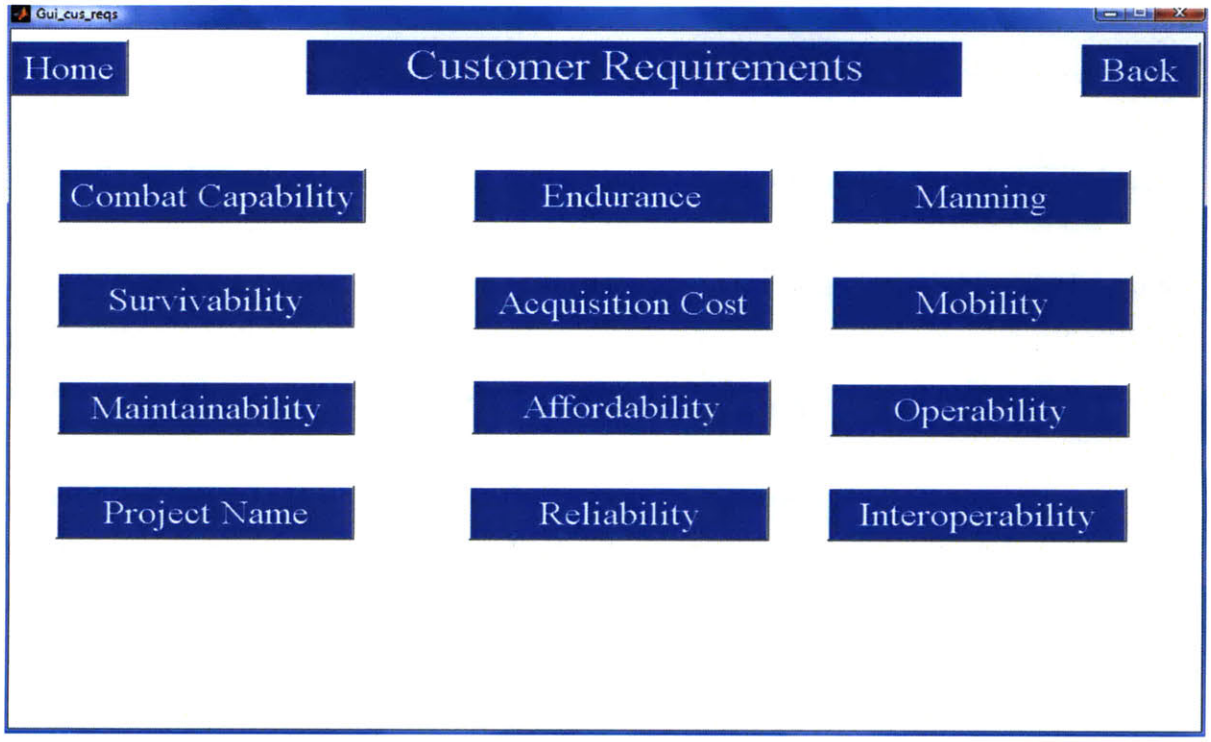


Figure 8 Customer Requirements Page from ESCET

In ESCET, to reach this customer requirements page (Figure 8), user has to select the customer requirements tab on the home page of ESCET. Figure 9 presents the home page of ESCET. The home page of ESCET has ten different tabs. First push button from the top of the page is created to define the customer requirements. The use of the customer requirements page is explained in this section. The second push button, which is called *Payloads and Inputs Summary*, is built to display every input that user enters in ESCET. This *Payloads and Inputs Summary* will pop up whenever user changes the payload for the desired ship. The third push button to the right is built to run a historical comparison within the historical database. The user

could see if the desired ship has been built before or if there is any ship in the historical database matches the customer requirements, the program will give the summary of the ship and let the user print out the results. If the user does not want to use the same ship as in the results of the historical database, he could also move on to analyze a new ship. The fourth push button, which is written as *Start Analysis*, runs the written script to analyze the desired ship. ***The user should not start the analysis until he completes the customer requirements of the desired ship***. The written code for the analysis is explained in chapter 4. The remaining six push buttons display the summary results after running the program. These modules are explained in chapter 4 as well.

In this section, the process of gathering the customer requirements is presented for the developed program. All user inputs are gathered by using a graphical user interface (GUI). Matlab™ provides this function called *GUIDE,* which aides in the building of the GUIs. All GUIs used in ESCET are created using the *GUIDE* function. The customer requirements push button, which can be simply selected to see contents of this page, is placed at the home page of ESCET. The purpose of the customer requirements (Figure 8) page is to gather user desires and store the information for use later in ESCET by querying the user for relevant data in an easy to understand format using GUIs.

The user inputs are divided into 12 segments: combat capability, project name, survivability, manning, endurance, acquisition cost, affordability, operability, reliability, mobility, interoperability and maintainability. Most of these segments are based on the -abilities of the ship as it is described above. The customer requirements page is created because of the need that a customer, who is interested in building a warship, wouldn't have the naval architectural knowledge. He would only ask for the -abilities of the ship. Most of the Initial Capabilities Documents (ICD) just cover the -abilities of the ship. This customer requirements page asks the customer what he desires to see on board. In future developments of this model, these -abilities will be replaced by slider bars, so customer could change the importance of the each -ability by defining either measure of performances (MOP) or measure of effectiveness (MOE).

The last nine -abilities of the ship (affordability, operability, reliability, mobility, interoperability, maintainability, survivability, manning, and endurance) are not developed in ESCET and are included for future development of the model. However, endurance tab is used to gather some inputs for the machinery module.

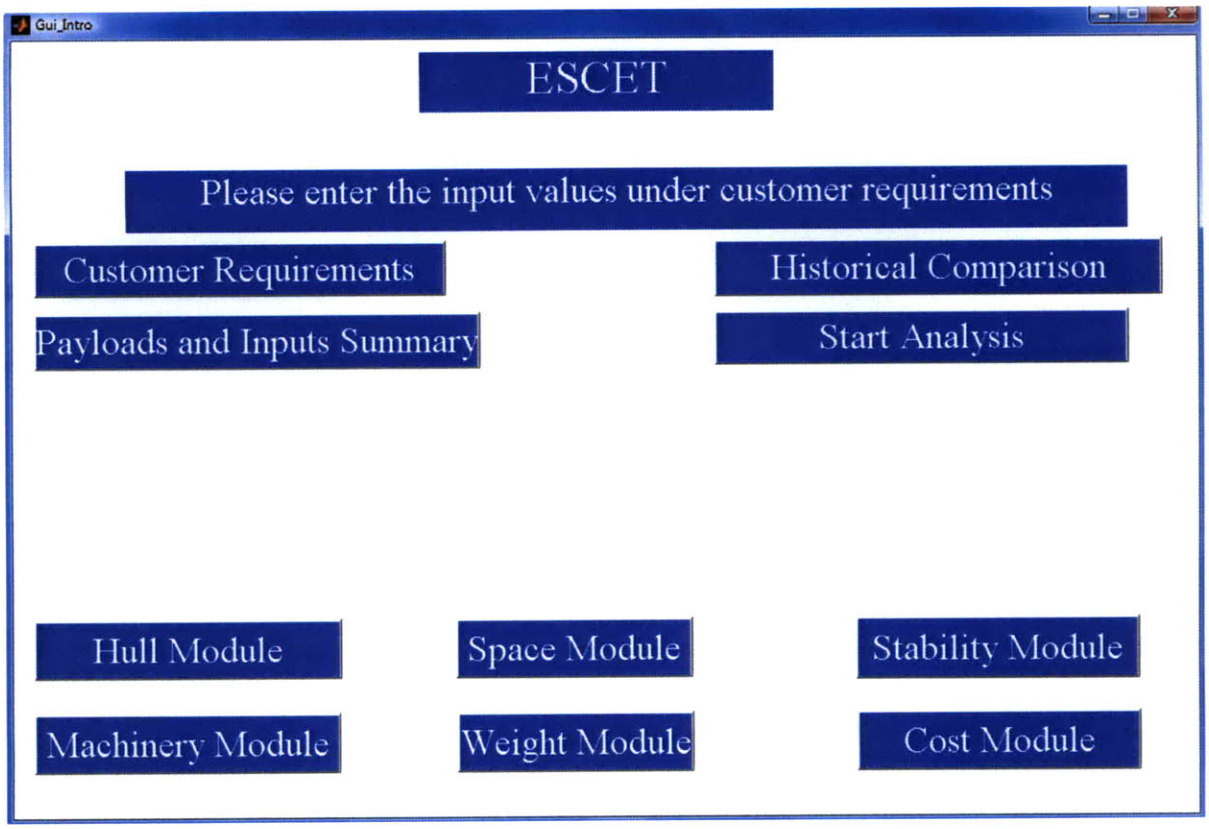


Figure 9 ESCET Home Page Screenshot

3.1 Combat Capability

Combat capability push button can be selected from the customer requirements page. In ESCET, every page has a *Home* and *Back* push button so that user can navigate between the pages easily. This combat capability page presents missions of the ship such as ASW, ASuW, AAW, ISR, and F/C. Since corvette missions are typically focused on littoral operations and due to the limited payload data available for the historical ships, only the ASW, ASuW, AAW, ISR, and F/C capabilities are included in ESCET. Figure 10 shows the combat capabilities of the ship. The other capabilities are shown for future development of the model.

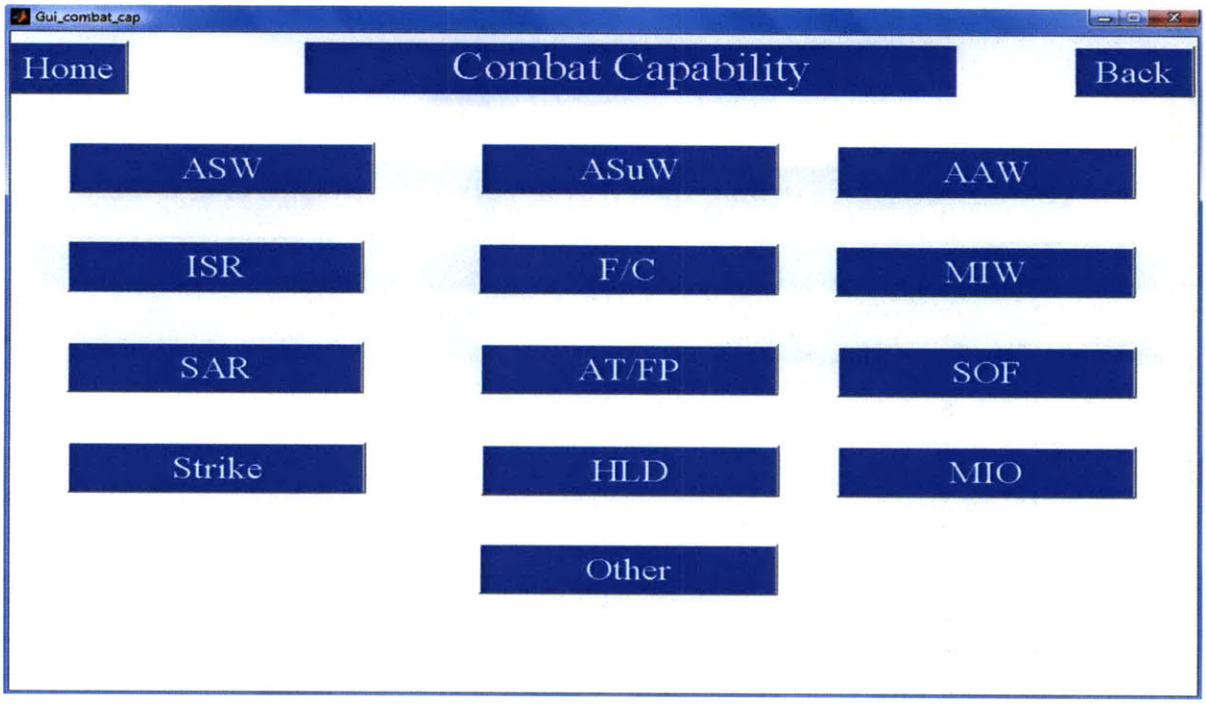


Figure 10 Combat Capability Input Page in ESCET

Figure 11 presents the input page of ASW. This page allows the user to input the payloads for ASW missions. The user has four different options on this page. There are drop-down menus for torpedoes and sonars, and radio buttons for the helicopter platform and the helicopter hangar. The characteristics of torpedoes are entered by using the historical database. The torpedo specifications are not defaulted to any specific torpedo. These specifications are gathered using Jane's Naval Weapon Systems [15]. There are six different types of torpedoes under this drop-down menu. The torpedo specifications, which are based on the historical database presented in appendices, are built in the program. The user selects the desired type of the torpedo and enters the quantity required. The user has the option to use the torpedoes defined under this drop-down menu or can enter the required values and specifications for a defined torpedo with the "OTHER" tab.

Figure 12 shows the torpedo user defined page. All units in this page are SI system. In this user defined page, the user is asked to enter certain values for the analysis. These values are:

- Quantity
- SWBS Group
- Type
- Weight
- Footprint
- Volume
- Vcg
- and Power Required

These values are built into the program for each type of weapon. Seven parts of these values are used by ESCET. However, last one is not used directly in the program and is included or future development of the program. This "OTHER" option is all same for all payloads and is not included in the explanation for the remaining combat capabilities. The "OTHER" option tab is added to the program to help the user accommodate changes in current as well as including future payloads. This process is the same for sonars as well. There are sixteen sonars in the historical database. However, sonar values are defaulted to the Simrad 950's specifications due to the lack of data availability.

Helicopter hangar and helicopter platform inputs are entered into ESCET on this page as well. On this page, the radio buttons are included for these helicopter missions. The user can select these radio buttons to give inputs for helicopter missions. These radio buttons set the variables in ESCET to one or zero. These inputs are required for calculations in the space module.

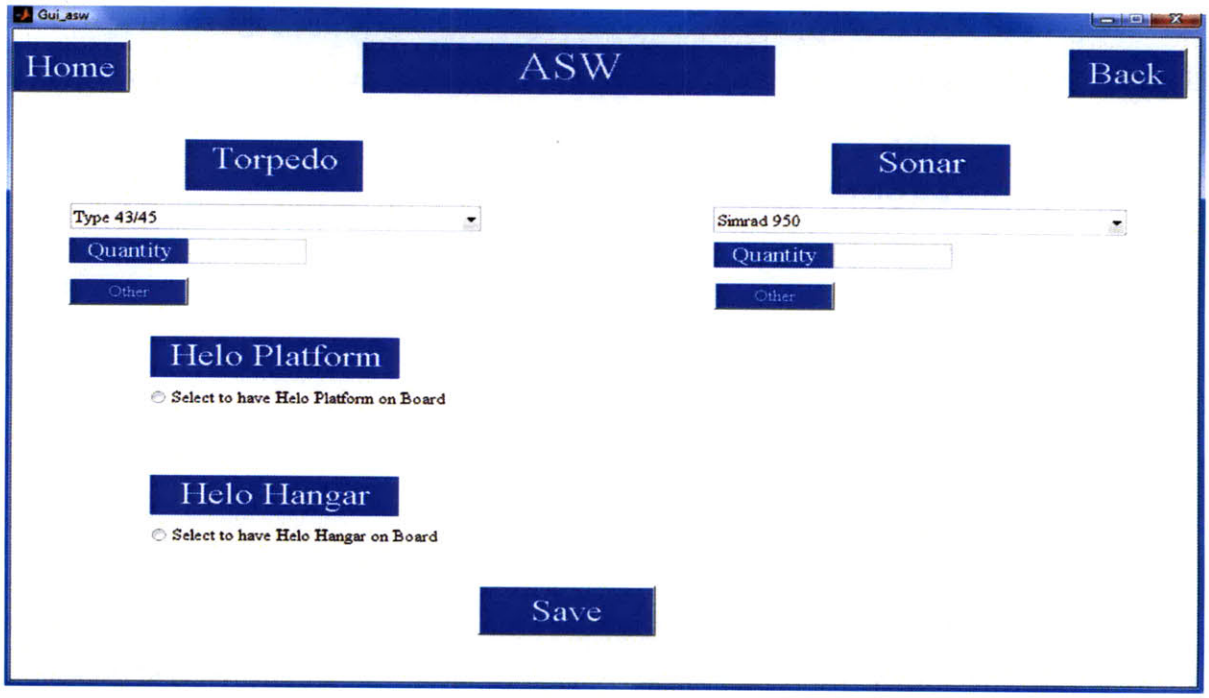


Figure 11 ASW Input Page in ESCET

Figure 12 "OTHER" Option Input Tab (Torpedo User Defined) in ESCET

Figure 13 shows the input page of ASuW. This page allows the user to input the payloads for ASuW missions. The user has two different types of payload on this page. There are two drop-down menus that are guns and surface to surface missiles (SSM). The characteristics of the guns are gathered by using the historical database in the same manner as discussed previously for torpedoes, and all the other payloads that are explained in this chapter. There are twelve different types of guns under this drop-down menu. The gun specifications are built in the program as well. The gun specifications are not defaulted to any other gun. These specifications are gathered using Jane's Naval Weapon Systems [15].

There are eight surface to surface missiles in the historical database and these SSMs could be selected under the second drop-down menu. The SSM specifications are not defaulted to any other SSM. These specifications are gathered using Jane's Naval Weapon Systems [15]. The number of launchers could be entered or selected using the radio buttons. Once the ASuW payloads are entered or selected, the *Payloads and Input Summary Page* pops up and shows the payloads that are entered so far. The "OTHER" option is also available for the user on this page as well.

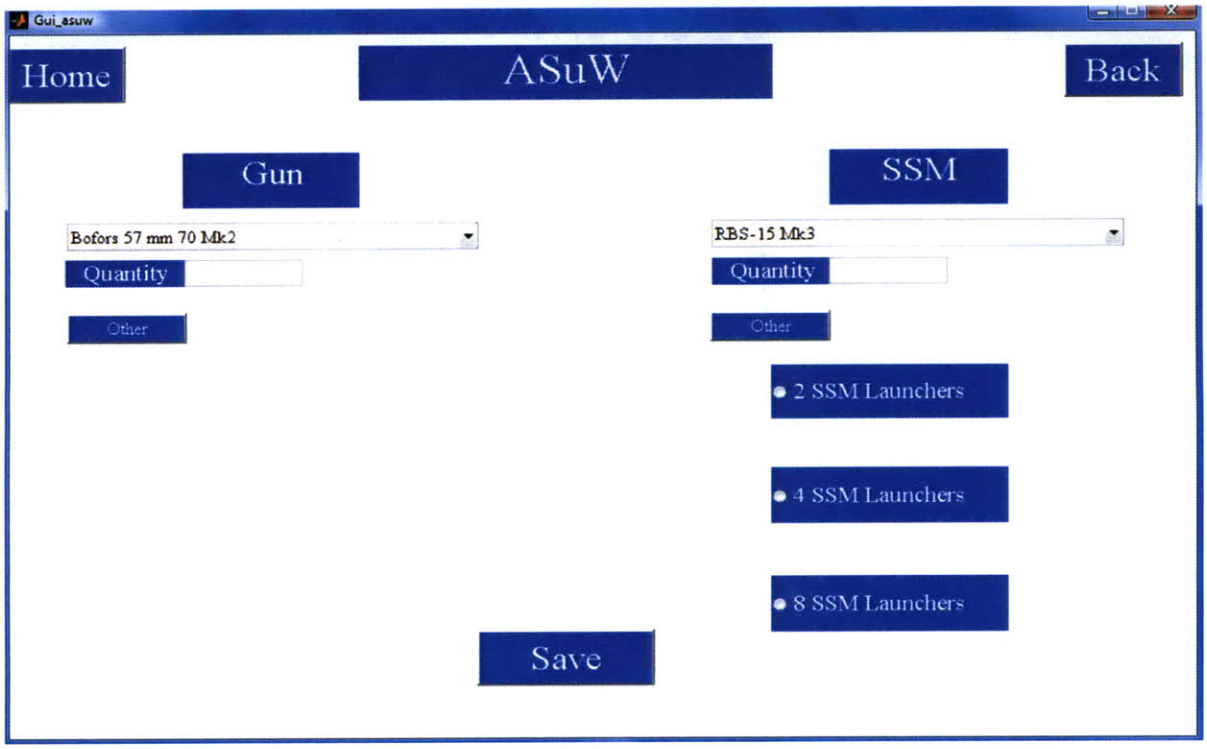


Figure 13 ASuW Input Page in ESCET

Figure 14 shows the input page of AAW. This page allows the user to input the payloads for AAW missions. The user has two options on this page. There are two drop-down menus, which are guns and surface to air missiles (SAM). The gun specifications are gathered by using the historical database in the same manner as discussed previously for other payloads. There are five different types of guns under the drop-down menu. The gun specifications are built in the program. The gun specifications are not defaulted to any other gun. These specifications are gathered using Jane's Naval Weapon Systems [15].

There are five SAMs in the historical database and these SAMs could be selected using the second drop-down menu on this page. The SAM specifications are not defaulted to any other SAM. These specifications are gathered using Jane's Naval Weapon Systems [15]. Once the AAW payloads are entered or selected, the *Payloads and Input Summary Page* pops up and shows the inputs that are entered so far. The "OTHER" option is also available for the user on this page as well.

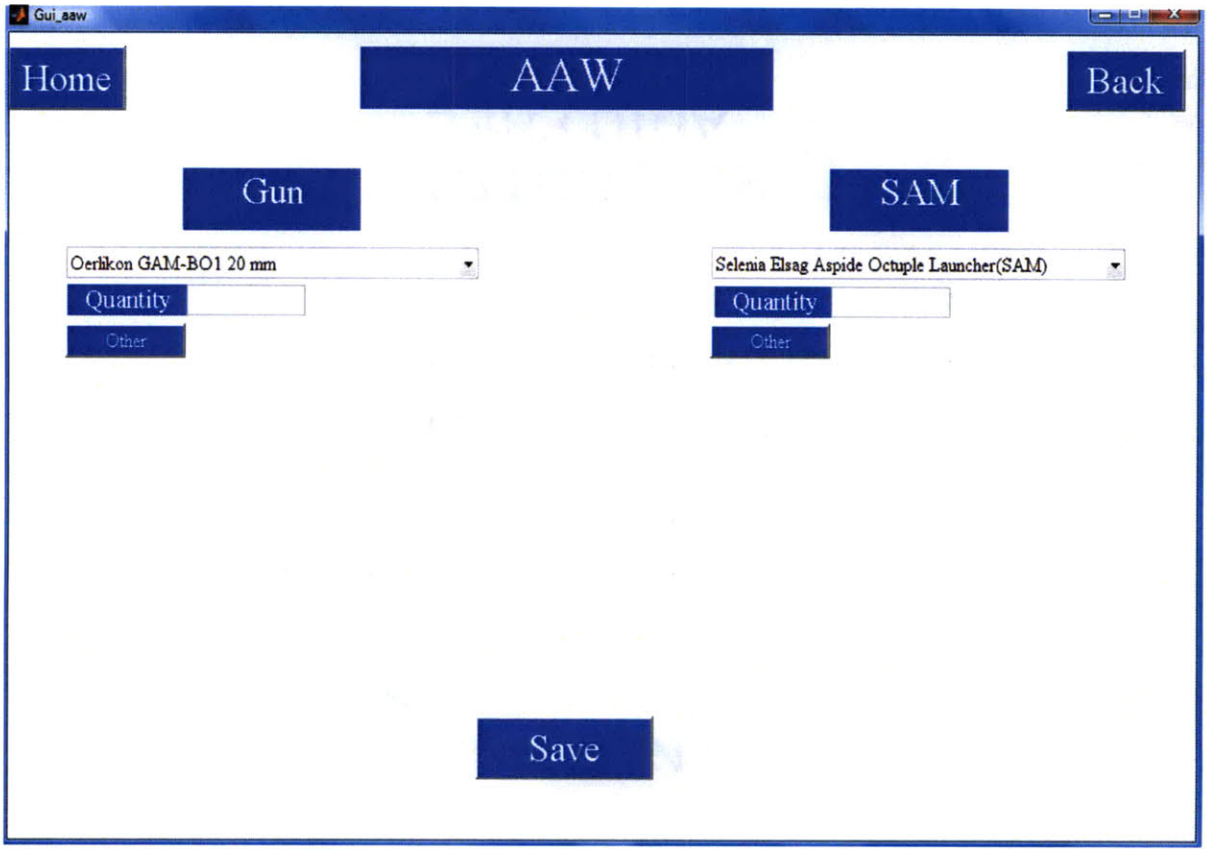


Figure 14 AAW Input Page in ESCET

Figure 15 shows the input page of ISR. This page allows the user to input the payloads for ISR missions. The user has four different options on this page. There are four drop-down menus, which are navigation radar, air radar, surface radar and multi-function radar. Air radar, surface radar and multi-function radar data is gathered by using the historical database. However, the navigation radar specifications are gathered by using the ASSET [16] payloads and adjustments library. Gillespy explains the assessment of the ASSET and the other tools as follows,

"ASSET is a synthesis tool developed and maintained by the U.S. Naval Sea Systems Command, Carderock Division. It allows for the designer to input design variables such as hull form, ship subdivisions, and weapon system weights, and attempts to synthesize the design into a single ship. ASSET has the ability to take inputs from other programs such as a spreadsheet, manipulate the information, and return synthesized data. ASSET's capabilities match very closely with the objectives of this thesis. It incorporates all major hull systems and design variables into a program that requires no manipulation of data by the user and displays results in a timely manner" [6].

There are five different types of navigation radars, six different types of surface radars, two different types of air radars and three different types of multi-function radars under the drop-down menus. Navigation radars' characteristics and specifications are gathered from ASSET payloads and adjustments library. Due to the lack of data availability, air radars are defaulted to the DA-08 radar, surface radars are defaulted to the SPS-64 and multi function radars are defaulted to the Signaal Giraffe 150 HC. The user may simply change the radio buttons to put any radar into the program, which appears on the *Payloads and Inputs Summary* page later.

ECM and EDM payloads are left user defined. The user has to select the push buttons and define the ECM and EDM payloads; if there is no data entered, ESCET assumes that there is no ECM or EDM payload onboard.

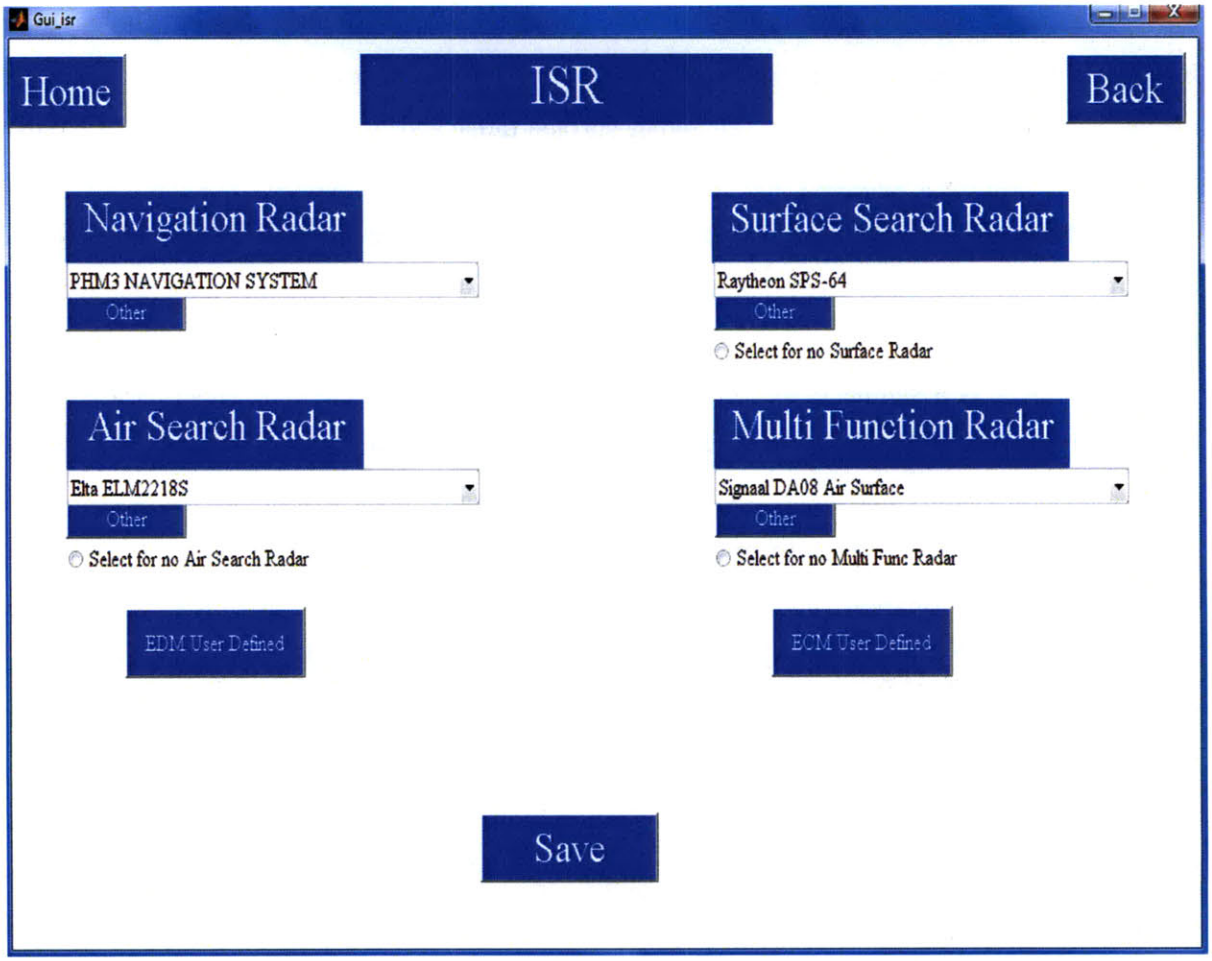


Figure 15 ISR Input Page in ESCET

Figure 16 shows the input page of Fire and Control (F/C). This page allows the user to input the payloads for the F/C systems. On this page user has 5 different push buttons for each mission. The F/C specifications have to be entered by the user as it is in the "OTHER" option for other payloads. These F/C specifications have to be related to the payloads that are already given as an input to the program. The user could check which systems need F/C system by simply going back to home page and selecting the *Payloads and Inputs Summary* push button.

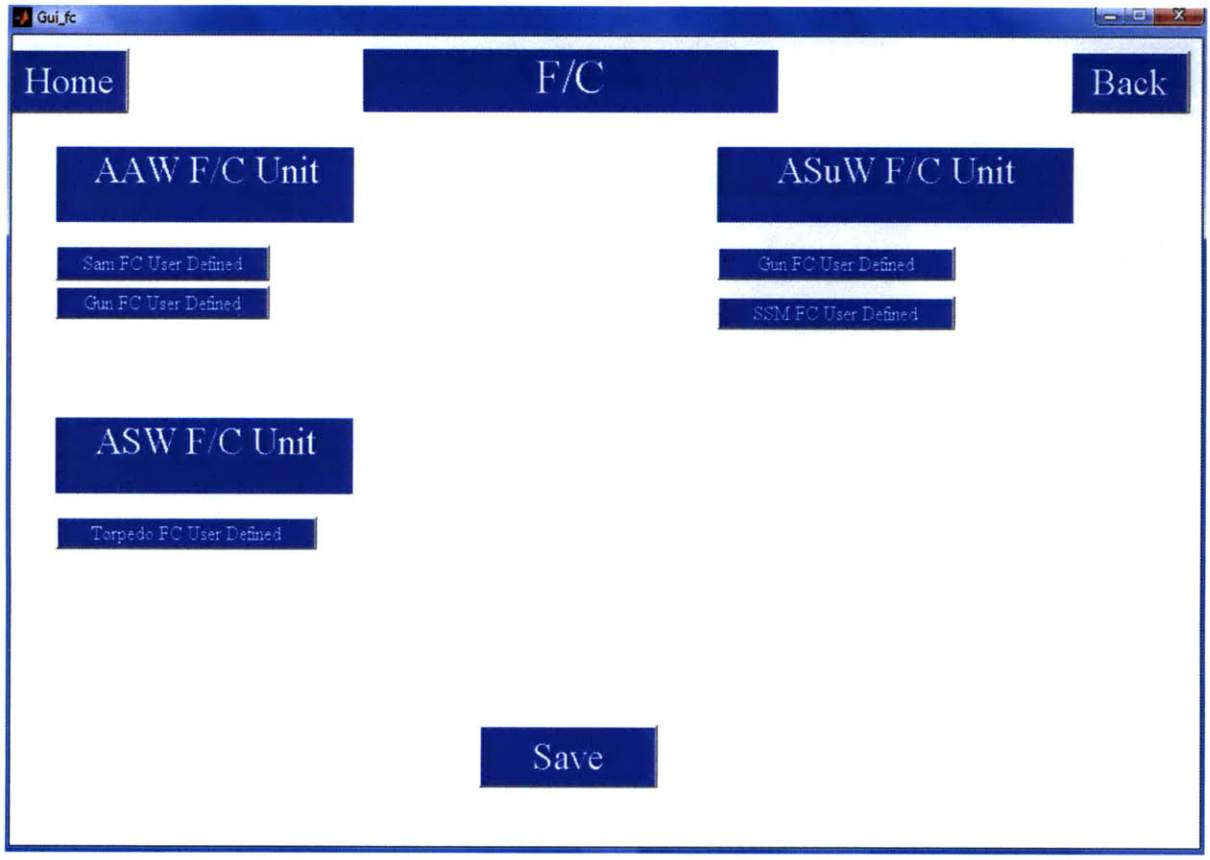


Figure 16 F/C Input Page in ESCET

3.2 Endurance

Figure 17 shows the input page of endurance. This page allows the user to enter the desired values for endurance requirements. This page requires user to enter:

- Endurance Speed [KTS]
- Maximum Speed [KTS]
- Stores Period [Days]
- Range [NM].

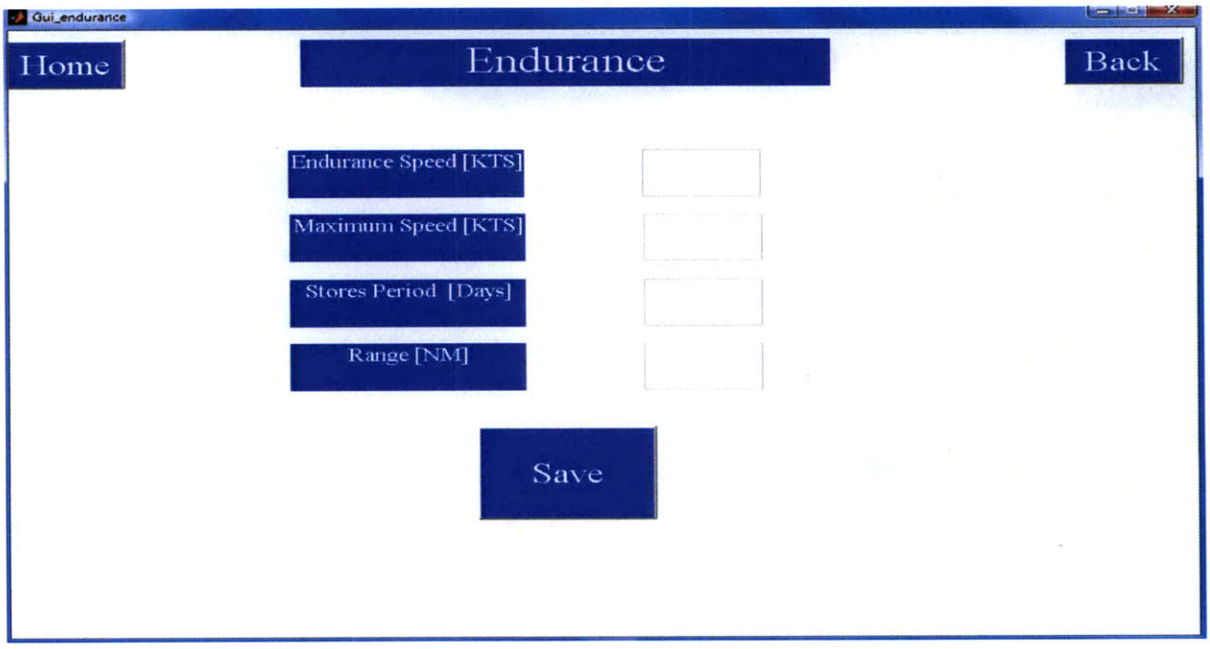


Figure 17 Endurance Input Page in ESCET

3.3 Project Details

Figure 18 shows the input page of project details. This input page allows the user to change the project name for each run.

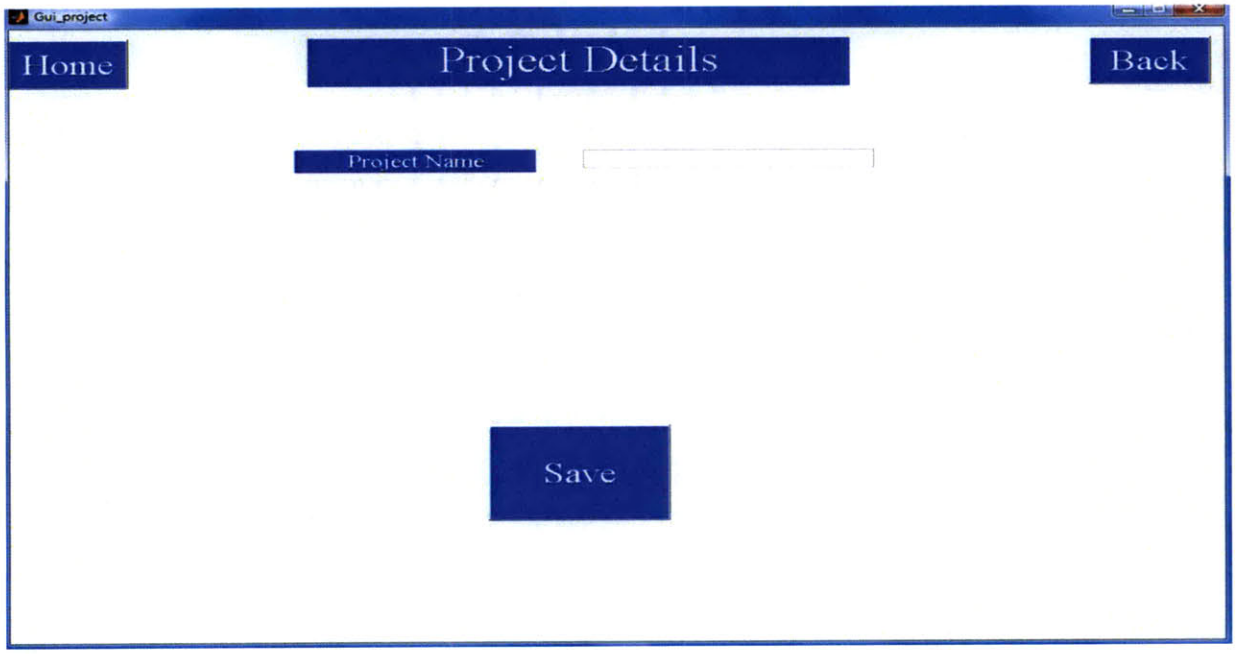


Figure 18 Project Name Input Page in ESCET

3.4 Acquisition Cost

In this thesis the acquisition cost is calculated by using the 2N Cost Model [12]. Since a description of the inputs and the basis for determining the acquisition cost are provided by Smith [17], this thesis does not present the calculations of the model. However, some inputs are explained in this section. Figure 19 presents the input page of acquisition cost.

The required inputs from the user are:

- For lead ship cost, the percentage of change orders; is the probability of the change of the orders for the leading ship
- For follow ship cost, the percentage of change orders; is the probability of the change of the orders for the following ship
- Profit; is the percentage of revenue that shipyard makes from each ship
- Lead ship T unit; is the amount of lead ships designated by the user (this number needs to be 1)
- Follow ship T unit; is the amount of follow ships designated by the user (this number could be changed depending on the number of following ships)
- Learning curve; is the slope of the learning curve for the shipyard between subsequent projects.

The default values for cost module inputs are;

- Change orders (lead ship) =10
- Change orders (follow ship) =5
- Profit=15
- Lead ship T unit=1
- Follow ship T unit=2
- Learning curve=92.

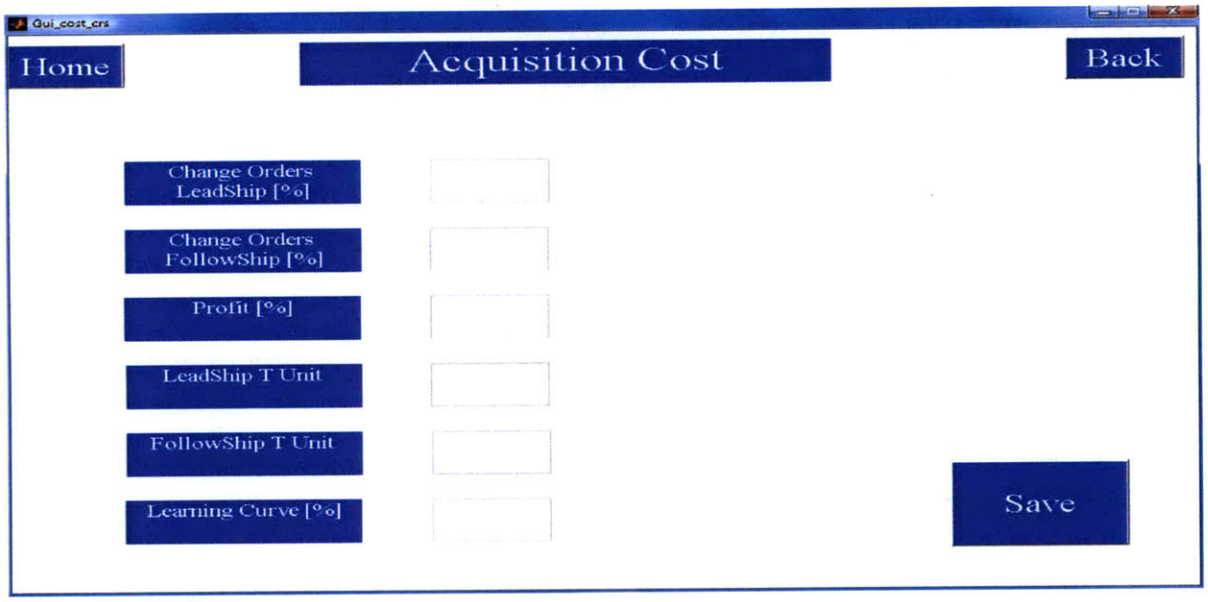


Figure 19 Acquisition Cost Input Page in ESCET

3.5 Survivability

Figure 20 shows the input page of survivability. In ESCET, this section is not used in calculations and this page is included for future development of the model.

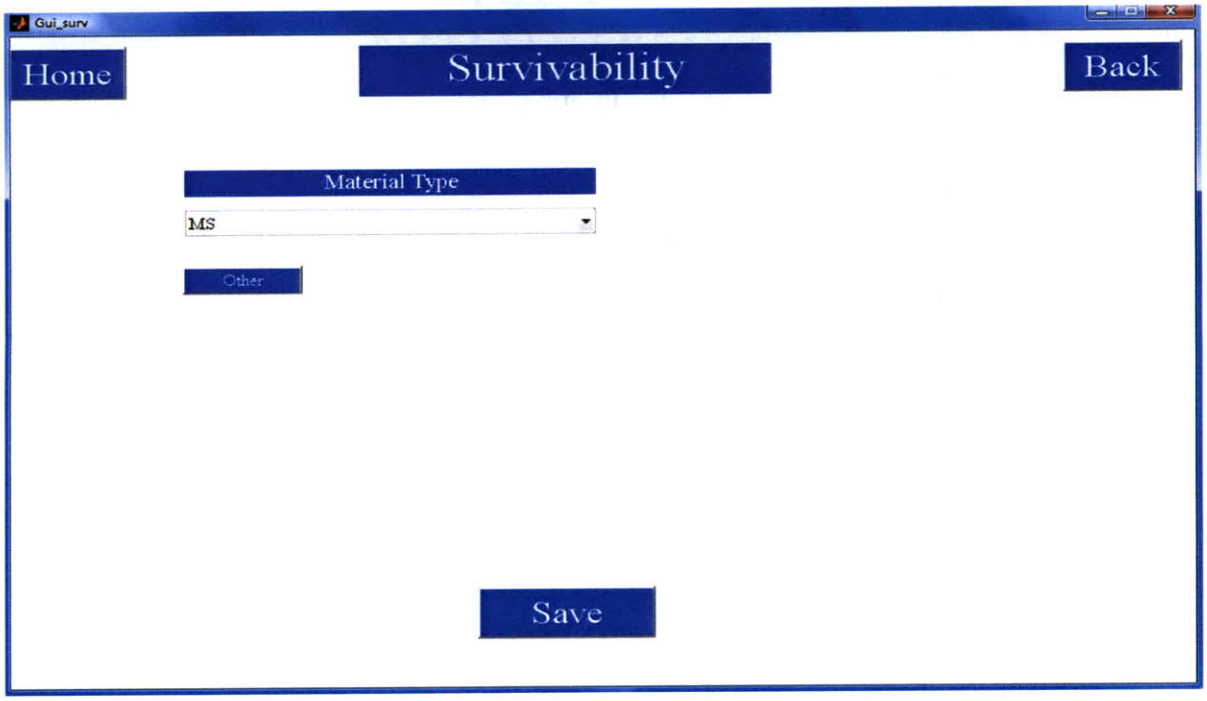


Figure 20 Survivability Input Page in ESCET

3.6 Affordability, Operability, Reliability, Mobility, Interoperability and Maintainability

In Figure 8 these -abilities are shown. However, in this thesis these push buttons are not activated. These push buttons are included for future development of the model. In future developments of this model, these -abilities will be arranged by slider bars and customer could also enter in the importance of the each -ability by defining either measure of performances (MOP) or measure of effectiveness (MOE).

CHAPTER 4

4 Development of the Early-Stage Design Tool

ESCET is developed to allow the customer to use it without the aid of a naval architect or a ship designer. In Figure 9, the home page of ESCET is shown. The home page is divided into ten different tabs. Customer requirements tab is explained in chapter 3.

The payloads and inputs tab provides the user a summary of the customer requirements input. Figure 21 shows the *Payloads and Inputs Summary* page from ESCET. Historical comparison tab is explained in this chapter as well. *Start Analysis* tab is built in to run the written script in an order. This *Start Analysis* tab could be selected after entering the entire customer requirements explained in chapter 3. ESCET warns the customer, if there is any mistake or wrong calculation. The warning message, which is written as *"Based on the available data current run is out of the Historical Database or Military Payload is to big!, LWL range has to be between 50 and 90 meters!, You can still click on the modules to see the results, however they are not in the data range!"*, pops up if the entered data is out of the range of the historical database. If entered data is in the range of the historical database, ESCET outputs another message that warns the user as *"Analysis Completed; Click on the modules to see the Results"*. After getting this message user could review the summaries of the each module by selecting the rest of the tabs on the home page of ESCET.

The overall flow of ESCET is shown in Table 9. Firstly, the hull module is run by ESCET and it populates the specific values of the desired ship. After the hull module, the machinery module is run. The machinery module populates the required outputs. This module is followed by the space module and the weight module. In the weight module, ESCET compares the current full load displacement of the ship, which is calculated by the hull module, to the full load displacement of the ship that is calculated by the weight module. If these two values are different, the weight module sets the current full load displacement of the ship to the value that is calculated by the weight module and ESCET runs the following modules again: hull module, machinery module, space module and weight module. The hull module assumes that the right value for the full load displacement of the ship is calculated by weight module and recalculates the hull parameters depending on the LWL and the full load displacement of the ship. Since the weight module has changed the full load displacement of the ship, ESCET runs the stability and

the cost module afterwards. The results of these modules could be reached by selecting the tabs, which are called by each of their names. User could select any of these modules to see the results for the desired ship after running the script by selecting *Start Analysis* push button.

ESCET is developed to access this home page easily. Each page is set to have *Home* and *Back* push button, which lets the user to navigate easily through the program. Some of the inputs are restricted by the program and warning message boxes pop up as soon as the customer enters a value that is not covered by the historical database. The following pages explain how each module is developed and the underlying analysis performed.

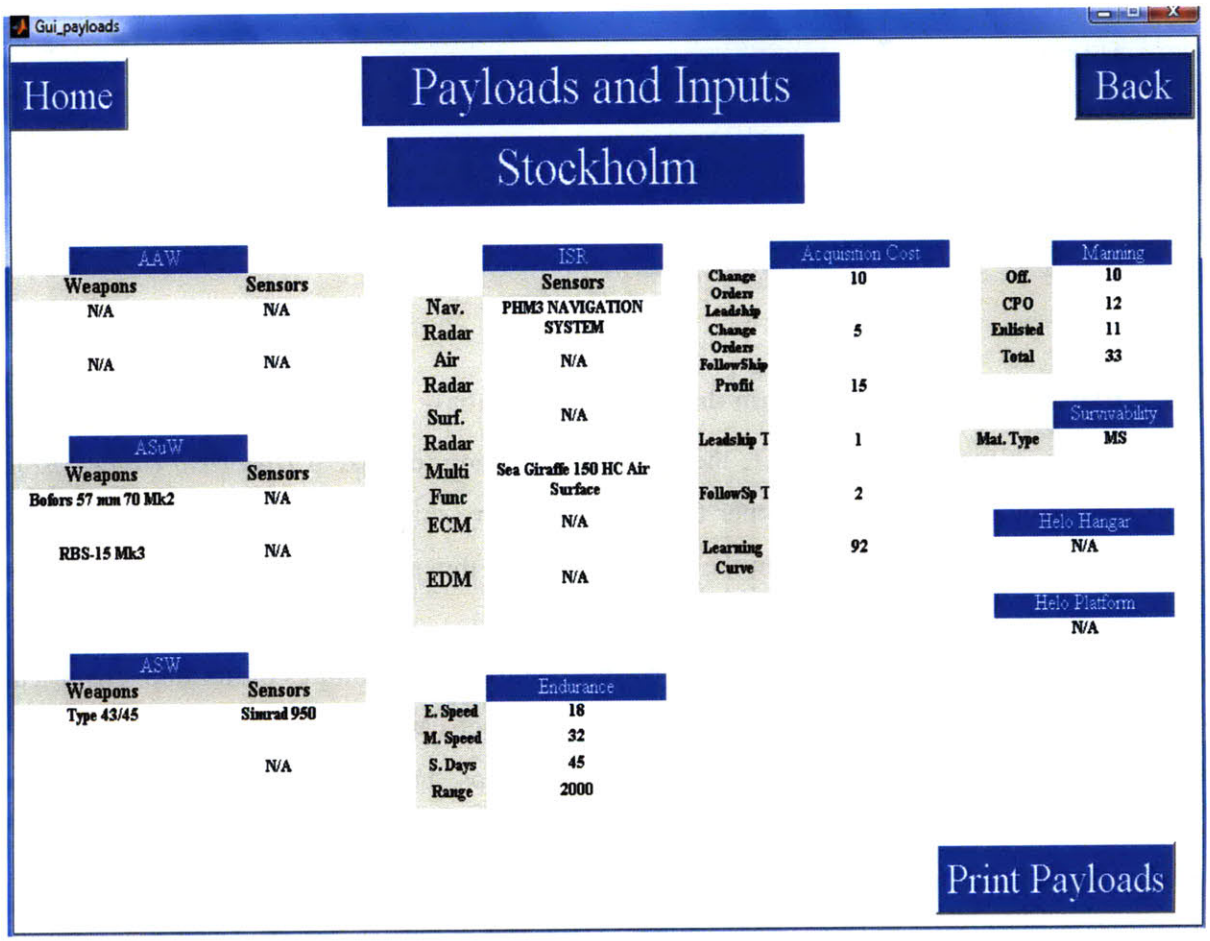
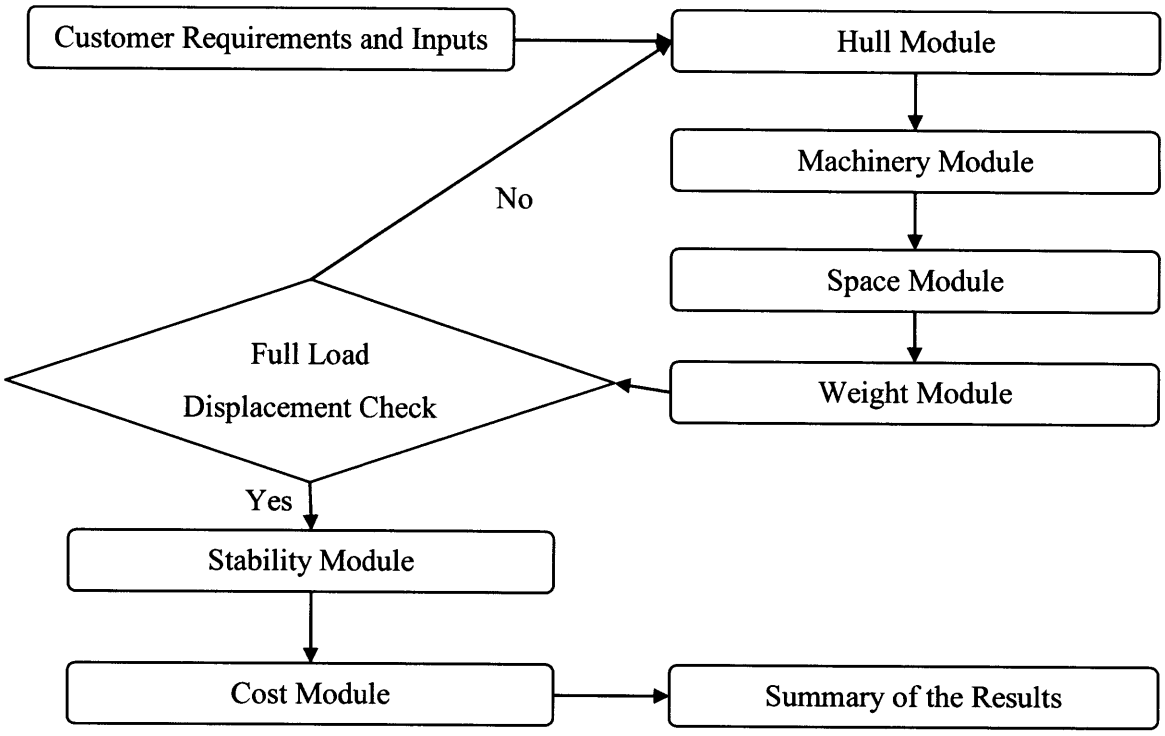


Figure 21 Payloads and Inputs Tab built in ESCET Home Screen

Table 9 ESCET Flow Chart



4.1 Historical Comparison within the Historical Database

On the home page of ESCET, there is another option to make a *Historical Comparison*. This push button allows the customer to determine if any ship has been built before with the same customer requirements. When the customer selects this pushbutton, mapping results page will pop up.

Historical Comparison is carried out by just comparing the abilities of the ship. *Historical Comparison* also compares the missions that they are not capable of and counts them. After comparing these abilities of the desired ship to the ships that are in the historical database, ESCET outputs two different results for *Historical Comparison; Exact Match* and *Close Match.* A ship has to pass the statement of being able to carry out six missions (out of ten) to be the *Exact Match* for the desired customer requirements. If a ship can pass the statement of being able to carry out more than three missions (out of ten) and less than six missions (out of ten), then it appears as a *Close Match.*

Figure 22 shows the mapping results page for the historical comparison with 'N/A' results.

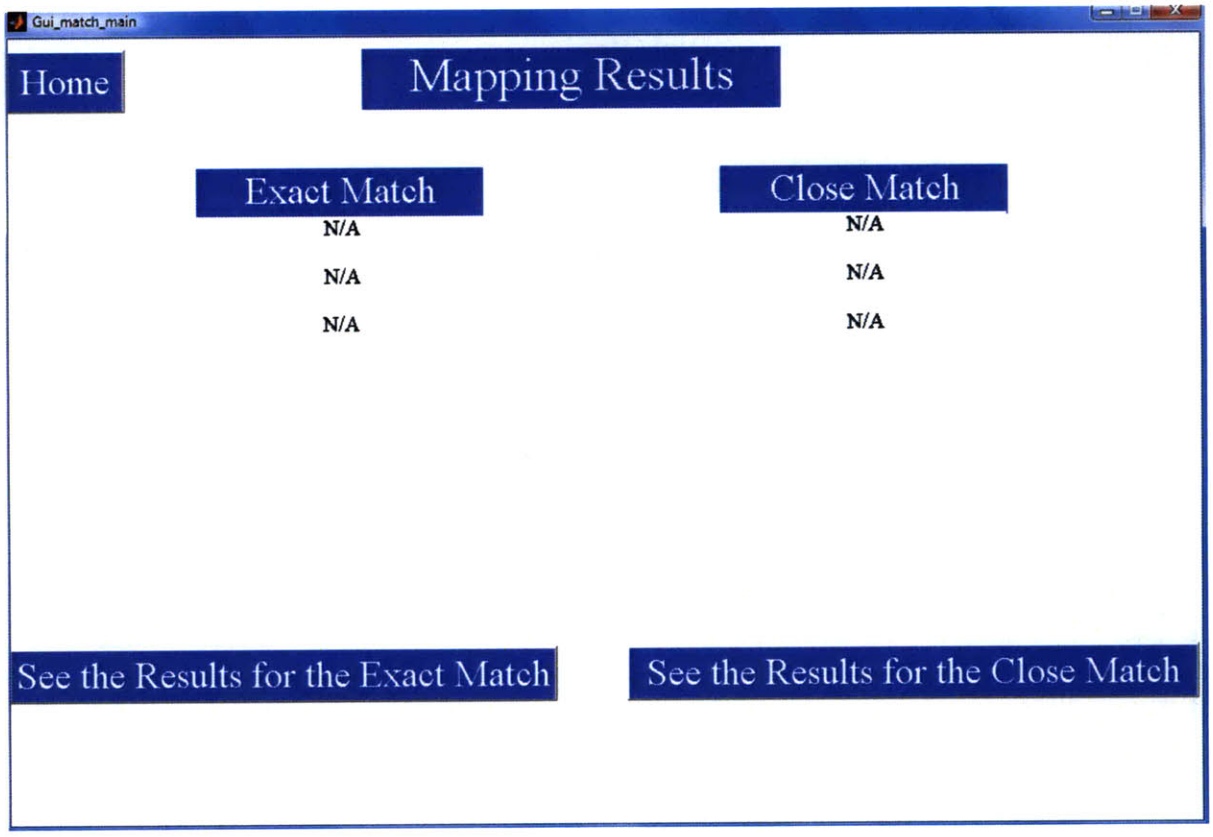


Figure 22 Mapping Results for the Historical Comparison, Picturing 'N/A' Screen

Figure 23 presents an *Exact Match* and *Close Match* results page for specific customer requirements. On this page, customer could select the *See the Results for the Exact Match* or *See the Results for the Close Match* push buttons to see the characteristics of the ships. Figure 24 shows the specifications of some *Close Matches*. The specifications of the entire historical database are presented in appendices. These specifications are built in the program and ESCET pulls out the data out of the historical database to make the *Historical Comparison* and present these *Exact Match* and *Close Match* results.

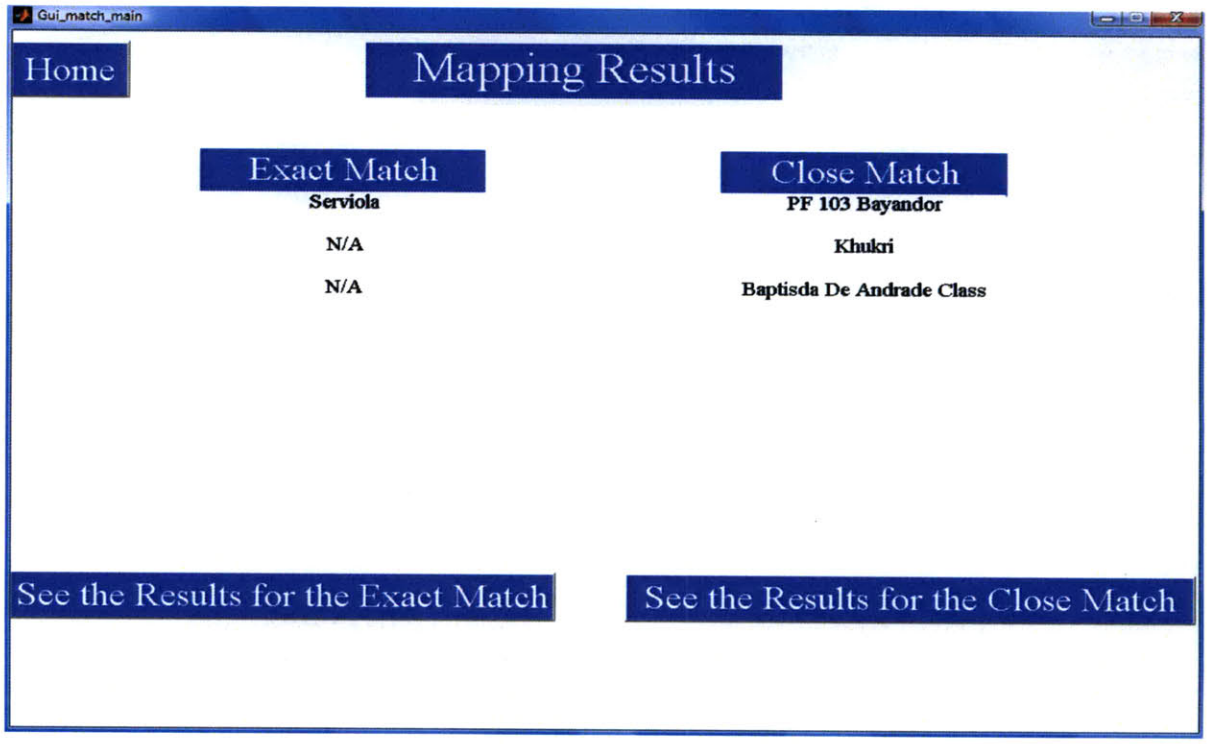


Figure 23 Mapping Results for the Historical Comparison, Picturing Exact Match

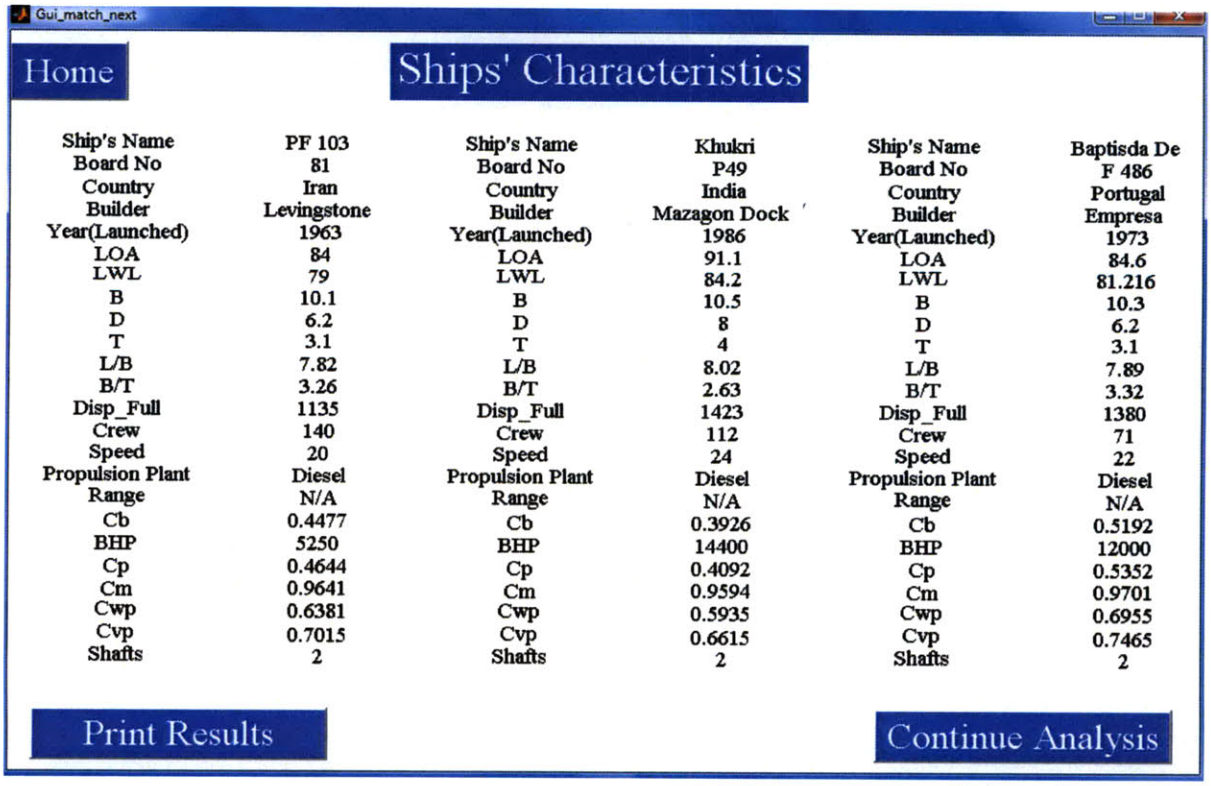


Figure 24 Matching Ship Characteristics Screen Shot

4.2 Hull Geometry Module

Hull module is the main module that calculates the hull characteristics of the ship. The hull module starts with summing up all of the required Command & Surveillance and Armament (W_{400}+W_{700}) weight groups and assigns a variable called *wpayload* in the hull module. The overall flow chart of the hull module is presented in Table 10. The payload weight is the first input of the program and is used to make the first estimation for the hull parameters. The hull module uses another variable, which is called *ploadfrac*, in order to calculate the full load displacement of the desired ship. Analysis of the historical database results in an assumed *ploadfrac*=0.06. Previous studies for larger surface combatants (Frigates, DDG-51 and WMEC 270 Coast Guard Cutter) used a value of 0.09 for the *ploadfrac.* Equation (8) is used to make the first estimation for Δ_{full} in the hull module.

$$wpayload = W_{400} + W_{700} \tag{7}$$

$$\Delta_{full} = \frac{wpayload}{ploadfrac} \tag{8}$$

After the Δ_{full} is determined, the hull module assumes values for C_p, C_m, C_{vol} and B/T ratio in order to initialize calculations. C_P is calculated using the parametric equation (9) developed from the analysis of the historical database shown graphically in Figure 25. The equation for C_P is:

$$C_p = 5 * E^{-0.5} * \Delta_{full} + 0.4035 \tag{9}$$

C_m is calculated using the parametric equation (10) developed from the analysis of the historical database shown graphically in Figure 27. The equation for C_m is:

$$C_m = 5 * E^{-0.6} * \Delta_{full} + 0.9589 \tag{10}$$

C_{vol} is calculated using the parametric equation (11) developed from the analysis of the historical database shown graphically in Figure 26. The equation for C_{vol} is:

$$C_{vol} = -0.0002 * \Delta_{full} + 2.8278 \tag{11}$$

B/T ratio equals to 3.23, which is the average of all ships in the historical database. The range for B/T value is 2.23-4.16. The ranges of these coefficients and ratios are explained in Table 5. After calculating these values presented above, the hull module calculates the LWL using (12), which is presented in Lamb [2]. The equation for LWL is:

$$LWL = \left(\left(\frac{\nabla_{full}}{C_{vol}} \right)^{\frac{1}{3}} \right) * 10 \tag{12}$$

B is calculated using (13), which is presented in Lamb [2]. The equation for B is:

$$B = \left(\frac{\frac{B}{T} * \nabla full}{(C_p * C_m * LWL)} \right)^{0.5} \tag{13}$$

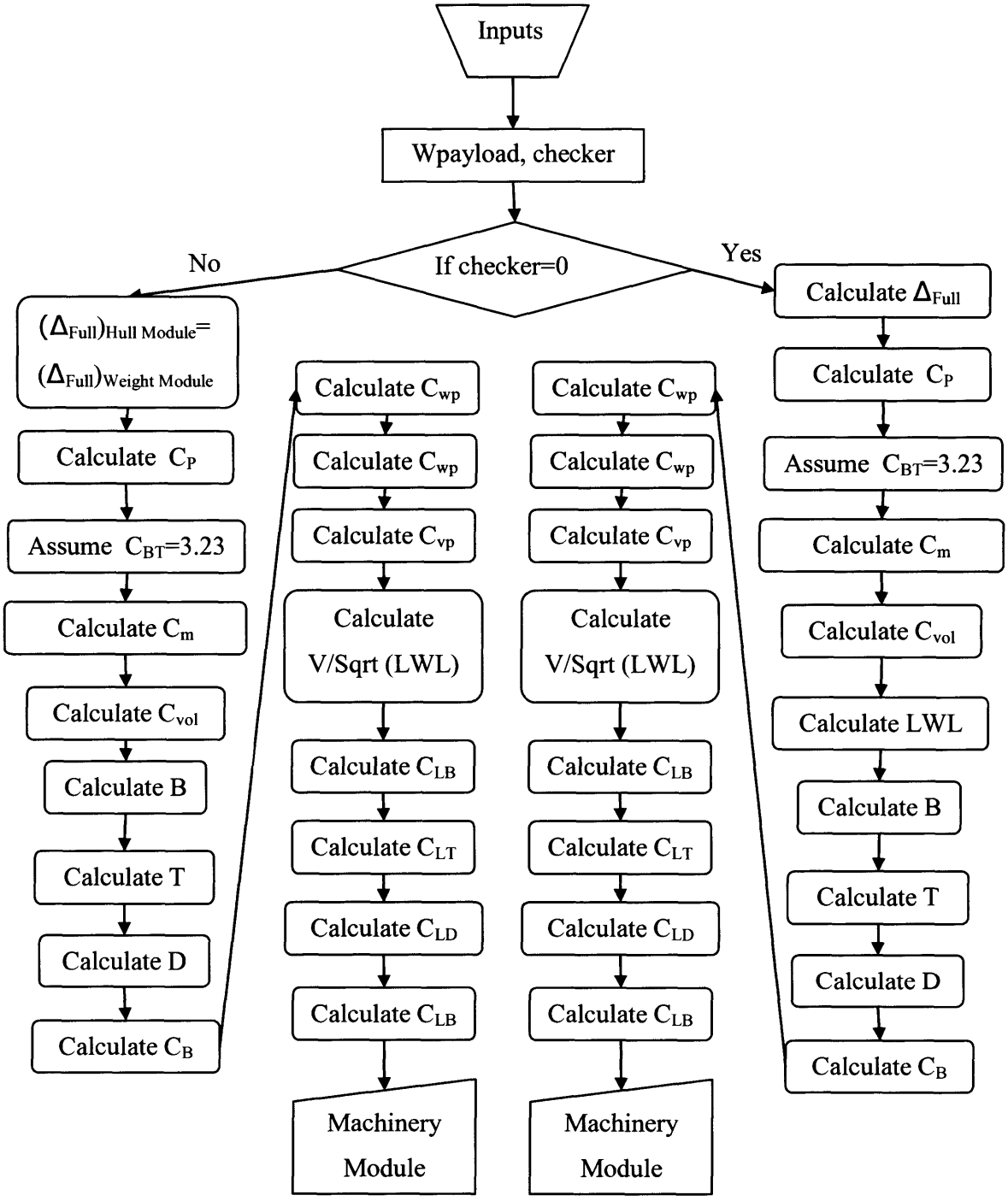
Since the data on D is not presented in Jane's fighting ships [7], D values are estimated using (14). The equation for D is:

$$D = 2 * T \tag{14}$$

C_B, C_{wp} and C_{vp} are calculated using equations (1), (5) and (6), which are described in chapter 2 and presented in Introduction to Naval Architecture [9] and Lamb [2]. Speed to length ratio is calculated using (15), which is presented in Introduction to Naval Architecture [9].

$$Speedtolength = \frac{V_{max}}{\sqrt{LWL}} \tag{15}$$

Table 10 Hull Module Flow Chart



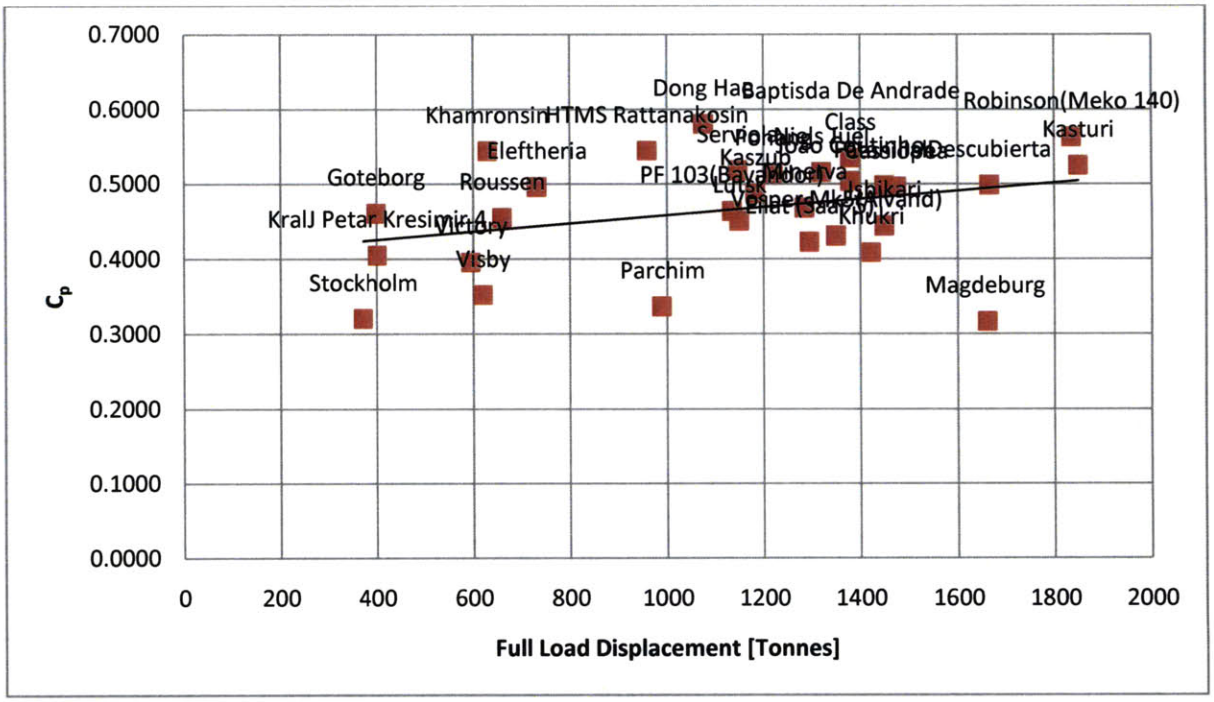


Figure 25 Full Load Displacement vs. C_p Relationship in the Historical Database

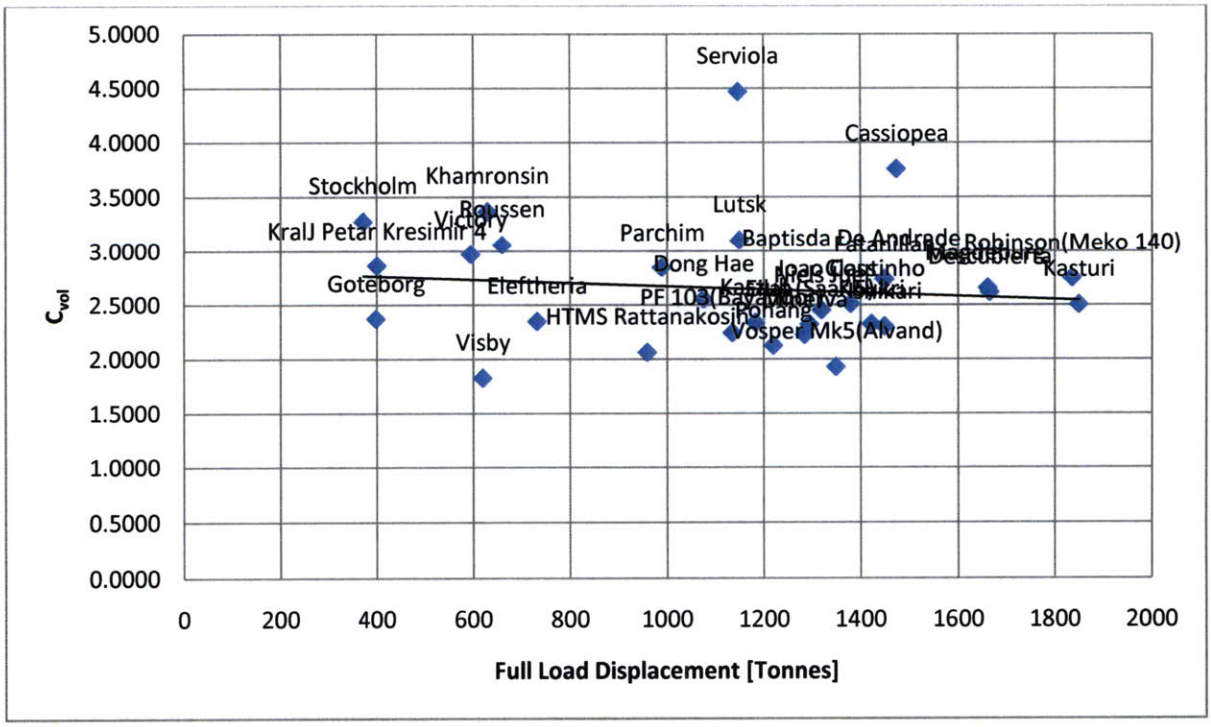


Figure 26 Full Load Displacement vs. C_{vol} Relationship in the Historical Database

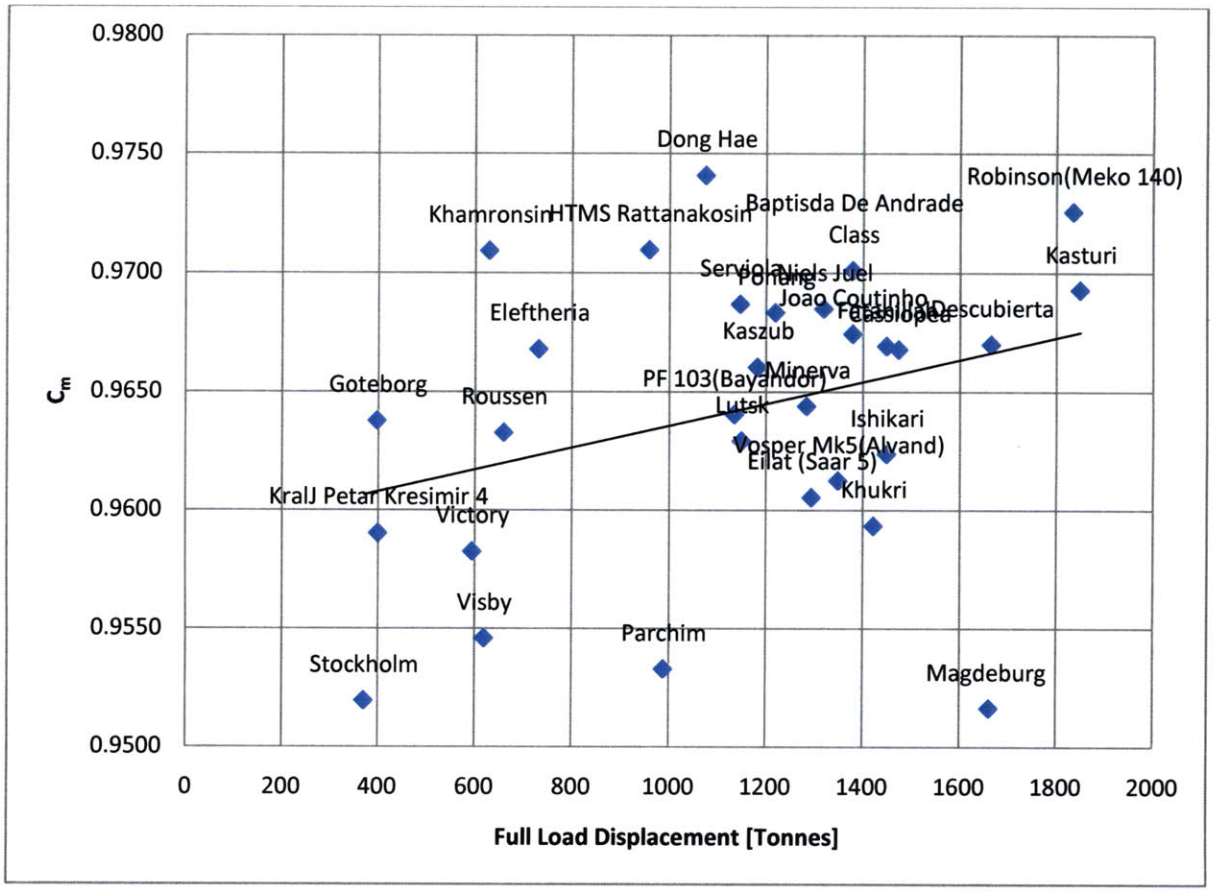


Figure 27 Full Load Displacement vs. C_m Relationship in the Historical Database

The hull module is the first module of ESCET and is the most important part of the program. The output from this module is used in the weight module as well as in the other modules. The hull module calculates these specific coefficients and the parameters for the desired ship and sets the current full load displacement of the ship. After calculating these values, ESCET runs the machinery module which calculates the specific parameters for the machinery of the desired ship. The machinery module is described in section 4.3.

4.2.1 Initial Validation of the Hull Module

The hull module was validated using FFG-7 data. Since FFG-7 is not in the range of historical database, the *ploadfrac* is set to surface combatant value, which is 0.09. Inputs for the hull module validation are *wpayload*=402.9 tons and *ploadfrac*=0.09. Table 11 shows the validation of the data.

Table 11 Initial Validation of the Hull Module by Using FFG-7 Data

	FFG-7	ESCET	Error %
LWL	125.46	131.23	4.60
B	13.86	12.08	-12.84
D	9.14	8.94	-2.19
T	5.13	4.47	-12.87
C_P	0.618	0.627	1.46
C_X	0.776	0.981	26.42
wpayload	402.9	402.9	0.00
ploadfrac	0.09	0.09	0.00
Full Load Displacement	4453	4476	0.52
L/B	9.05	10.86	20.00
B/T	2.7	2.7	0.00
L/D	13.72	14.66	6.85
L/T	24.45	29.32	19.92

As it is presented in Table 11, LWL for the ESCET model is only 5 % off from the FFG-7 actual values. However, the other specifications are not in the range this is because of the fact that ESCET does use the corvette ratios. It was expected to make the first estimation of the length correct, which gives less than 5% error. The estimation of the length is important because of the fact that the weight module uses this LWL value to calculate each weight group.

4.3 Machinery Module

Machinery module is developed in order to allow the user to gather the early-stage estimations for the machinery of the desired ship. In appendices, entire machinery specifications are presented for the selected ships in the historical database. Table 12 presents the flow chart for the machinery module, which uses the maximum speed that user enters into the program while defining the customer requirements. Maximum speed is the only input that defines the machinery specifications. The machinery module estimates the vertical center of gravity of the machinery using the equation below:

$$Machinery_{Vcg} = D * 0.5 \quad (16)$$

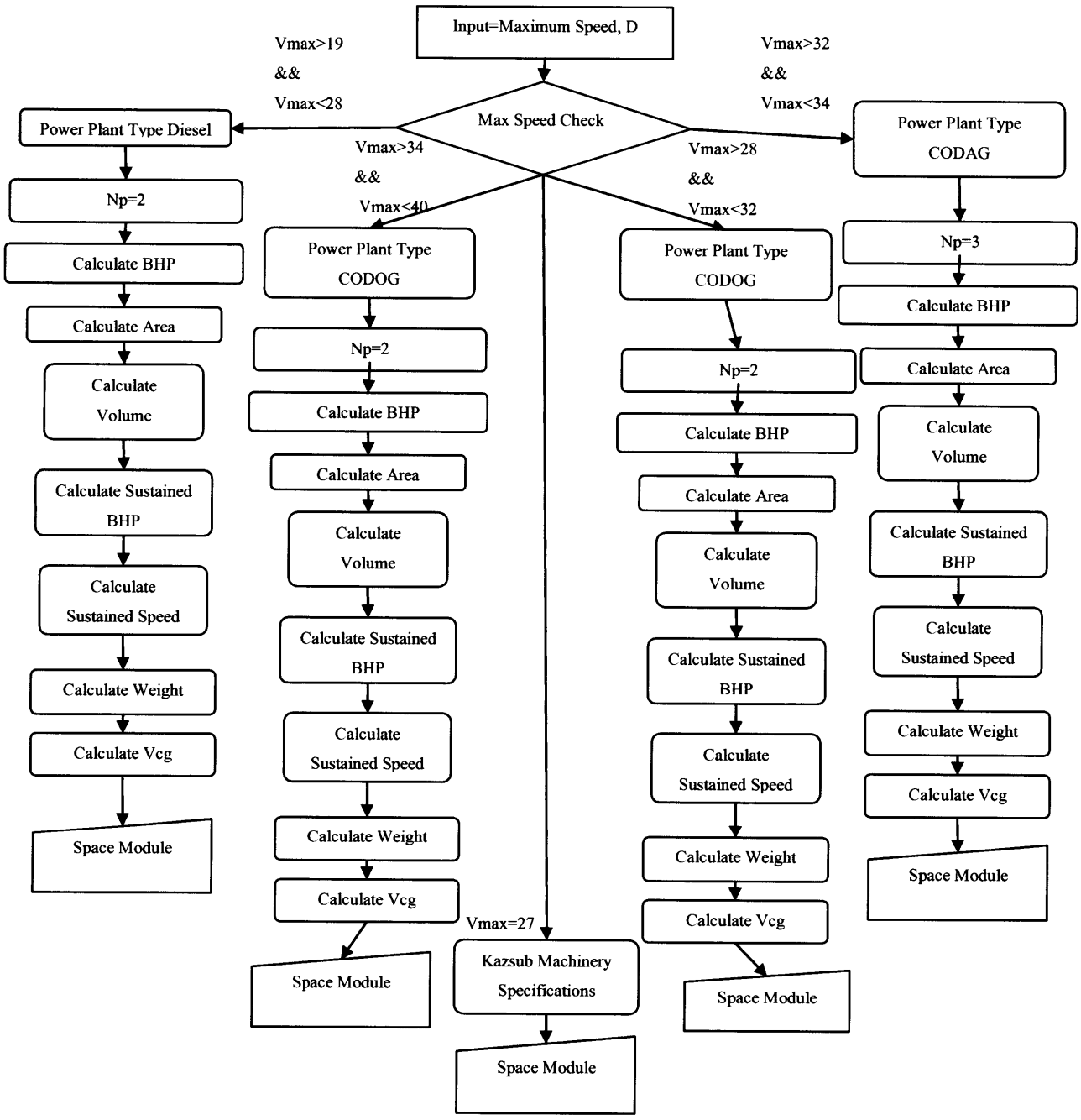
Since the data is gathered for the machinery of the selected ships in the historical database, the estimation of the specifications are carried out by using the trend lines derived from this historical database. In the following sections these trend lines are shown and the equations used are explicitly described. Figure 6 presents the relationship between the power plants and maximum speed. From Figure 6, the natural groupings of power plant types and maximum speeds are:

- If required maximum speed equals to 19-28 then power plant=Diesel
- If required maximum speed equals to 26-28 then power plant=CODAD
- If required maximum speed equals to 28-32 then power plant=CODOG
- If required maximum speed equals to 32-34 then power plant=CODAG
- If required maximum speed equals to 34-40 then power plant=CODOG

The power plant specifications are described in the following sections. CODAD power plant is not included in these sections because there is only one ship, which has CODAD power plant, however it is built into the program if the customer asks for specific maximum speed, which is 27 KTS, then ESCET will assign the values from this ship, called Kazsub.

The number of the propellers is assigned in the machinery module by using the historical database for each power plant in Figure 7.

Table 12 Machinery Module Flow Chart



4.3.1 Diesel Power Plant

The historical database reveals that most of the corvettes have a diesel power plant. The historical database shows that there are 19 ships using diesel power plant. This is the most reliable data in the machinery module. However, Kral J Petar Kresimir 4, Victory, Stockholm and Goteborg are excluded since their engines do not represent current technology, common power plant and common number of shafts for corvettes. In Figure 28, the relationship between the maximum speed and BHP is shown. Kral J Petar Kresimir 4, Victory, Stockholm and Goteborg are excluded from data in the chart. This is because of the fact that these ships' shafts do not represent common number of shafts for corvettes. After excluding these ships from the data in Figure 28, the relationship comes out to be an exponential line. In the range of 19-28 KTS, except 27 KTS, the machinery module uses (17) in order to calculate the BHP of the desired ship. V_{max} is the desired maximum speed in KTS, which is defined by the user.

$$BHP = 546.12 * exp^{0.1309 * V_{max}} \quad (17)$$

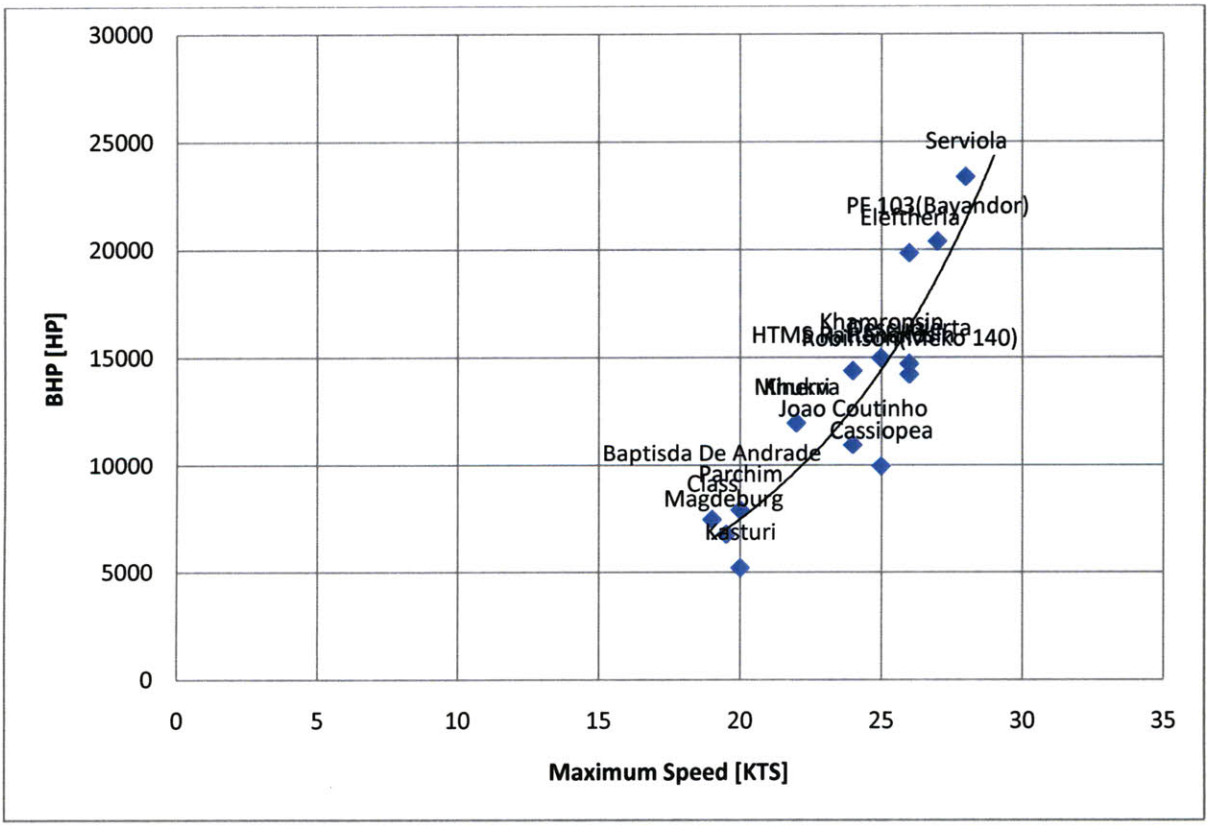


Figure 28 Diesel Power Plant; Maximum Speed vs. BHP Relationship

After calculating the BHP for the desired ship, ESCET finds the machinery area for the desired ship. Figure 29 shows the relationship between BHP and machinery area. In this chart PF103, Bapdista De Andrede Class, Joa Coutinho, Robinson, Kasturi and Roussen are excluded from the graph as well; since their engines do not represent current technology, common diesel power plant and common number of shafts for corvettes. After excluding these ships, the relationship between BHP and the machinery area concludes linearly. Figure 29 shows the relationship described by equation (18), where $Mach_{Area}$ is in m^2 and BHP is in HP. The machinery module uses (18) to calculate the machinery area for the desired ship.

$$Mach_{Area} = 0.0009 * BHP + 7.8772 \qquad (18)$$

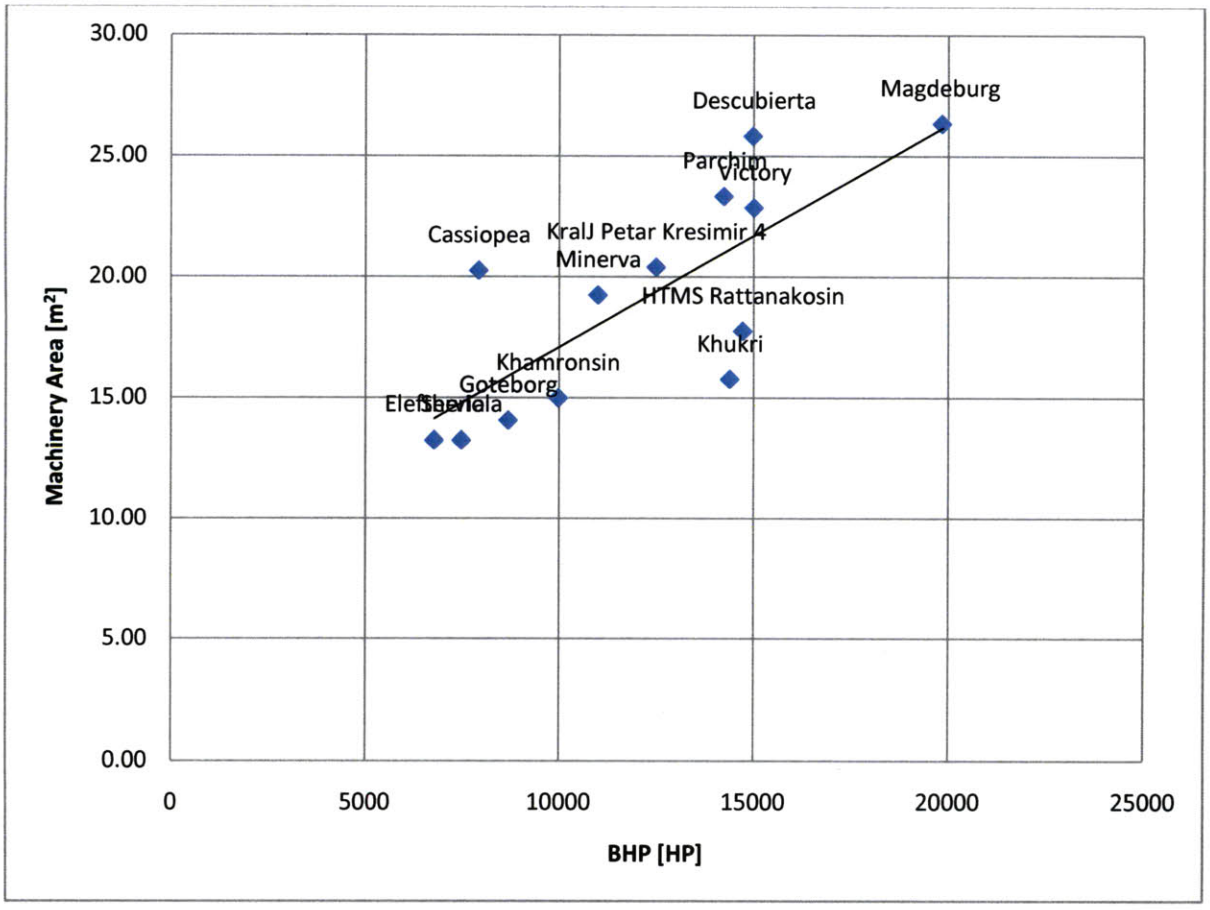


Figure 29 Diesel Power Plant; BHP vs. Machinery Area Relationship

After calculating the machinery area for the desired ship, ESCET calculates the machinery volume. Figure 30 shows the relationship between BHP and machinery volume. In this chart PF103, Bapdista De Andrede Class, Joa Coutinho, Robinson, Kasturi and Roussen are excluded from the graph, since their engines do not represent current technology, common power plant and common number of shafts for corvettes. After excluding these ships, the relationship between BHP and the machinery volume concludes linearly. Figure 30 shows the relationship described by equation (19), where $Mach_{Volume}$ is in m^3 and BHP is in HP. The machinery module uses (19) to calculate the machinery volume for the desired ship.

$$Mach_{Volume} = 0.0036 * BHP + 7.1895 \qquad (19)$$

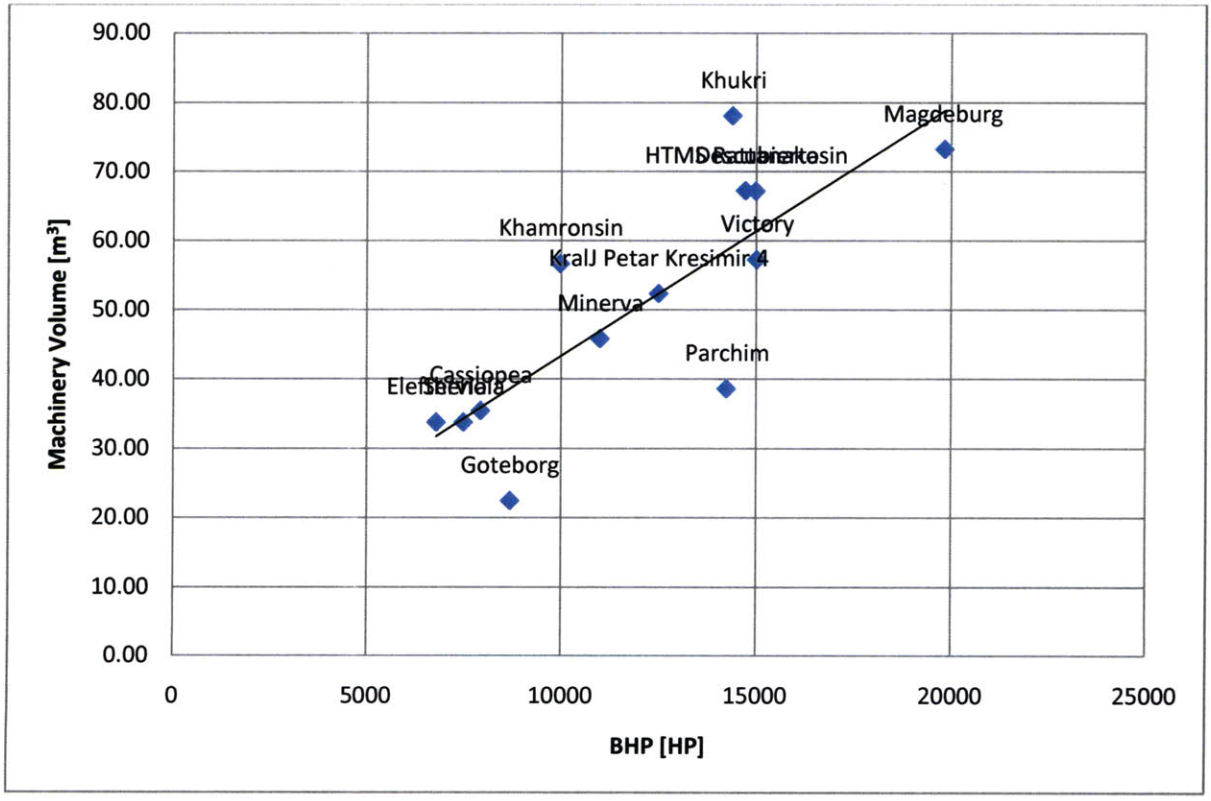


Figure 30 Diesel Power Plant; BHP vs. Machinery Volume Relationship

After calculating the machinery volume for the desired ship, ESCET calculates the machinery weight. Analysis of the historical database revealed a linear relationship between the machinery weight and the machinery volume. Figure 31 presents the relationship between machinery volume and machinery weight described by equation (20) where $Mach_{Weight}$ is in

tonnes and $Mach_{Volume}$ in m^3. The machinery module uses (20) to calculate the machinery volume for the desired ship.

$$Mach_{Weight} = 0.8934 * Mach_{Volume} - 5.3506 \quad (20)$$

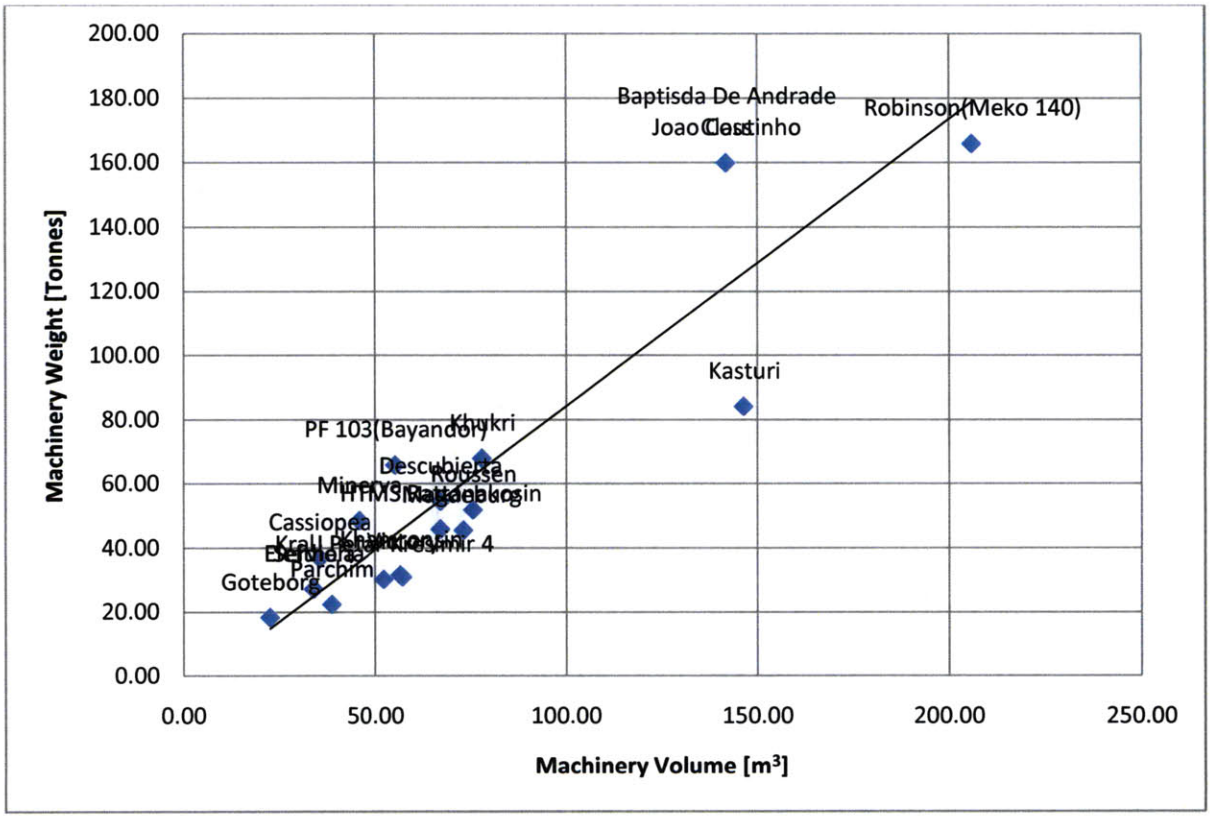


Figure 31 Diesel Power Plant; Machinery Volume vs. Machinery Weight Relationship

After calculating the machinery weight for the desired ship, ESCET calculates the sustained speed, sustained speed BHP and vertical center of gravity of engines. Methodology of these calculations is all the same for other power plants. These calculations are not explained in the following sections. These equations as follow:

$$Sustained\ Speed\ BHP = 0.8 * BHP \quad (21)$$

$$Sustained\ Speed = (\log\frac{BHP}{546.12})/0.1309 \quad (22)$$

$$Machinery\ Vcg = D/2 \quad (23)$$

4.3.2 CODOG (COmbined Diesel or Gas Turbine) Power Plant

The historical database reveals that CODOG power plant is preferred in eight ships. In Figure 32, Victory and Ishikari are excluded from the graph, since Victory has a high Froude number compared to the other CODOG power plant ships, and Ishikari's engine does not represent current technology. After excluding these ships, the relationship between BHP and the maximum speed is an exponential. Figure 32 is described by equation (24), where BHP is in HP and V_{max} is in KTS. In the range of 28-32 and 34-40 KTS, the machinery module uses (24) to calculate the BHP of the desired ship.

$$BHP = 6378.6 * exp^{0.0466 * V_{max}} \quad (24)$$

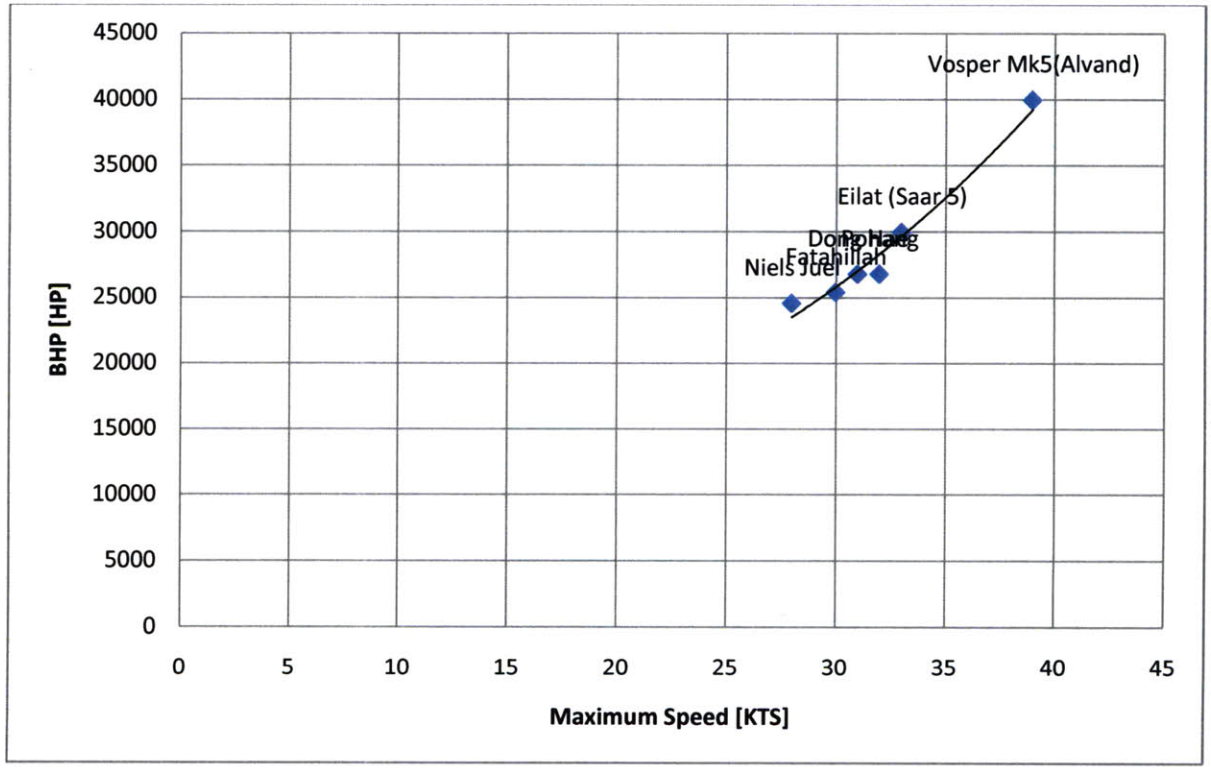


Figure 32 CODOG Power Plant; Maximum Speed vs. BHP Relationship

After calculating the BHP for the desired ship, ESCET calculates the machinery area for the desired CODOG power plant. Fatahillah is excluded from the graph, since its engine does not represent current technology. Figure 33 shows the relationship between BHP and the machinery area. Analysis of the historical database revealed a polynomial relationship between BHP and the machinery area in CODOG power plant. Figure 33 presents the relationship between BHP and

the machinery area described by equation (25) where BHP is in HP and $Mach_{Area}$ in m^2. The machinery module uses (25) to calculate the machinery area for the desired ship.

$$Mach_{Area} = -4 * E^{-8} * BHP^2 + 0.0042 * BHP - 55.761 \qquad (25)$$

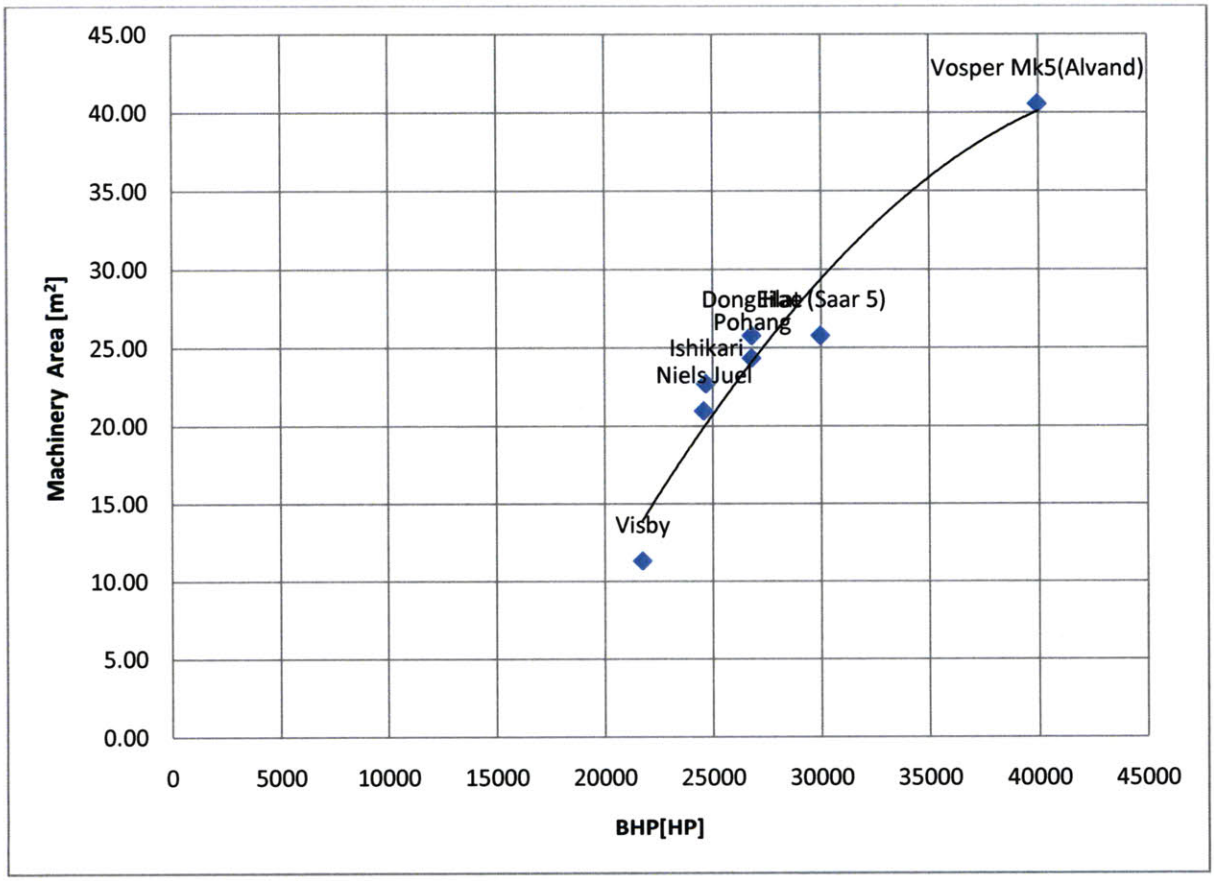


Figure 33 CODOG Power Plant; BHP vs. Machinery Area Relationship

After determining the machinery area for the desired ship, ESCET calculates the machinery volume for the CODOG power plant. Figure 34 shows the relationship between the machinery area and the machinery volume. In this chart, Fatahillah is excluded from the graph since its engine does not represent the current technology for CODOG power plants. After excluding this ship, Figure 34 shows the relationship between the machinery area and the machinery volume, which is polynomial, described by equation (26). The machinery module uses (26) to calculate the machinery volume for the desired ship, where $Mach_{Area}$ is in m^2 and $Mach_{Volume}$ is in m^3.

$$Mach_{Volume} = -0.0367 * Mach_{Area}{}^{2} + 5.4151 * Mach_{Area} - 43.424 \quad (26)$$

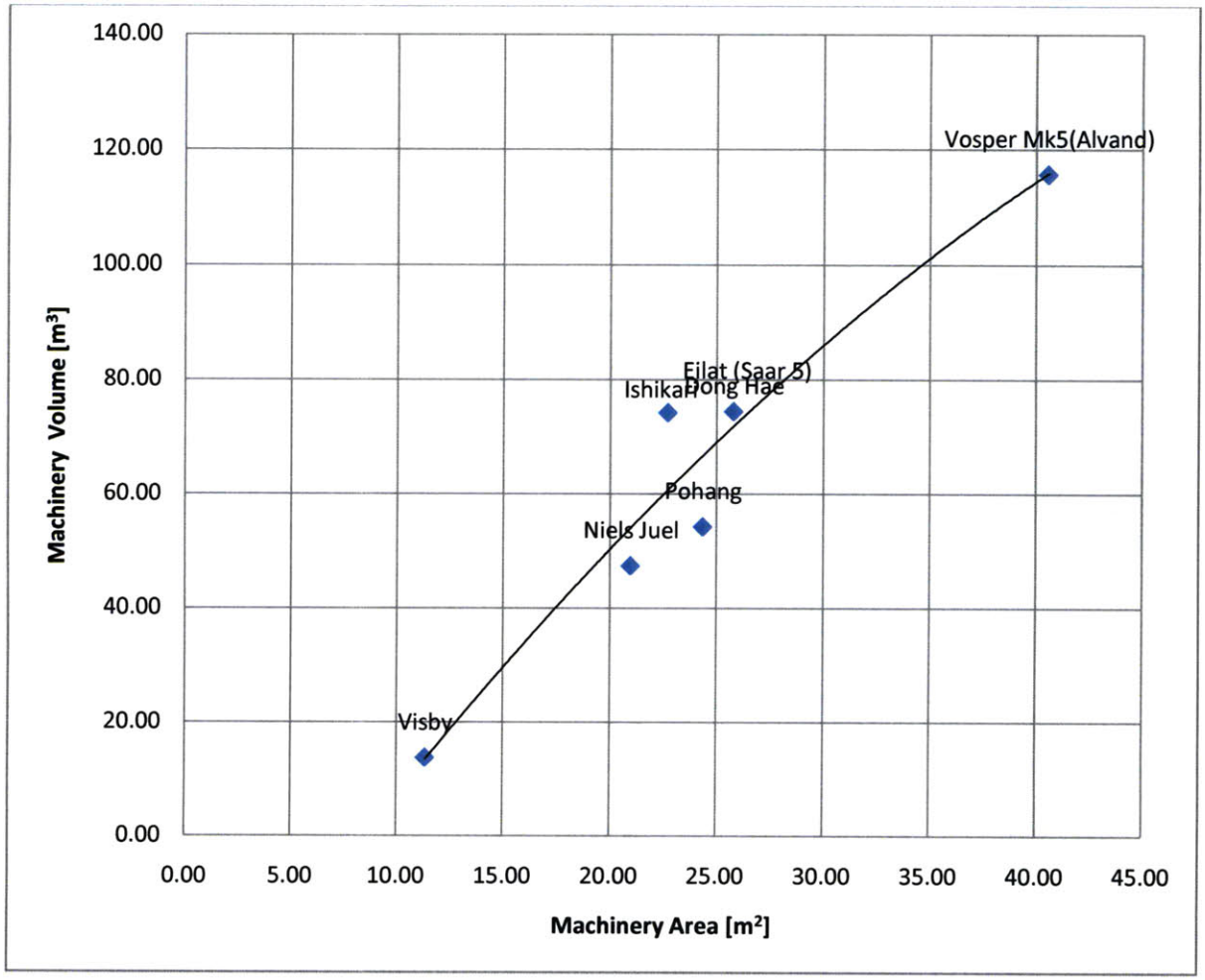


Figure 34 CODOG Power Plant; Machinery Area vs. Machinery Volume Relationship

After determining the machinery volume for the desired CODOG power plant, ESCET calculates the machinery weight. Figure 35 shows the relationship between the machinery volume and the machinery weight. Since Fatahillah's engine does not represent the current technology for CODOG power plants, it is excluded from the graph. After excluding this ship, Figure 35 presents the relationship between the machinery volume and the machinery weight, described by equation (27). The machinery module uses (27) to calculate the machinery weight for the desired CODOG power plant, where $Mach_{Weight}$ is in tonnes and the $Mach_{Volume}$ is in m^3.

$$Mach_{Weight} = 0.5144 * Mach_{Volume} - 0.3693 \quad (27)$$

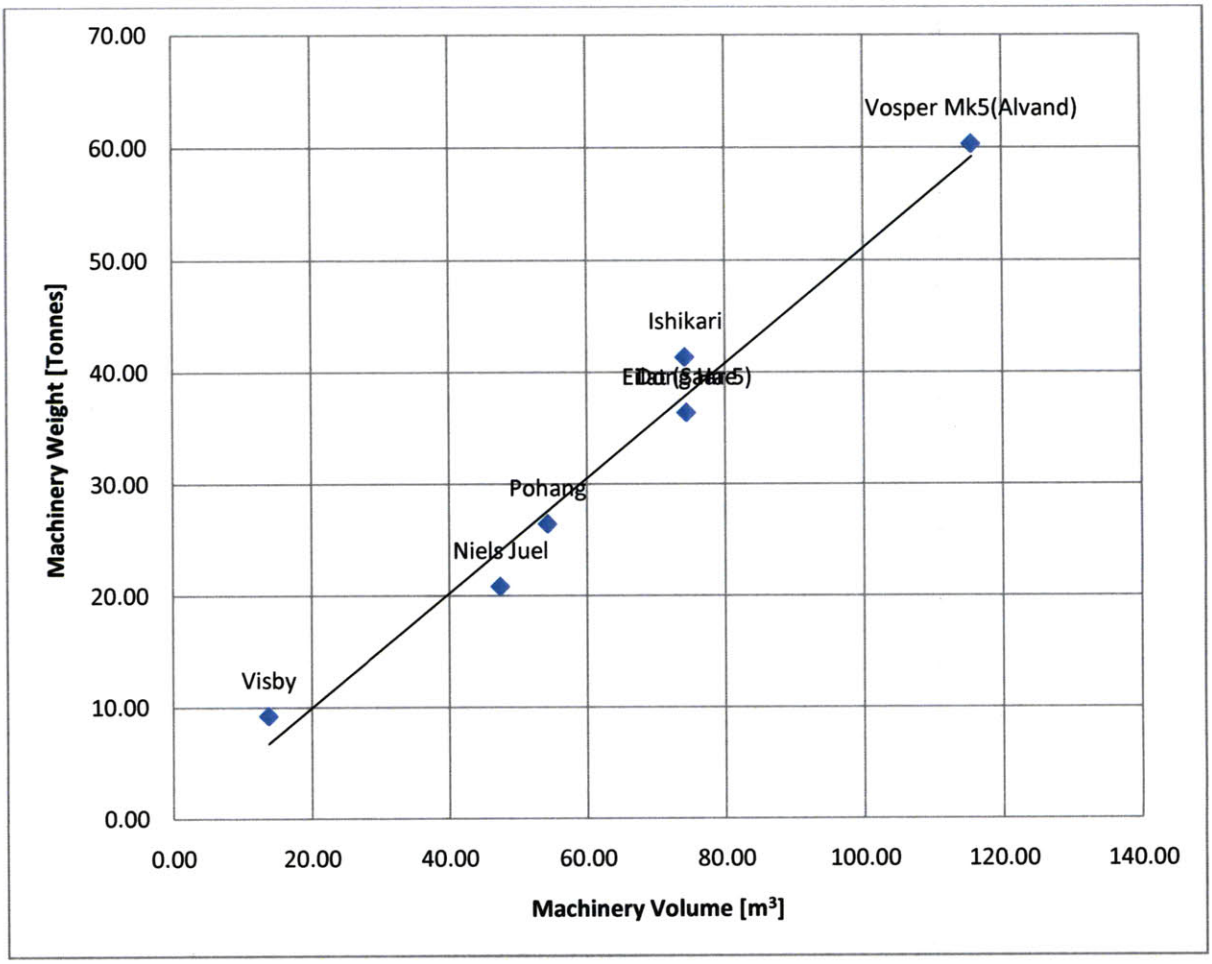


Figure 35 CODOG Power Plant; Machinery Volume vs. Machinery Weight Relationship

4.3.3 CODAG (COmbined Diesel And Gas Turbine) Power Plant

The historical database reveals that there are two ships used CODAG power plant. To have more reliable results there has to be more ships in the historical database. However, this power plant does not cover an extensive speed range. This graph is valid only for the maximum speeds from 32 to 34 KTS. Figure 36 shows the relationship between the maximum speed and BHP. In the range of 32-34 KTS, the machinery module uses (28) to calculate the BHP of the desired ship. V_{max} is the desired maximum speed in KTS.

$$BHP = 16280 * V_{max} - 515520 \qquad (28)$$

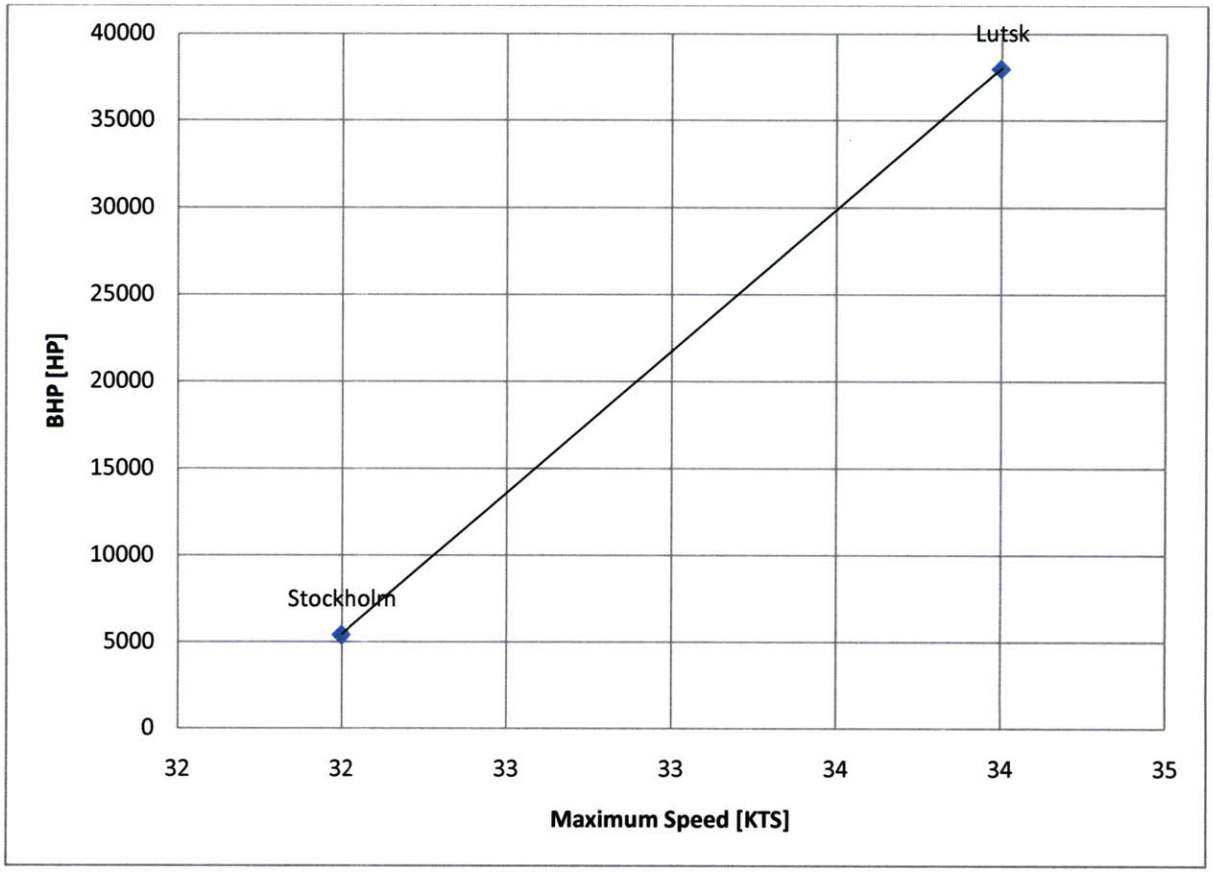


Figure 36 CODAG Power Plant; Maximum Speed vs. BHP Relationship

After determining the BHP for the desired ship, ESCET calculates the machinery area for the desired CODAG power plant. Figure 37 shows the relationship between BHP and the machinery area, described by equation (29). The machinery module uses (29) to calculate the machinery area for the desired CODAG power plant. In this equation, BHP is in HP and the $\text{Mach}_{\text{Area}}$ is in m^2.

$$Mach_{Area} = 0.0009 * BHP + 6.0098 \qquad (29)$$

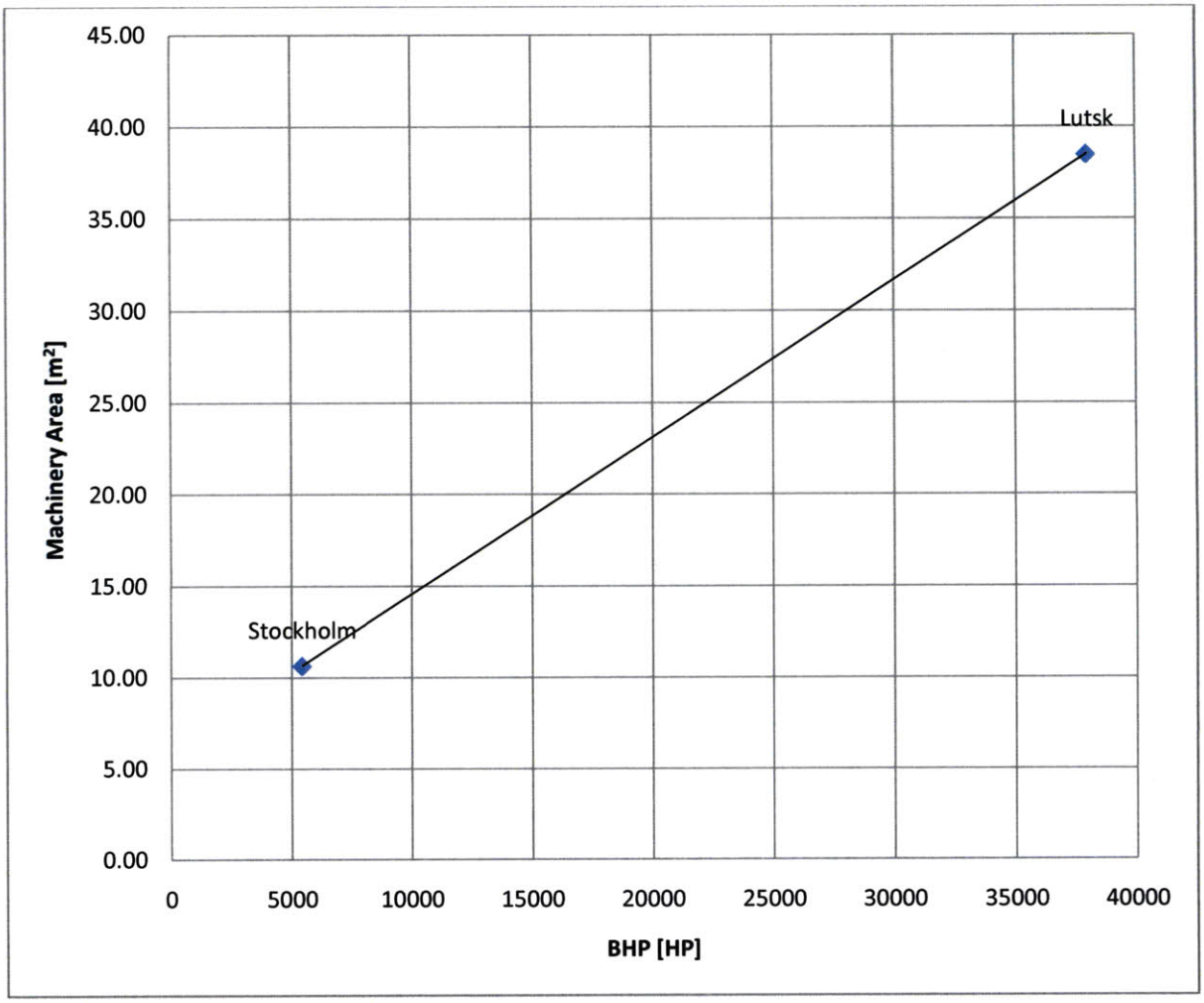


Figure 37 CODAG Power Plant; BHP vs. Machinery Area Relationship

After determining the machinery area for the desired ship, ESCET calculates the machinery volume for the CODAG power plant. Figure 38 shows the relationship between the machinery area and the machinery volume, described by equation (30). The machinery module uses (30) to calculate the machinery volume for the desired ship, where $Mach_{Area}$ is in m^2 and the $Mach_{Volume}$ is in m^3.

$$Mach_{Volume} = 2.9977 * Mach_{Area} - 15.506 \quad (30)$$

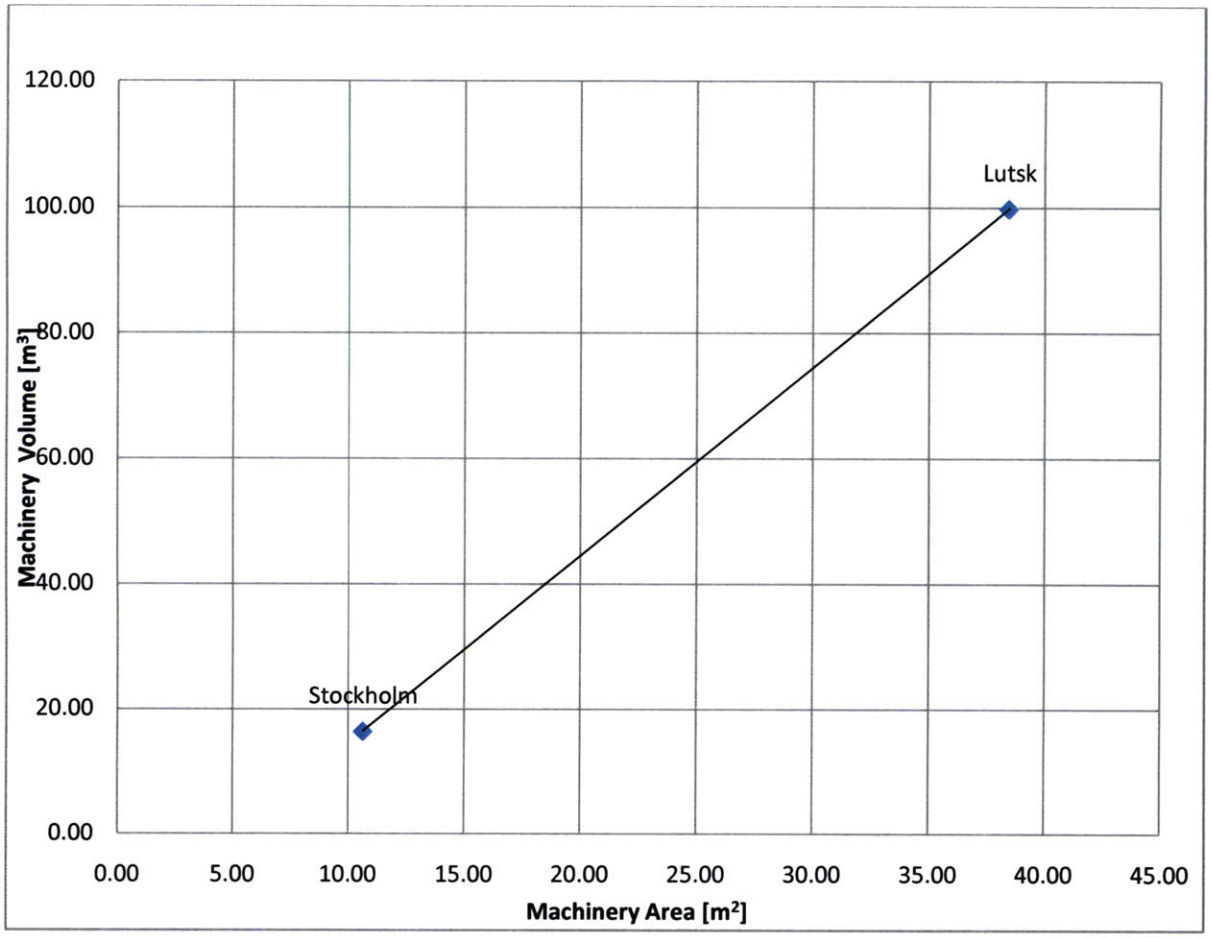


Figure 38 CODAG Power Plant; Machinery Area vs. Machinery Volume Relationship

After determining the machinery volume for the desired CODAG power plant, ESCET calculates the machinery weight. Figure 39 shows the relationship between machinery volume and machinery weight, described by equation (31). The machinery module uses (31) to calculate the machinery weight for the desired CODAG power plant, $Mach_{Weight}$ is in tonnes and the $Mach_{Volume}$ is in m^3.

$$Mach_{Weight} = 0.3926 * Mach_{Volume} + 6.4989 \qquad (31)$$

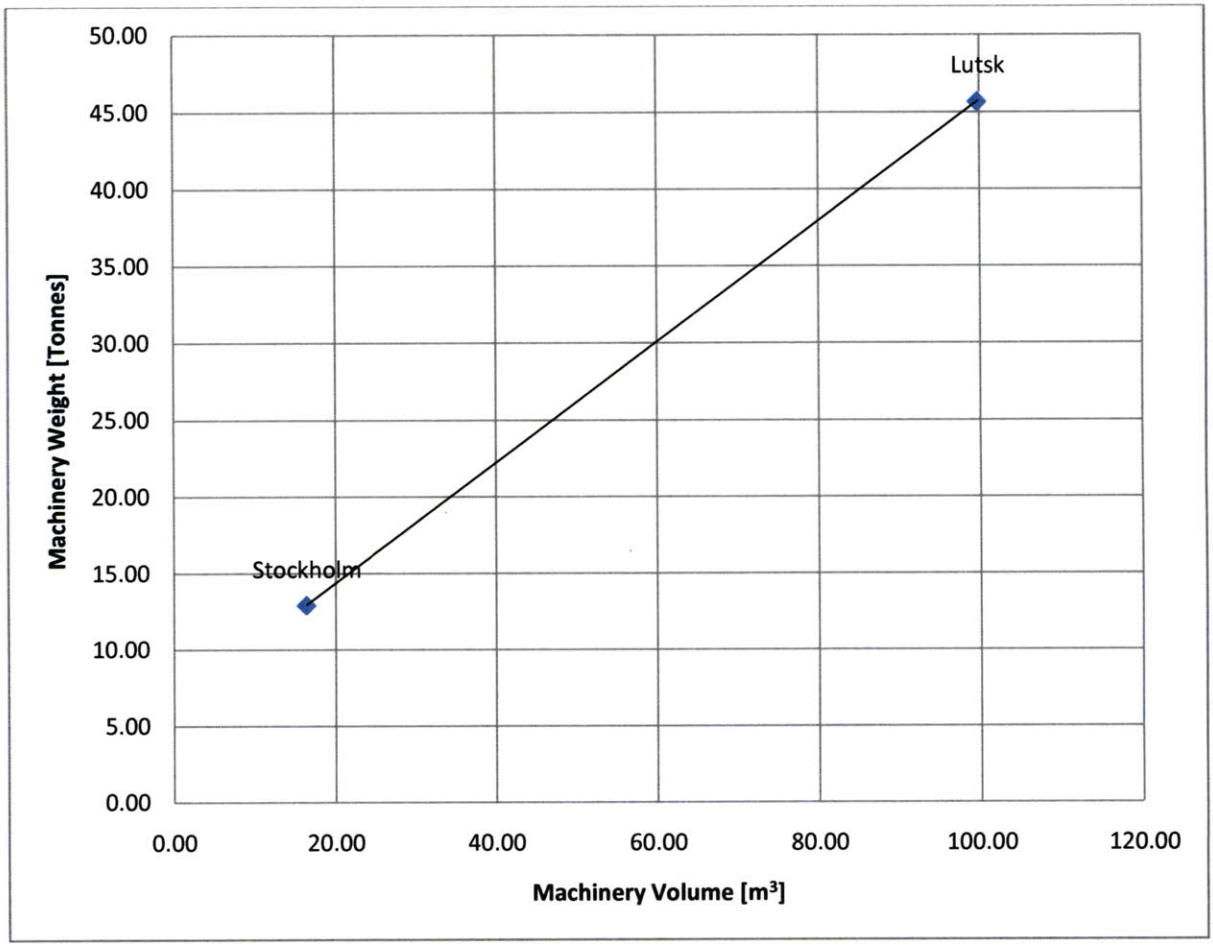


Figure 39 CODAG Power Plant; Machinery Volume vs. Machinery Weight Relationship

4.3.4 CODAD (COmbined Diesel and Diesel) Power Plant

The historical database shows that there is only one ship, which is called Kazsub, has CODAD power plant. The machinery specifications of this ship are built in the program. If the user inputs 27 KTS maximum speed, ESCET outputs these values:

- BHP= 16900 HP
- Number of propellers= 4
- Sustained speed= 24.51 KTS
- Sustained BHP= 13520
- Machinery area= 62 m^2
- Machinery volume= 172 m^3
- Machinery weight= 150 tonnes.

4.3.5 Initial Validation of the Machinery Module

The machinery module is validated using Stockholm, Vosper and Descubierta's data. Table 13 presents the results for each ship. The results show that ESCET can pull out the right data for the power plant type for all ships. Also, ESCET estimates total BHP within 4% error for all ships included in the validation while it estimates the machinery area within 2% error for smaller ships and within 26% for larger ships. However, the results also show that ESCET estimates the machinery volume and the machinery weight within 14% error.

The validation of the machinery module shows that ESCET could estimate the BHP and the machinery area with a low percentage error; while it estimates the machinery volume and the machinery weight with a high percentage error. This error occurs due to lack of data availability. ESCET's estimations are based on a limited number of ships. The error percentage for the machinery module could decrease by adding more ships and more data associated with the weight and the volume of the machinery for the selected ships in the historical database. The weight of the engines and the volume of the engines were estimated by using the main dimensions of the power plants. If the data on the actual area, volume and weight could be gathered, these error percentages would decrease and the machinery module would give better results.

Table 13 Initial Validation of the Machinery Module

	Stockholm			Vosper			Descubierta		
	Actual Data	**ESCET**	**Error %**	**Actual Data**	**ESCET**	**Error %**	**Actual Data**	**ESCET**	**Error %**
Power Plant	CODAG	CODAG	0	CODOG	CODOG	0	Diesel	Diesel	0
Number of Propellers	3	3	0	2	2	0	2	3	50
Total BHP	5440	5440	0	40000	39265	-1.84	15000	14405	-3.97
Machinery Area	10.65	10.9	2.35	40.59	47.48	16.98	26.36	20.84	-20.94
Machinery Volume	16.44	17.18	4.5	115.72	130.95	13.16	67.23	59.04	-12.18
Max. Speed	32	32	N/A	39.00	39.00	0.00	25	25	N/A
Machinery Weight	12.96	13.24	2.16	60.36	66.99	10.98	54.61	47.4	-13.2

4.4 Space Module

Estimation of the areas and volumes throughout the ship is extremely hard in the early-stage design. The ships in ASSET's library were analyzed to find relationships between SSCS (Ship Space Classification System) groups and required areas and volumes. The results are shown in Table 14. ASSET breaks down the space module into five different areas.

These areas are:

- 1.0 Mission Support
- 2.0 Human Support
- 3.0 Ship Support
- 4.0 Ship Mobility
- 5.0 Unassigned

The space estimation in ASSET is performed by dividing areas into five groups, which are called SSCS. The space module in ASSET uses this system to provide data for the internal deck-area of the ship. SSCS is divided into five first-level groups as it is mentioned above. Each of these first-level groups is composed of second-level groups, each second-level group is composed of a series of third-level and this division could go up to five-level group.

ASSET can give these values depending on its sub-division module; however, ESCET only calculates these groups in one-digit level based on the parametric relationships shown in Table 14 and Table 15. For instance, in Table 14 for FLIGHT 1, 26.3% of the total available area on board is the mission support area. The inputs for ESCET's space module are gathered by the customer requirements. ESCET gives an output for each SSCS group. This section describes how these relationships are derived and how integrated into the program.

Table 16 presents the flow chart for the space module. Firstly, ESCET calculates the required area for the helicopter platform and required volume for the helicopter hangar. DDG-51 helicopter platform area and volume data is used in the space module for the calculations. Required helicopter area for the DDG-51 is 201.86 m^2 and required helicopter hangar volume for the DDG-51 is 2047.65 m^3.

ESCET uses the equations below to estimate the total required areas for the ship. The equations (32) and (33) are derived from WMEC 270 data, which is presented on Table 15. WMEC 270 is the closest design for corvettes in ASSET library, thus its values are found more appropriate for corvettes.

$$Total\ Required\ Area_{DKHS\ only} = \frac{Required\ Area_{DKHS\ only}}{0.486} \quad (32)$$

$$Total\ Required\ Area_{DKHS\ or\ Hull} = \frac{Required\ Area_{DKHS\ or\ Hull}}{0.172} \quad (33)$$

After determining the total required areas for the desired ship, ESCET calculates the available area for SSCS groups separately. The customer requirements define the required mission support area (SSCS group Mission Support 1.0). Total available area is calculated by using the data in Table 14. ESCET uses the average values for Flight 1, Frigate and WMEC 270 data and estimates human support area, ship support area, ship mobility area respectively. These equations are:

$$Total\ Available\ Area = \frac{Mission\ Support\ Area\ (SSCS\ 1.0)}{0.256} \quad (34)$$

$$Human\ Support\ Area\ (SSCS\ 2.0) = Total\ Available\ Area * 0.327 \quad (35)$$

$$Ship\ Support\ Area\ (SSCS\ 3.0) = Total\ Available\ Area * 0.275 \quad (36)$$

$$Ship\ Mobility\ Area\ (SSCS\ 4.0) = Total\ Available\ Area * 0.141 \quad (37)$$

where areas are in m^2 and the numbers are average values for selected ships from ASSET library. These parametric ratios are presented in Table 14 at the last row.

Finally, ESCET compares the available area to the required area. If available area is less than required area ESCET incrementally increases the available area until it reaches the same value for required area. Volume calculations are similar to the area calculations, however average deck height is estimated to a 2.5 m value, which is reasonable for corvettes. Average deck height is multiplied with the mission support area to estimate the volume for the mission support.

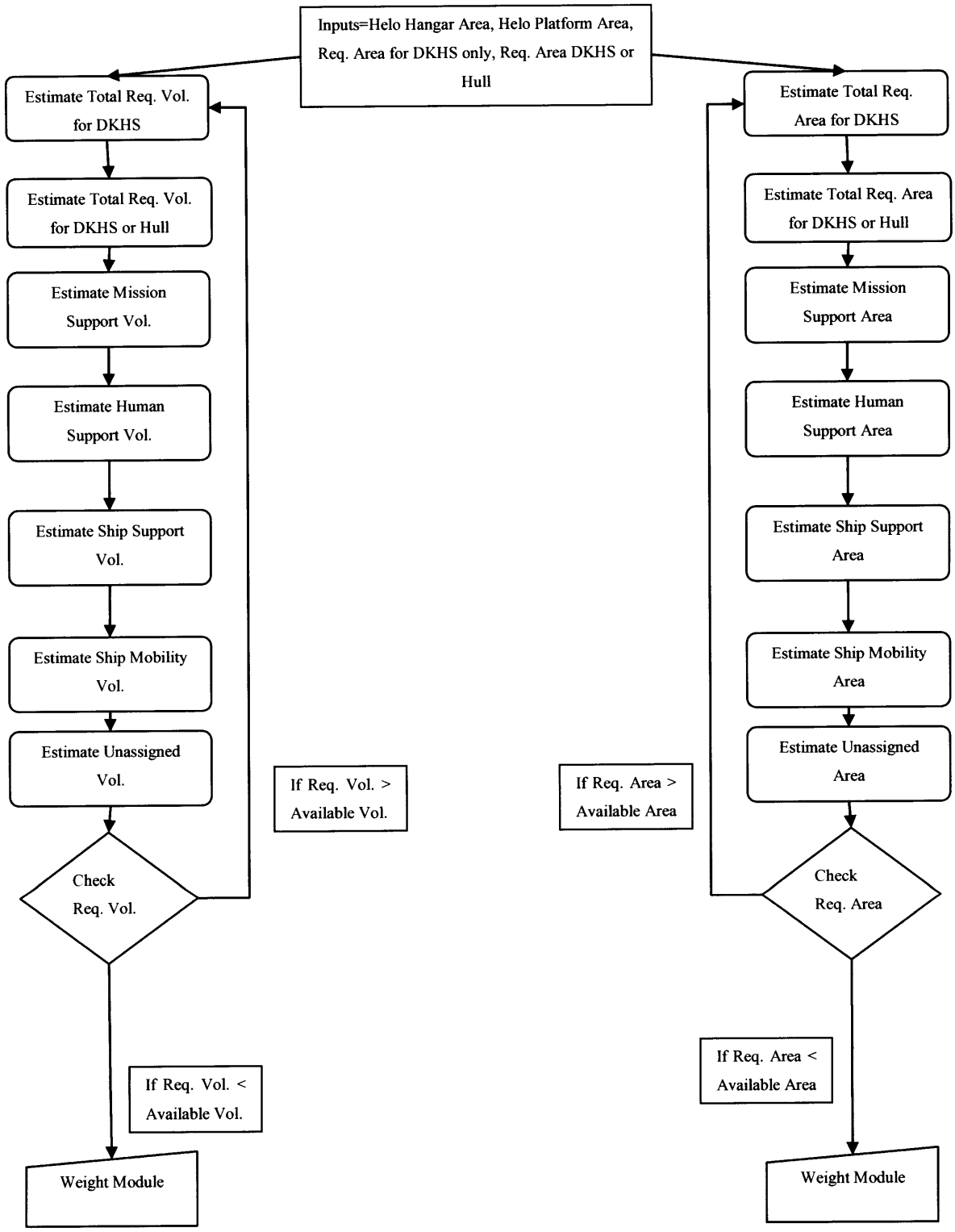
Table 14 Space Breakdown of the Ships in ASSET

Ship's Class	Space Module				
	1.0 Mission Support %	2.0 Human Support %	3.0 Ship Support %	4.0 Ship Mobility %	5.0 Unassigned %
FLIGHT 1	26.3	29.8	30.8	13.0	0.0
FRIGATE	26.5	26.4	28.6	18.4	0.0
LHD 5	37.2	29.6	21.1	11.5	0.6
LHD 8	21.7	41.2	22.8	13.6	0.6
WMEC 270	24.1	41.9	23.1	10.9	0.0
LSD 41	23.3	34.7	29.8	7.4	4.8
LPD 17	28.8	17.7	28.9	23.6	1.0
DDX	34.1	14.5	30.0	16.6	4.8
Standard Deviation for all ships	5.4	9.9	3.9	5.0	2.1
Average for all ships	27.8	29.5	26.9	14.4	1.5
Standard Deviation for Flight1, Frigate, WMEC 270	1.3	8.1	4.0	3.9	0.0
Average for Flight1, Frigate, WMEC 270	**25.6**	**32.7**	**27.5**	**14.1**	**0.0**

Table 15 Space Module; Deckhouse and Total Required Area Ratios

Ship's Class	Payload Req. for DKHS	Payload Req. for DKHS or HULL	Ratio Payload Req./Total	Area Req. for DKHS	Area Req. for DKHS or HULL	Ratio Payload Req. DKHS or Hull/Total	Total Req. Area
FLIGHT 1	376	856	0.324	1161	5175	0.165	6336
FRIGATE	584	243	0.574	1017	2801	0.087	3818
LHD 5	0	10634	0.000	675	43882	0.242	44557
LHD 8	12	1514	0.021	560	35382	0.043	35942
WMEC 270	**157**	**223**	**0.486**	**323**	**1295**	**0.172**	**1618**
LSD 41	0	0	0.000	936	10404	0.000	11340
LPD 17	5191	2777	0.820	6330	19423	0.143	25753
DDX	1552	3639	0.498	3114	9541	0.381	12655

Table 16 Space Module Flow Chart



4.4.1 Initial Validation of the Space Module

The space module is validated using WMEC 270 (US Coast Guard Cutter), Frigate(FFG-7) and Flight 1 (DDG-51) data. Inputs for the space module are: SSCS group 1.0 (Mission Support), helicopter platform area, helicopter hangar volume, required area for deckhouse only, required area for deckhouse or hull. Table 17 presents the results of the initial validation. Since the data on areas for corvettes could not be gathered, the validation of the space module is carried out using selected ships from ASSET library.

First ship used in the validation is WMEC 270. The results present that the space module estimated the total available area within 6% error. The higher error percentages are on the human support and ship mobility, which are almost 26% and 22%.

Second ship used in the validation is Frigate. The results present that the space module estimated the total available area within 2% error. The higher error percentages are on the human support and ship mobility for this ship as well, which are almost 28% and 21%. However, the space module estimated the ship support areas only within 1% error.

Last ship used in the validation is Flight 1. The results present that the space module estimated the total available area within 22% error. Also, the space module estimated the ship support areas within 9% error.

The initial validation of the space module shows that ESCET estimates the areas within 5-20% error. Additionally, the error on the total available areas for the smaller ships is less than 6% which is acceptable in the early-stage design.

Table 17 Initial Validation of the Space Module

	WMEC 270			Frigate			Flight 1		
	Actual	**ESCET**	**Error %**	**Actual**	**ESCET**	**Error %**	**Actual**	**ESCET**	**Error %**
1.0 Mission Support	390	390	0.000	1012	1012	0.000	1668	1668	0.000
2.0 Human Support	678	499	26.46	1009	1293	-28.14	1891	2132	-12.74
3.0 Ship Support	373	418	-12.17	1093	1085	0.73	1951	1789	8.30
4.0 Ship Mobility	177	215	-21.20	704	557	20.92	825	917	-11.15
5.0 Unassigned	0	0	N/A	0	0	N/A	0	0	N/A
Total Available Area	1617	1521	5.90	3874	3948	-1.91	5891	7158	-21.50
Total Required Area	1617	1220	24.58	3818	3216	15.76	6336	6780	-7.00

4.5 Weight Module

Weight Module is developed to calculate the weight for each weight group of the desired ship. This weight group system follows the SWBS (*Ship Work Breakdown Structure*) [18]. Using the SWBS system, material in a ship is broken down into seven major categories, or SWBS groups. The sum of the weights of the seven major SWBS groups (plus the weight of the margin) is the total lightship weight for the ship. SWBS numbers have three digits in them which are used to define material contained in that specific group. The first digit in a SWBS group number describes the most basic category to which a particular piece of material belongs.

The first study to develop the weight module was focused on some selected ships in ASSET library. The following pages present the relationships and tables derived to estimate the weight groups for corvettes from the selected ships in ASSET library. However, the full load displacement of these ships is larger than corvettes' displacement. Therefore, their relationships are not appropriate for corvettes. But it is found valuable to present these relationships for further studies, which could cover these ships. Table 18, Table 19, Table 20 and Table 21 show the weight group relationships and the specifications of the selected ships from ASSET's databank. The selected ships are: WMEC 270 (US Coast Guard Cutter), Frigate (FFG-7), and Flight 1 (DDG-51).

Table 18 shows the specifications of the selected ships. In this table, the length of the ships change from 77.7 to 142 m, where corvettes' range in the historical database change 48 to 89.7 m. C_P values are well in the range and C_X values are less than corvettes' values.

Table 18 Specifications of the Selected Ships from ASSET Databank

	WMEC 270	FRIGATE	FLIGHT1
LBP	77.7	124.4	142
LOA	81	136.6	153
B	11.5	13.7	18
D	9.5	9.1	12.7
T	4.2	5.1	6.7
GM_T	0.2	1	0.9
C_P	0.583	0.596	0.587
C_X	0.764	0.749	0.825
Endurance Speed	16	20	20
Endurance	4628.1	3469.2	3700.2
Military Payload	115.9	402.9	1115.8
Cubic Number	7.29	10.00	10.07

Table 19 shows the SWBS groups for WMEC 270, which is the only ship whose design characteristics are closest to a corvette in ASSET library. Its VCG/D ratios are calculated to use in the weight module to estimate corvettes SWBS groups VCGs. Then its VCG/D ratios compared to the SAWE's [11] VCG/D ratios. The results show that the difference between the WMEC 270's data and the SAWE's data negligible; however, SAWE's [11] VCG/D ratios for FF class ships are used in the weight module instead of WMEC 270 VCG/D ratios.

Table 19 WMEC 270 SWBS Groups and LCG, VCG Ratios from ASSET

SWBS	GROUP	WEIGHT	PERCENT	LCG	LCG/LWL	VCG	VCG/D
100	HULL STRUCTURE	618.9	33.9	38.73	0.498	5.26	0.554
200	PROPULSION PLANT	152.4	8.3	46.48	0.598	3.15	0.332
300	ELECTRIC PLANT	83.4	4.6	44.3	0.570	6.06	0.638
400	COMMAND + SURVEILLANCE	53.5	2.9	36.04	0.464	9.49	0.999
500	AUXILIARY SYSTEMS	210.9	11.5	44.13	0.568	6.35	0.668
600	OUTFIT + FURNISHINGS	157.6	8.6	35.45	0.456	4.65	0.489
700	ARMAMENT	12.9	0.7	36.71	0.472	10.38	1.093
	LIGHTSHIP	1289.6	70.5	40.35	0.519	5.39	0.567
M21	PD MARGIN %2.4	30.95			**KG MARGIN%2.4**	0.12	0.014
M22	CD MARGIN %2.4	30.95			**KG MARGIN%2.4**	0.12	0.014
M11	D&B MARGIN %5.3	68.34			**KG MARGIN%5.3**	0.28	0.030
M23	CON MOD MARGIN %1.4	18.05			**KG MARGIN%1.4**	0.075	0.008
M24	GFM MARGIN %0.6	7.73			**KG MARGIN%0.6**	0.032	0.003
	LIGHTSHIP w/ MARGINS	1445.64	79.4	40.35	0.519	6.04	0.636
F00	FULL LOADS	376.1	20.6	41.24	0.531	3.11	0.327
F10	SHIP FORCE EFFECTS	13		36.53	0.470	6.78	0.714
F20	MISSION RELATED EXPENDABLES	17.9		38.86	0.500	10.02	1.055
F30	SHIP STORES	8.9		41.97	0.540	5.1	0.537
F40	FUELS&LUBRICANTS	280		41.84	0.538	2.25	0.237
F50	LIQUIDS&GASES (NON-FUEL)	56.3		39.97	0.514	4.06	0.427
F60	CARGO	0		0	0.000	0	0.000
	FULL LOAD WEIGHT	1821.74	100	40.54	0.522	5.46	0.575

Table 20 shows the SWBS groups for Frigate in ASSET library. Since LCG/LWL ratios in SAWE [11] are not explicitly presented, these ratios are calculated to use in the weight module for each ship from ASSET library. The weight module uses the average values for LCG/LWL ratios, which is presented in Table 22. These equations used in the weight module are explained in the following pages.

Table 20 Frigate SWBS Groups and LCG, VCG Ratios from ASSET

SWBS	GROUP	WEIGHT	PERCENT	LCG	LCG/LWL	VCG	VCG/D
100	HULL STRUCTURE	1551.9	34.8	65.35	0.525	5.11	0.562
200	PROPULSION PLANT	307.2	6.9	87.66	0.705	3.39	0.373
300	ELECTRIC PLANT	245.1	5.5	69.53	0.559	5.88	0.646
400	COMMAND + SURVEILLANCE	143.5	3.2	48.28	0.388	9.34	1.026
500	AUXILIARY SYSTEMS	523.4	11.8	72.89	0.586	6.43	0.707
600	OUTFIT + FURNISHINGS	349.1	7.8	61.95	0.498	4.51	0.496
700	ARMAMENT	99	2.2	61.72	0.496	10.01	1.100
	LIGHTSHIP	3219.2	72.2	67.78	0.545	5.49	0.603
M21	PD MARGIN %2.4	77.26			**KG MARGIN%2.4**	0.131	0.014
M22	CD MARGIN %2.4	77.26			**KG MARGIN%2.4**	0.131	0.014
M11	D&B MARGIN %5.3	170.61			**KG MARGIN%5.3**	0.290	0.032
M23	CON MOD MARGIN %1.4	45.06			**KG MARGIN%1.4**	0.076	0.008
M24	GFM MARGIN %0.6	19.31			**KG MARGIN%0.6**	0.032	0.004
	LIGHTSHIP w/ MARGINS	3608.72	81	67.78	0.545	6.15	0.676
F00	FULL LOADS	845.1	19	57.01	0.458	3.73	0.410
F10	SHIP FORCE EFFECTS	21.8		58.45	0.470	7.08	0.778
F20	MISSION RELATED EXPENDABLES	81.8		62.18	0.500	10.12	1.112
F30	SHIP STORES	43.6		67.15	0.540	5.42	0.596
F40	FUELS&LUBRICANTS	665.6		55.78	0.448	2.78	0.305
F50	LIQUIDS&GASES (NON-FUEL)	32.3		54.59	0.439	2.7	0.297
F60	CARGO	0		0	0.000	0	0.000
	FULL LOAD WEIGHT	4453.82	100	65.74	0.528	5.73	0.630

Table 21 shows the weight groups for the Flight 1. This ship is the largest ship in the ASSET databank and its specifications are different than corvette-sized ships. In the weight module, this ship is not included in any calculation. However, its LCG/LWL ratios are included into the calculation of the average LCG/LWL ratios to have more the data points.

Table 21 Flight 1 SWBS Groups and LCG, VCG Ratios from ASSET

SWBS	GROUP	WEIGHT	PERCENT	LCG	LCG/LWL	VCG	VCG/D
100	HULL STRUCTURE	3270.4	35.8	72.17	0.508	7.61	0.599
200	PROPULSION PLANT	761.3	8.3	88.14	0.621	5.13	0.404
300	ELECTRIC PLANT	317.6	3.5	76.84	0.541	8.04	0.633
400	COMMAND + SURVEILLANCE	436.1	4.8	43.1	0.304	8.43	0.664
500	AUXILIARY SYSTEMS	839.8	9.2	83.22	0.586	8.51	0.670
600	OUTFIT + FURNISHINGS	662.9	7.2	62.81	0.442	6.34	0.499
700	ARMAMENT	320	3.5	70.27	0.495	10.08	0.794
	LIGHTSHIP	6608.1	72.3	72.69	0.512	7.51	0.591
M21	PD MARGIN %2.4	158.59			**KG MARGIN%2.4**	0.180	0.014
M22	CD MARGIN %2.4	158.59			**KG MARGIN%2.4**	0.180	0.014
M11	D&B MARGIN %5.3	350.22			**KG MARGIN%5.3**	0.398	0.031
M23	CON MOD MARGIN %1.4	92.51			**KG MARGIN%1.4**	0.105	0.008
M24	GFM MARGIN %0.6	39.64			**KG MARGIN%0.6**	0.045	0.004
	LIGHTSHIP w/ MARGINS	7407.68	81.3	72.69	0.512	8.41871	0.663
F00	FULL LOADS	1710.4	18.7	71.1	0.501	4.95	0.390
F10	SHIP FORCE EFFECTS	38.7		66.76	0.470	9.19	0.724
F20	MISSION RELATED EXPENDABLES	206.4		71.02	0.500	10.06	0.792
F30	SHIP STORES	51		76.7	0.540	6.95	0.547
F40	FUELS&LUBRICANTS	1289.1		71.04	0.500	4.15	0.327
F50	LIQUIDS&GASES (NON-FUEL)	125.3		71.02	0.500	2.54	0.200
F60	CARGO	0		0	0.000	0	0.000
	FULL LOAD WEIGHT	9118.08	100	72.39	0.510	7.79	0.613

Figure 40 shows the relationship between the military payload and full load displacement of the ship. This is a reasonable and valuable relationship since it is linear. However, since these ships are not in the range from the full load displacement stand point, ESCET cannot use this relationship. This relationship is presented for future development of the program. Below is the equation of this relationship.

$$\Delta_{Full} = 7.153 * W_{Payload} + 1233.8 \quad (38)$$

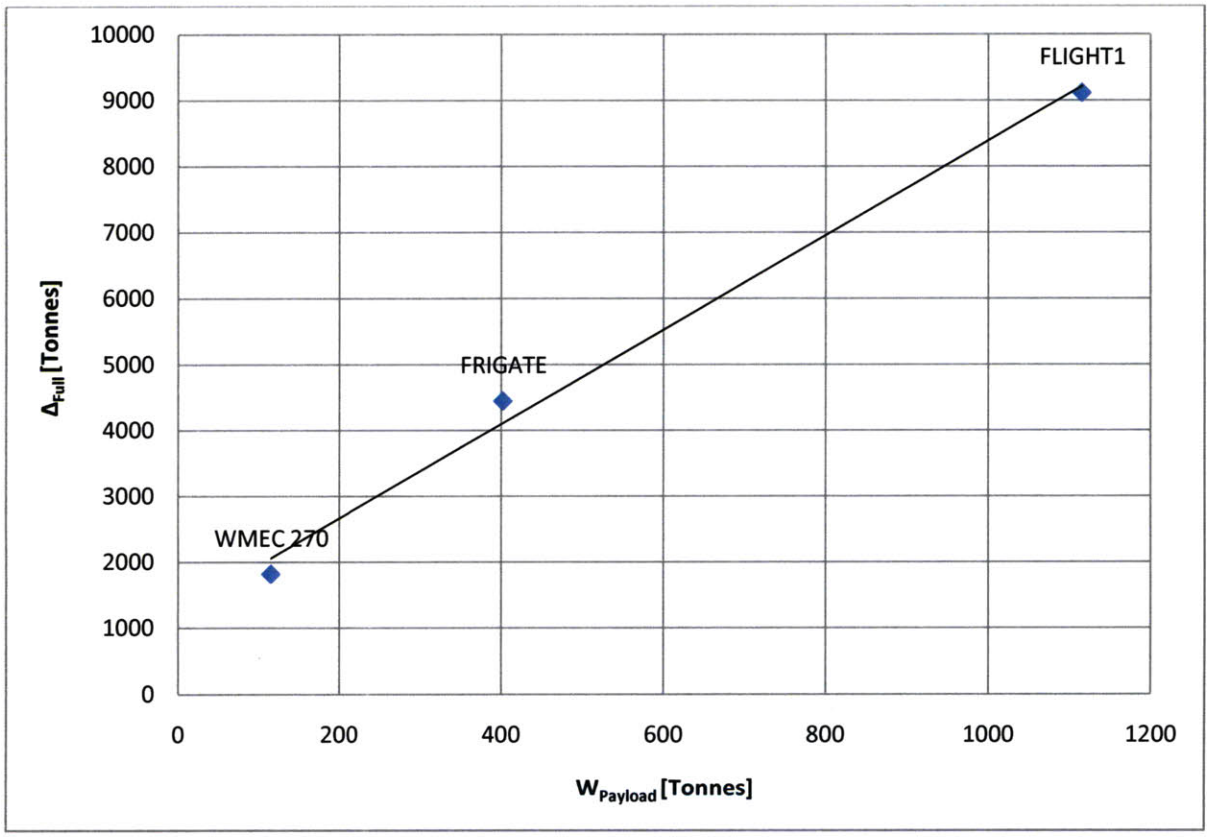


Figure 40 $W_{Payload}$ vs. Δ_{Full} Relationship for Selected Ships from ASSET Databank

Figure 41 shows another relationship for the selected ships from ASSET library. In this figure, the relationship between lightship weight and the full loads is presented. It is a linear relationship. It could also be used for future development of the model. (39) is the equation derived from this relationship.

These are the most important and clear relationships that are derived from the tables presented in the previous pages. However, these relationships could not be used in the weight module. Thus, the weight module estimates the weights using the ratiocination method, which is presented in chapter 2 using the ratios shown in SAWE [11]. The relationships used in ESCET are presented and explained in the following pages.

$$W_{Full\ Loads} = 0.2514 * \Delta_{Light\ Ship} + 45.657 \qquad (39)$$

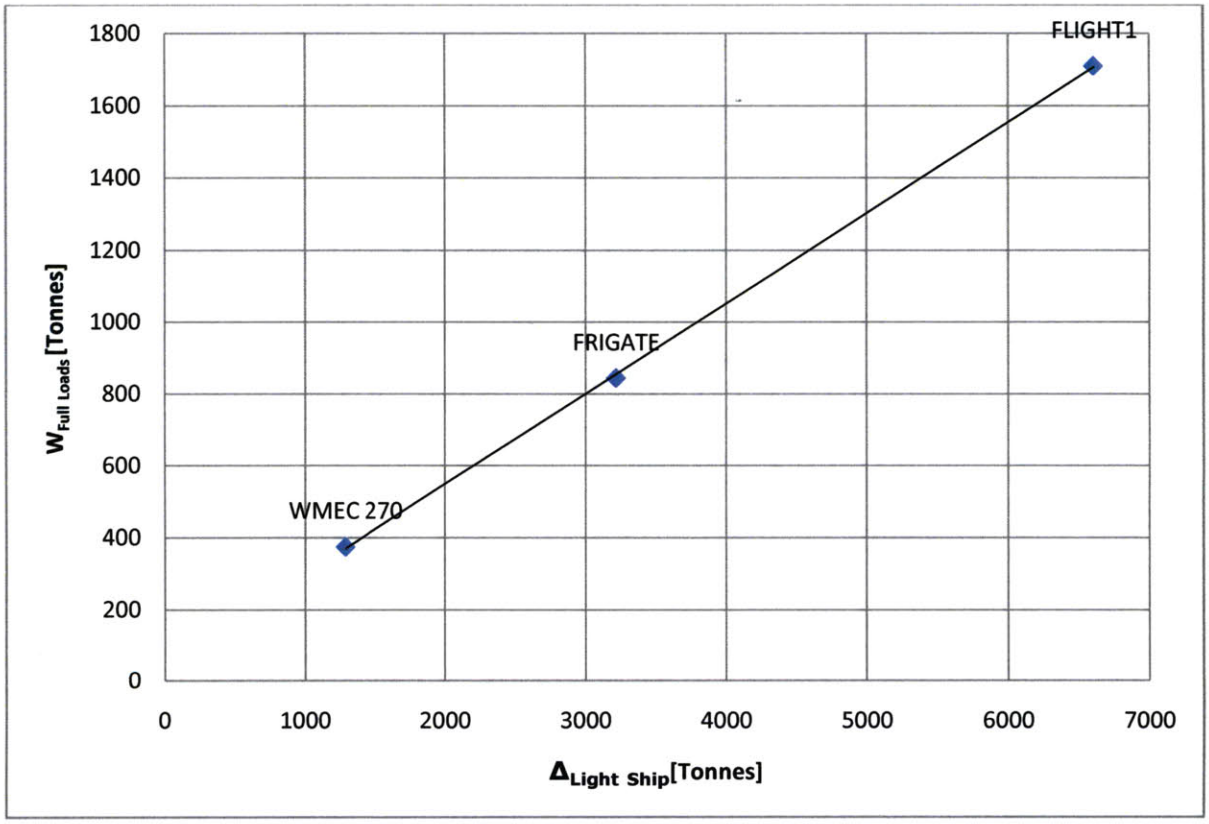


Figure 41 $\Delta_{Light\ Ship}$ vs. $W_{Full\ Loads}$ Relationship for the Selected Ships from ASSET Database

The weight module only uses the data from selected ships in ASSET library to estimate the LCGs for the desired ship. Table 22 shows the average values for LCG/LWL and VCG/D. Since SAWE [11] does not explicitly show LCG/LWL ratios for corvette-sized ships, The weight module uses average LCG/LWL ratio data from ASSET to calculate the LCGs. Table 23 presents the VCG/D ratios shown in SAWE [11] for FF class ships. These VCG/D ratios are used in ESCET to estimate the VCGs for each SWBS group.

Table 22 Avg. and Standard Deviation Values for the Selected Ships' LCG and VCG Ratios from ASSET

SWBS	GROUP	STD for LCG/LWL	AVG for LCG/LWL	STD for VCG/D	AVG for VCG/D
100	HULL STRUCTURE	0.014	**0.511**	0.024	0.571
200	PROPULSION PLANT	0.056	**0.641**	0.036	0.369
300	ELECTRIC PLANT	0.015	**0.557**	0.007	0.639
400	COMMAND + SURVEILLANCE	0.080	**0.385**	0.202	0.896
500	AUXILIARY SYSTEMS	0.010	**0.580**	0.022	0.682
600	OUTFIT + FURNISHINGS	0.029	**0.466**	0.005	0.495
700	ARMAMENT	0.013	**0.488**	0.175	0.995
F00	FULL LOADS	0.036	**0.497**	0.043	0.376
	LIGHTSHIP	0.017	**0.525**	0.018	0.587
	LIGHTSHIP w/ MARGINS	0.017	**0.525**	0.021	0.658
	FULL LOAD WEIGHT	0.009	**0.520**	0.028	0.606

Table 23 VCG/D Ratios from SAWE for FF Class Ships

SWBS	GROUP	VCG/D
100	HULL STRUCTURE	0.524
200	PROPULSION PLANT	0.396
300	ELECTRIC PLANT	0.673
400	COMMAND + SURVEILLANCE	1.041
500	AUXILIARY SYSTEMS	0.569
600	OUTFIT + FURNISHINGS	0.837
700	ARMAMENT	1.139
F00	FULL LOADS	0.309

After reviewing the data gathered from ASSET library, the weight module is built on the parametric relationships derived using SAWE [11] weight group ratios. The weight module calculates SWBS groups using the relationships in chapter 2.

Table 24 presents the flow chart for the weight module. The weight module uses the LWL and D, which the hull module populates, as an input. These inputs are used to define each SWBS group. The parametric relationships are derived by using each ships SWBS breakdown tables. The following pages show each chart for SWBS groups.

ESCET estimates three values for each SWBS group depending on the historical database, these specifications are:

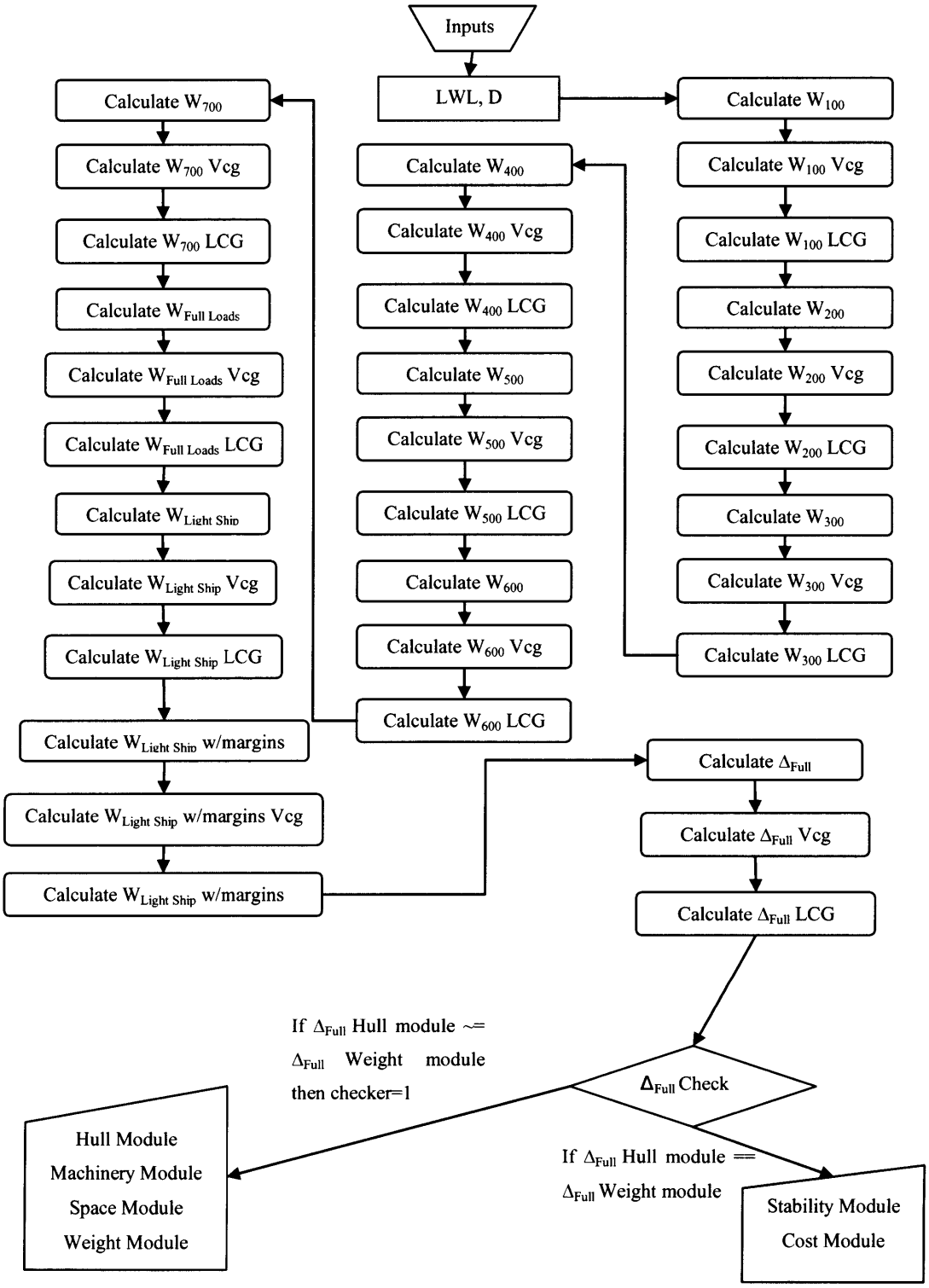
- $W_{\text{Group Number}}$
- Longitudinal Center of Gravity (LCG) for each $W_{\text{Group Number}}$
- Vertical Center of Gravity (VCG) for each $W_{\text{Group Number}}$

Estimation of the weight is based on the graphs shown in the following pages. LCG and VCG calculations are also presented. Table 22 shows the LCG/LWL average ratios for the ships in the ASSET library and ESCET uses these ratios to estimate the LCGs. VCG ratios are presented in SAWE [11] for a FF class ship and ESCET uses these VCG/D ratios to estimate the VCGs in the weight module.

After estimating each weight, the weight module compares the full load displacement of the ship calculated by the hull module to the full load displacement of the ship calculated by the weight module. If they are not equal, ESCET assumes that the weight module's estimation is correct, and sets the full load displacement of the ship to the weight module's estimation. After this comparison, ESCET recalculates the hull module, the machinery module, the space module and the weight module. The weight module passes the data to the stability module after recalculating the parameters for the modules. The stability module is followed by the cost module and they are described in the following sections.

The results from the weight module are only valid for LWLs between 48 to 89.7 m. ESCET cannot calculate the SWBS groups where the LWL is less than 48 m or more than 89.7 m.

Table 24 Weight Module Flow Chart



W_{100} refers to the assembled main hull body with all structural subdivisions. This group includes shell plating, longitudinal and transverse framing, platforms, masts, all of the interior and exterior decks, and the superstructure. Additionally all doors and closures fall into this group. Figure 42 shows the trend line for W_{100} group, and (40) is the derived equation used to calculate the W_{100} group, (41) shows the equation to calculate LCG for the W_{100} group and (42) shows the equation to calculate VCG for the W_{100} group.

$$W_{100} = 22.981 * exp^{0.0357 * LWL} \quad (40)$$

$$W_{100}\ lcg = 0.51 * LWL \quad (41)$$

$$W_{100}\ vcg = 0.524 * D \quad (42)$$

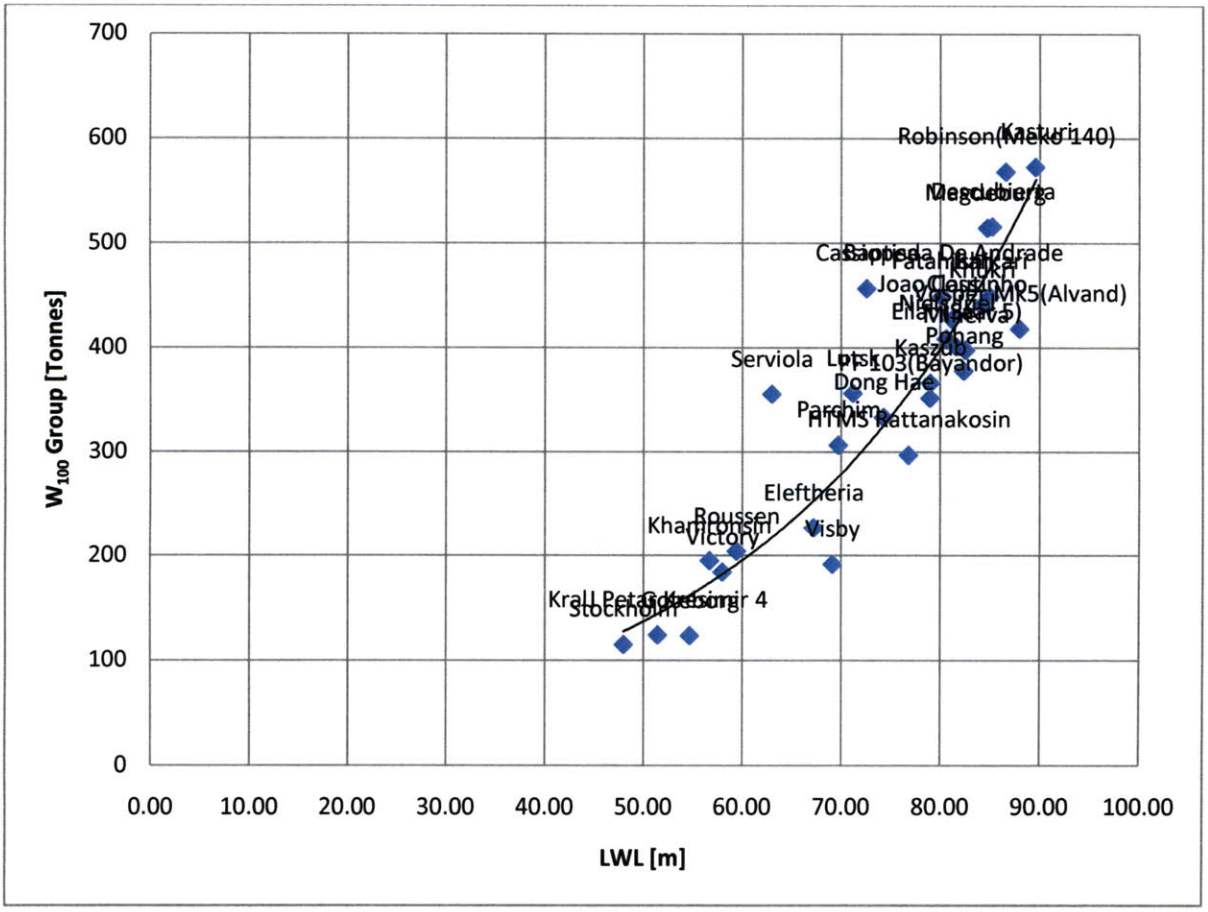


Figure 42 Weight Module; LWL vs. W_{100} Group Relationship

W_{200} refers to those major components installed primarily for propulsion and the systems necessary to make these components operable. This group contains engines, turbines, boilers and energy converters, main condensers and air ejectors, shafting, bearings and propellers.

Figure 43 shows the trend line for W_{200} group, and (43) is the derived equation used to calculate the W_{200} group, (44) shows the equation to calculate LCG for the W_{200} group and (45) shows the equation to calculate VCG for the W_{200} group.

$$W_{200} = 8.1546 * exp^{0.0357 * LWL} \tag{43}$$

$$W_{200}\ lcg = 0.641 * LWL \tag{44}$$

$$W_{200}\ vcg = 0.396 * D \tag{45}$$

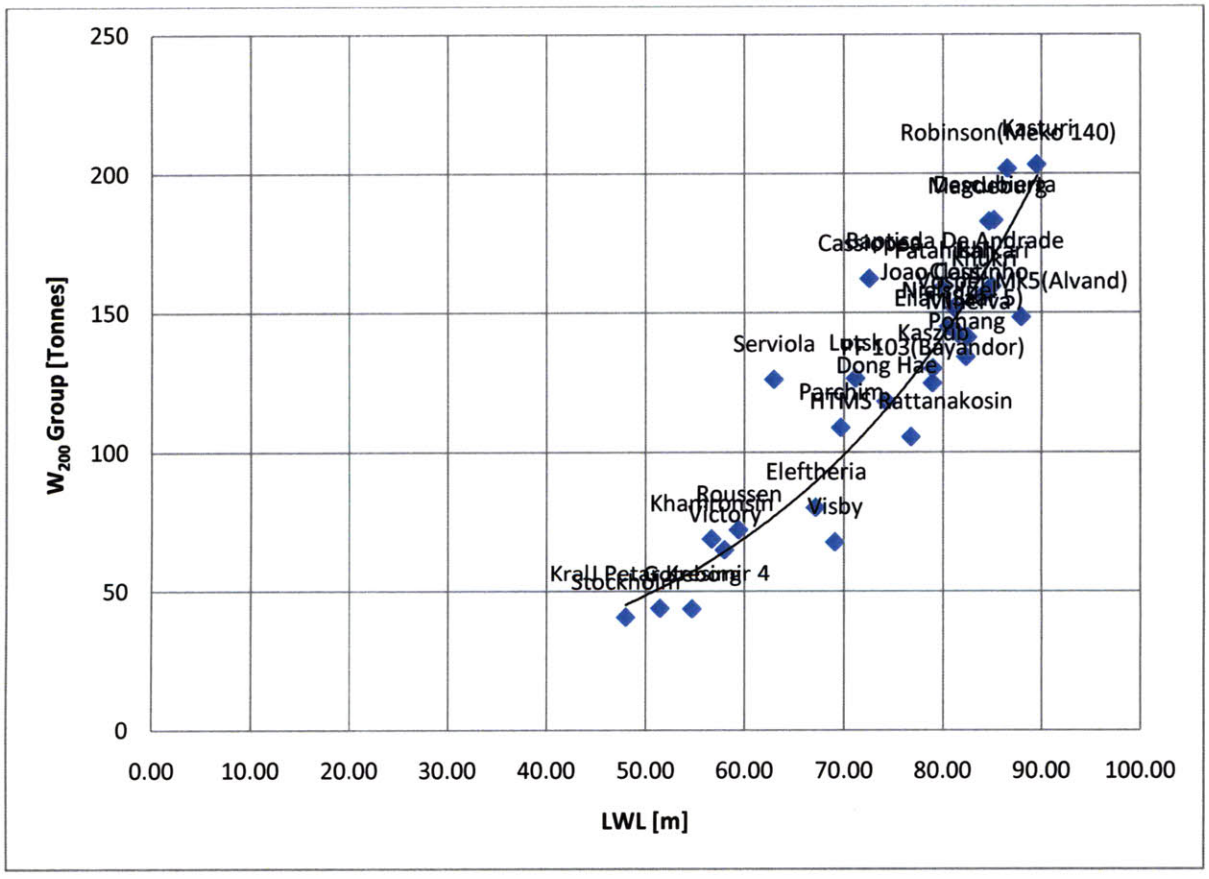


Figure 43 Weight Module; LWL vs. W_{200} Group Relationship

W_{300} refers to the power generating and distribution system installed primarily for ship service and emergency power and lighting. This includes generators, switchboards, lighting, and cables used for power distribution.

Figure 44 shows the trend line for W_{300} group, and (46) is the derived equation used to calculate the W_{300} group, (47) shows the equation to calculate LCG for the W_{300} group, and (48) shows the equation to calculate VCG for the W_{300} group.

$$W_{300} = 2.224 * exp^{0.0357 * LWL} \tag{46}$$

$$W_{300}\ lcg = 0.557 * LWL \tag{47}$$

$$W_{300}\ vcg = 0.673 * D \tag{48}$$

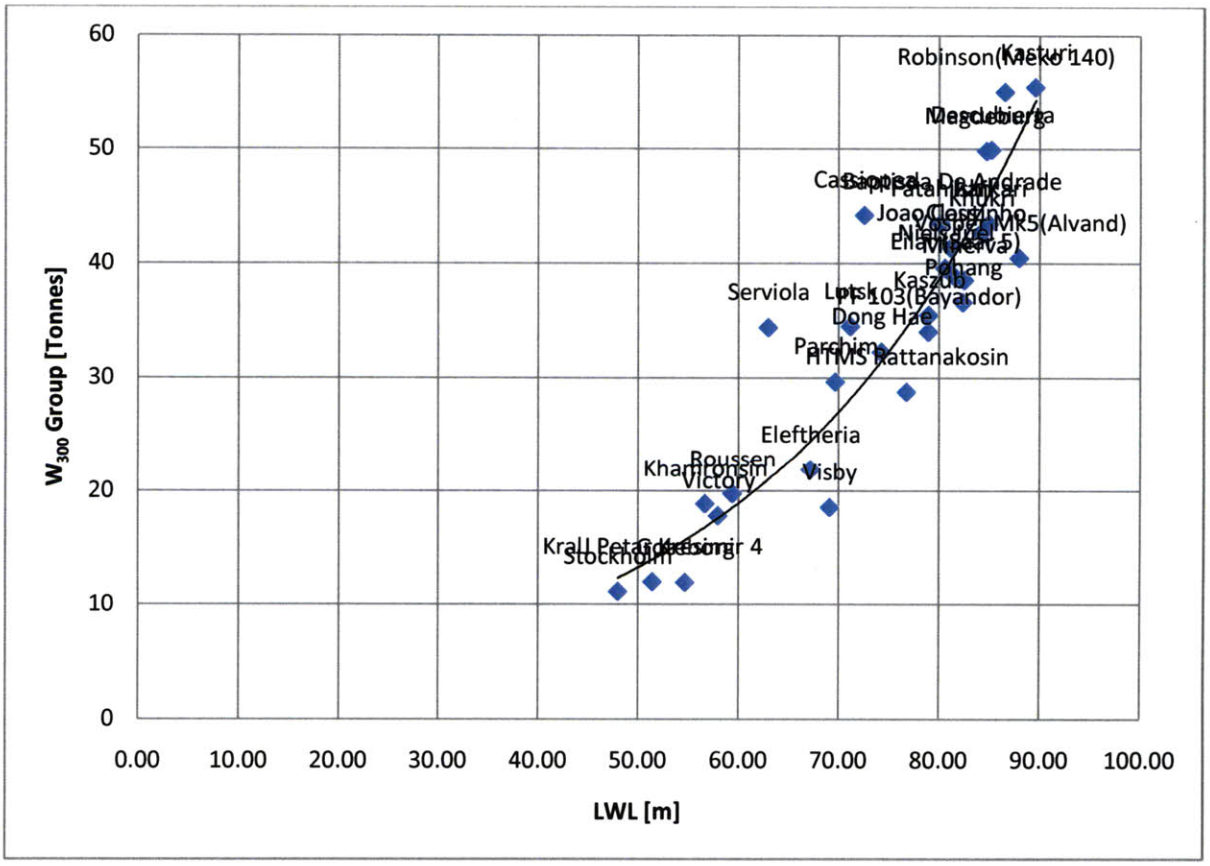


Figure 44 Weight Module; LWL vs. W_{300} Group Relationship

W_{400} refers to all equipment and associated systems installed to receive information from off-ship sources, to transmit to off-ship receivers and to distribute information throughout the ship. It also refers to sensing and data systems required for navigation and weapon fire control. This group also includes interior communications systems as well as countermeasure and protective systems.

Figure 45 shows the trend line for W_{400} group, and (49) is the derived equation used to calculate the W_{400} group, (50) shows the equation to calculate LCG for the W_{400} group and (51) shows the equation to calculate VCG for the W_{400} group.

$$W_{400} = 2.9653 * exp^{0.0357 * LWL} \tag{49}$$

$$W_{400}\ lcg = 0.385 * LWL \tag{50}$$

$$W_{400}\ vcg = 1.041 * D \tag{51}$$

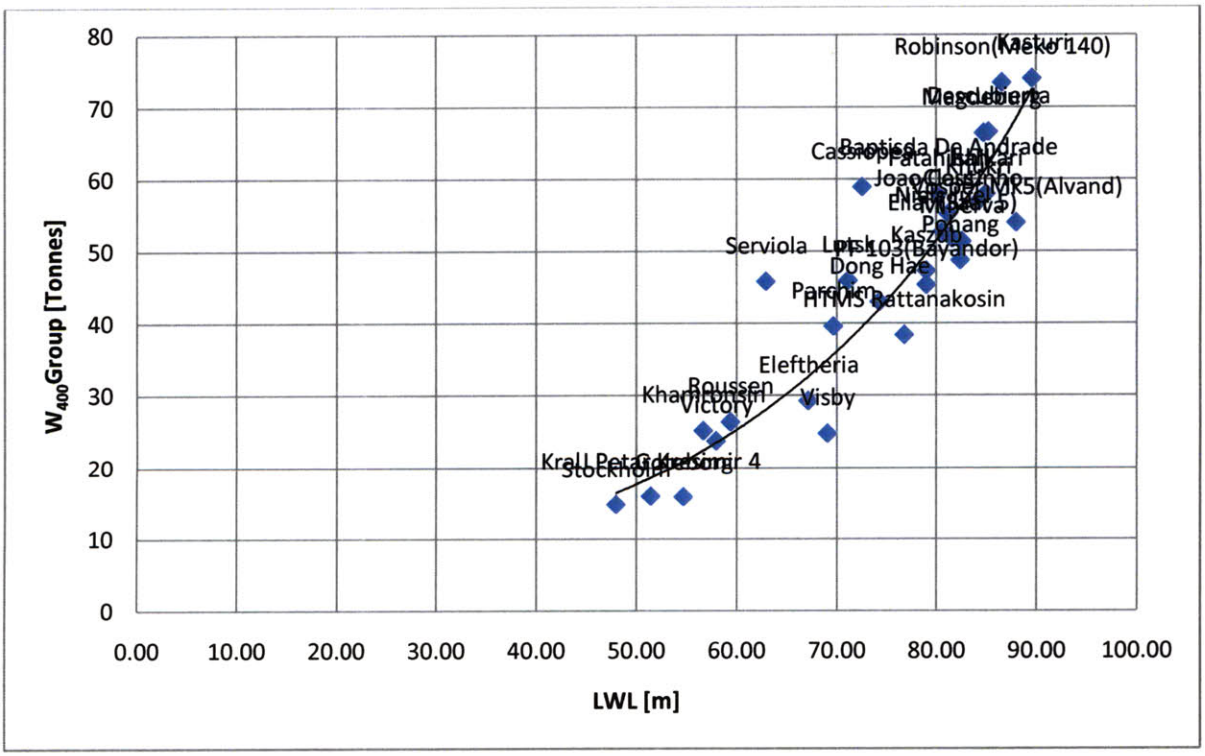


Figure 45 Weight Module; LWL vs. W_{400} Group Relationship

W_{500} refers to those systems required for ship control, safety, provisioning and habitability. All auxiliary systems including heating, ventilation, air-conditioning, refrigeration, plumbing, fire main, freshwater, rudders, steering gear, winches, capstans and cranes used for anchor stowage, as well as fuel and diesel oil filling are included in this group.

Figure 46 shows the trend line for W_{500} group, and (52) is the derived equation used to calculate the W_{500} group, (53) shows the equation to calculate LCG for the W_{500} group and (54) shows the equation to calculate VCG for the W_{500} group.

$$W_{500} = 6.6719 * exp^{0.0357 * LWL} \tag{52}$$

$$W_{500}\ lcg = 0.580 * LWL \tag{53}$$

$$W_{500}\ vcg = 0.569 * D \tag{54}$$

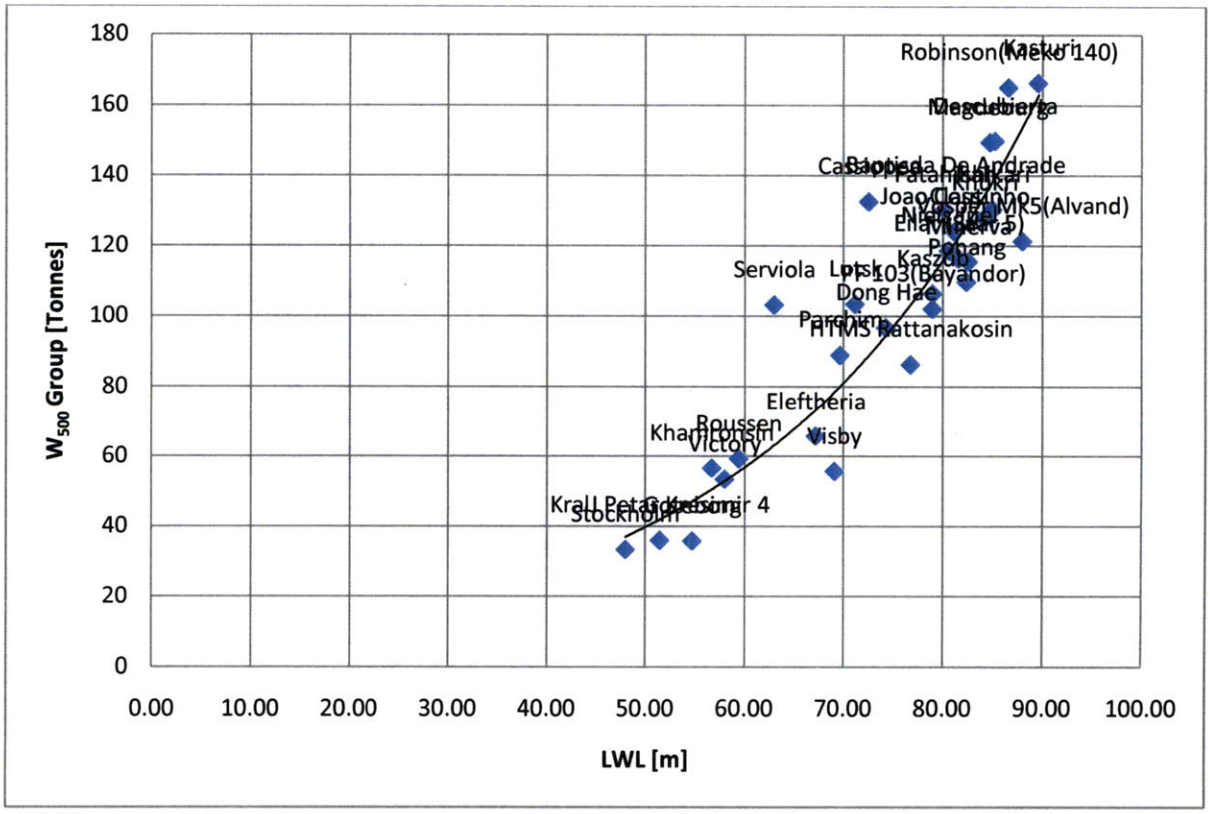


Figure 46 Weight Module; LWL vs. W_{500} Group Relationship

W_{600} refers to the outfit equipment and furnishings required for habitability and operability, which are specifically included in other Hardware Elements. Hull fittings, boats, boat stowage and handling, ladders and gratings, nonstructural bulkheads and doors, storerooms, furnishings for living, office, medical and dental spaces, and galley equipment are all included in this group.

Figure 47 shows the trend line for W_{600} group, and (55) is the derived equation used to calculate the W_{600} group, (56) shows the equation to calculate LCG for the W_{600} group and (57) shows the equation to calculate VCG for the W_{600} group as well.

$$W_{600} = 4.448 * exp^{0.0357 * LWL} \tag{55}$$

$$W_{600}\ lcg = 0.466 * LWL \tag{56}$$

$$W_{600}\ vcg = 0.837 * D \tag{57}$$

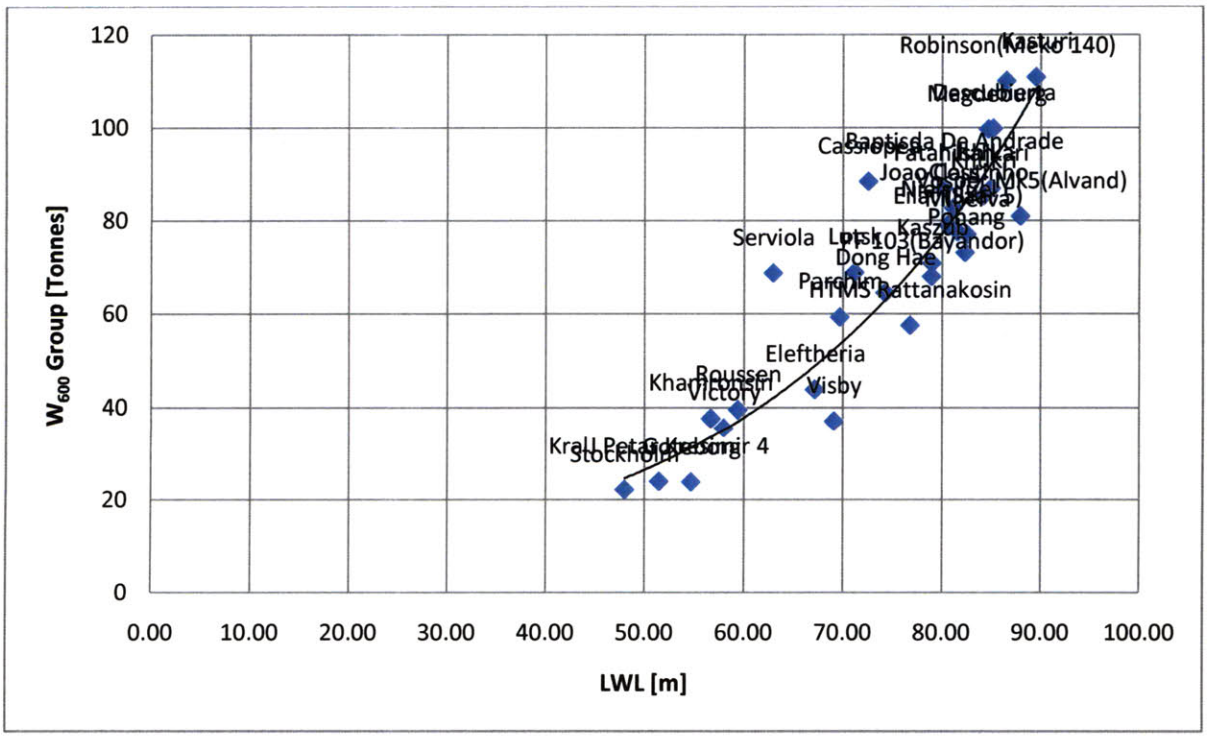


Figure 47 Weight Module; LWL vs. W_{600} Group Relationship

W_{700} refers to armament and related ammunition handling, stowage, and support facilities; and cargo munitions handling, stowage, and support facilities. Guns, their mounts and all weapons launching devices are included in this group.

Figure 48 shows the trend line for W_{700} group, and (58) is the derived equation used to calculate the W_{700} group, (59) shows the equation to calculate LCG for the W_{700} group and (60) shows the equation to calculate VCG for the W_{700} group.

$$W_{700} = 1.4827 * exp^{0.0357 * LWL} \quad (58)$$

$$W_{700}\ lcg = 0.488 * LWL \quad (59)$$

$$W_{700}\ vcg = 1.139 * D \quad (60)$$

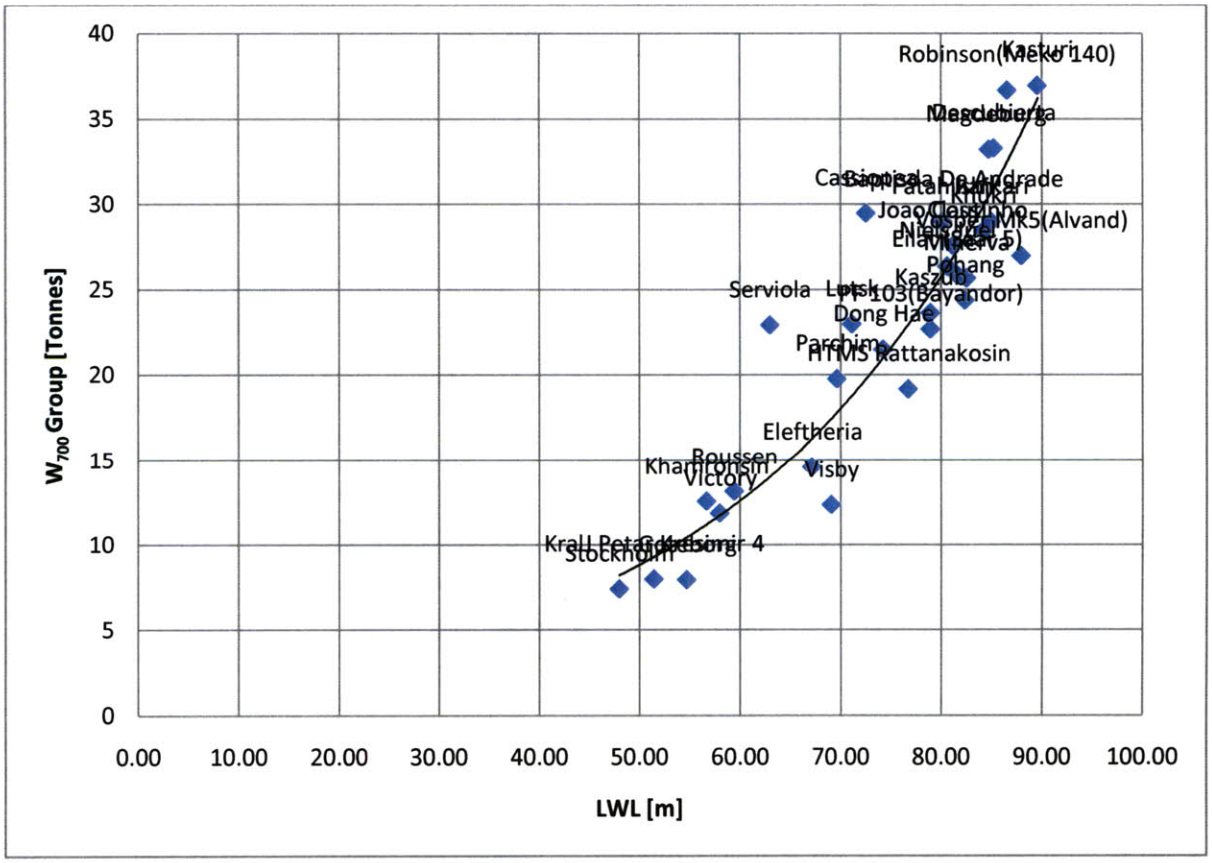


Figure 48 Weight Module; LWL vs. W_{700} Group Relationship

$W_{Full\ Loads}$ refers to ships force effect weights, mission related expendables, ship stores, fuel & lubricants, liquid and gases (non-fuel) and cargo weights.

Figure 49 shows the trend line for $W_{Full\ Loads}$ group, and (61) is the derived equation used to calculate the $W_{Full\ Loads}$ group, (62) shows the equation to calculate LCG for the $W_{Full\ Loads}$ group and (63) shows the equation to calculate VCG for the $W_{Full\ Loads}$ group.

$$W_{Full\ Loads} = 21.498 * exp^{0.0357 * LWL} \quad (61)$$

$$W_{Full\ Loads}\ lcg = 0.497 * LWL \quad (62)$$

$$W_{Full\ Loads}\ vcg = 0.309 * D \quad (63)$$

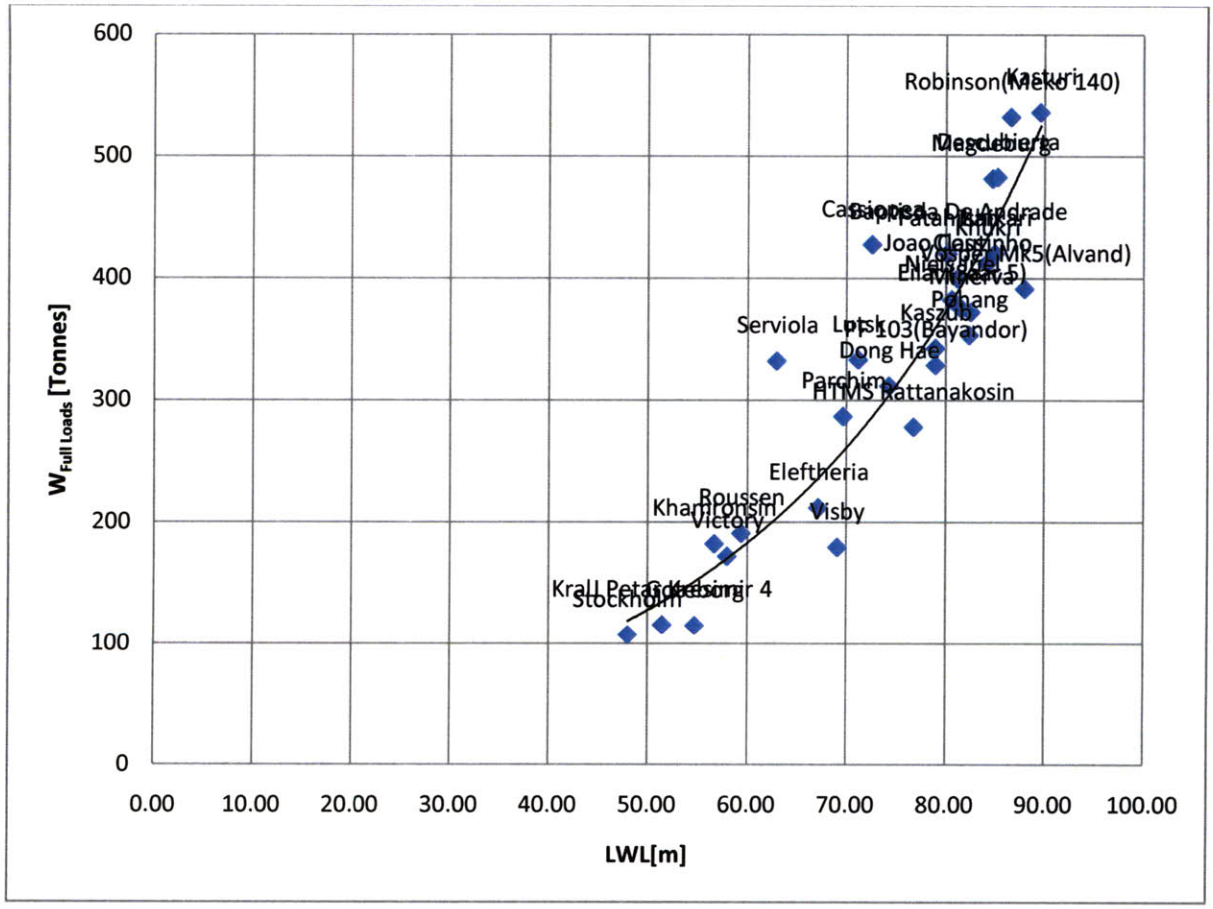


Figure 49 Weight Module; LWL vs. $W_{Full\ Loads}$ Group Relationship

4.5.1 Initial Validation of the Weight Module

The weight module is validated using LUTSK and WMEC 270. Table 25 and Table 26 show the comparison of the actual data and ESCET values. As it is presented in Table 25, ESCET's results show less than 3% error, which is acceptable in the early-stage design process, for LUTSK's weights. The average error percentage is 2.86%.

In Table 26, the validation of the weight module using WMEC 270 data is presented. The results show that WMEC 270 data does not fall into the desired lanes. The average error percentage is almost 40% for the weights and 30% for the VCGs. However, LCGs are estimated within 5% error.

This error gap between LUTSK data and WMEC 270 data is because of the fact that ESCET uses the historical database, which consists of corvettes, for its calculations. So, ESCET's weight module is not applicable to other non-corvette surface combatants. However, ESCET weight module still could estimate the LCGs for surface combatants because its calculations are based on the data from ASSET library. This is why ESCET estimated LCGs within 5% error for WMEC 270.

The weight module calculates the full load displacement of the ships as well. The estimation of the LUTSK's full load displacement is 1187 tonnes where the actual data is 1150 tonnes. The error percentage is less than 3%, which is acceptable in the early-stage design process. However, ESCET calculated the full load displacement of the WMEC 270 as 1187 tonnes where the actual data is 1821 tonnes. ESCET estimated the full load displacement for WMEC 270 within 34% error.

As it is mentioned before the weight module is valid for corvette-sized ships not for entire surface combatants. The only constraint for corvette-sized ships is that ESCET's weight module is only valid for LWLs between 48 m to 89.7 m. It cannot calculate the SWBS groups where the LWL is less than 48 m or more than 89.7 m. This is the restriction of the weight module and the program warns the user if the resulted LWL is more than expected.

Table 25 Initial Validation of the Weight Module Using Lutsk Data from Historical Database

LUTSK				
SWBS	**GROUP**	**WEIGHT**	**ESCET**	**ERROR %**
100	HULL STRUCTURE	356.5	368.17	3.27
200	PROPULSION PLANT	126.5	130.64	3.27
300	ELECTRIC PLANT	34.5	35	1.45
400	COMMAND + SURVEILLANCE	46	47	2.17
500	AUXILIARY SYSTEMS	103.5	106	2.42
600	OUTFIT + FURNISHINGS	69	71	2.90
700	ARMAMENT	23	23.7	3.04
	LIGHTSHIP	759	783	3.16
	LIGHTSHIP w/ MARGINS	816	843	3.31
F00	**FULL LOADS**	333.5	344	3.15
	FULL LOAD WEIGHT	1149.5	1187	3.26
			Avg. ERROR %	2.86

Table 26 Initial Validation of the Weight Module Using WMEC 270 Data from Historical Database

WMEC 270										
SWBS	**GROUP**	**WEIGHT**	**ESCET**	**ERROR %**	**LCG**	**ESCET**	**ERROR %**	**VCG**	**ESCET**	**ERROR %**
100	Hull Structure	618.9	368.17	-40.51	38.73	39.70	-2.50	5.26	3.36	36.12
200	Propulsion Plant	152.4	130.64	-14.28	46.48	49.80	-7.14	3.15	2.54	19.37
300	Electric Plant	83.4	35	-58.03	44.3	43.27	2.33	6.06	4.32	28.71
400	Command + Surveillance	53.5	47	-12.15	36.04	29.91	17.01	9.49	6.69	29.50
500	Auxiliary Systems	210.9	106	-49.74	44.13	45.06	-2.11	6.35	3.65	42.52
600	Outfit + Furnishings	157.6	71	-54.95	35.45	36.20	-2.12	4.65	5.38	-15.70
700	Armament	12.9	23.7	83.72	36.71	37.91	-3.27	10.38	7.32	29.48
	Lightship	1289.6	783	-39.28	40.35	40.79	-1.09	5.39	4.01	25.60
	Lightship w/ Margins	1445	843	-41.66	40.35	40.79	-1.09	5.39	4.01	25.60
F00	**Full loads**	376.1	344	-8.53	41.24	38.61	6.38	3.11	1.98	36.33
	Full Load Weight	1821.1	1187	-34.82	40.54	40.40	0.35	5.46	3.57	34.62
			Avg. ERROR %	39.79		**Avg. ERROR %**	4.13		**Avg. ERROR %**	29.41

4.6 Stability Module

One of the most important things in naval architecture is to verify if the ship floats upright. The hull module makes sure that the ship floats and the stability module validates that it floats upright. The inputs for the stability module come from the weight module and the hull module. The flow chart for the stability module is presented on Table 27.

First input is the vertical center of gravity of the ship which is estimated by the weight module. The stability module also uses data that the hull module populates (C_{wp}, B, LWL, T, C_m and ∇_{Full}). The other values needed for the calculation are estimated from equations described and explained in Lamb [2]. Figure 50 (source; Lamb [2]) shows the linear relationships for the non-dimensional waterplane transverse inertia coefficients. In the stability module all of these equations are built in and the most proper one is selected, which is Bauer's equation. The transverse waterplane coefficient of inertia is calculated using (64).

$$C_{IT} = \frac{(0.0372 * (2 * C_{wp} + 1))^3}{12} \tag{64}$$

After calculation of C_{IT}, the stability module calculates the I_t (moment of inertia). Moment of inertia (I_t) is calculated using (65).

$$I_t = C_{IT} * LWL * B^3 \tag{65}$$

KB is calculated using (66), which was derived by Normand. This equation is described in Lamb [2] as well. Normand's equation is found more proper for the corvettes.

$$KB = T * (0.9 - 0.36 * C_m) \tag{66}$$

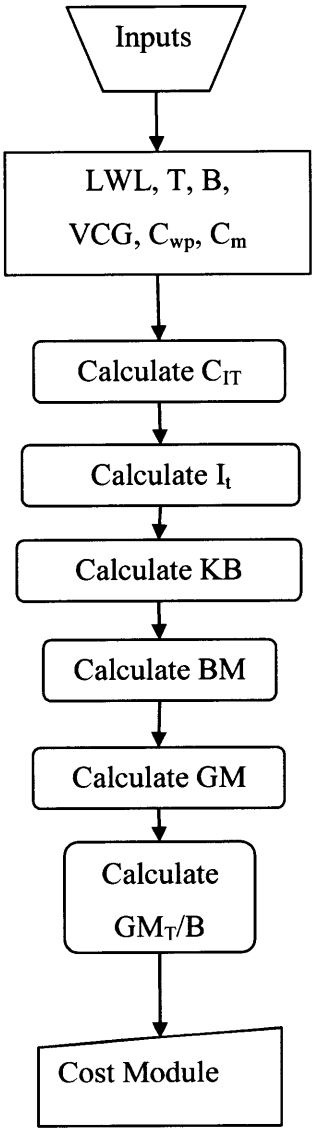
After calculating KB, BM is calculated using (67). GM and GM_T are calculated respectively by using equations (68) and (69).

$$BM = \frac{I_t}{\nabla_{Full}} \tag{67}$$

$$GM = KB + BM - KG \tag{68}$$

$$GM_T = GM/B \tag{69}$$

Table 27 Stability Module Flow Chart



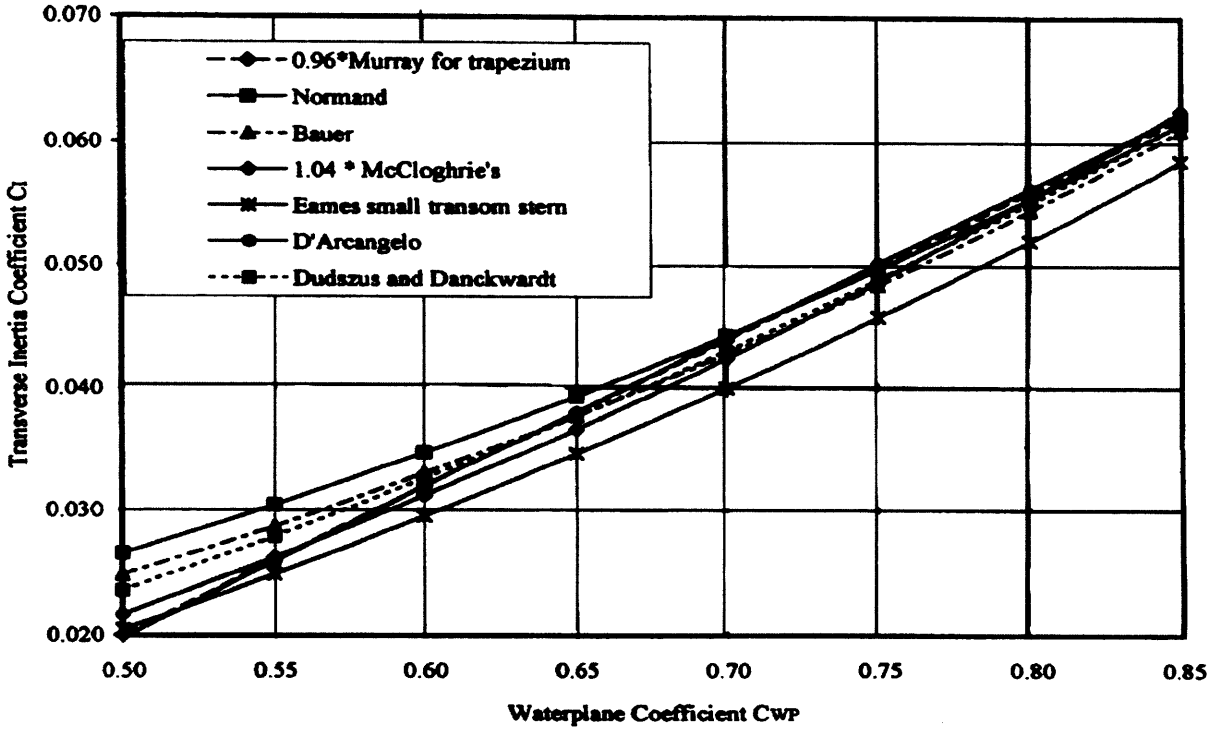


Figure 50 Estimates of the Transverse Inertia Coefficient CIT

4.6.1 Initial Validation of the Stability Module

The initial validation of the stability module is performed using WMEC 270 and Frigate data from ASSET library. As it is presented in Table 28, Frigate and WMEC 270 values are estimated with no error. The difference between ASSET's GM and ESCET's GM occurs because of the fact that ASSET includes a free surface correction factor into the calculation of the GM, but ESCET does not.

The stability module is a static module. It does not iterate to converge to an optimum ship. User has to know that $GM \geq 0$ and $0.5 \leq GM_T/B \leq 0.15$.

Table 28 Initial Validation of the Stability Module

	WMEC 270			Frigate		
	ASSET	ESCET	Error %	ASSET	ESCET	Error %
KB	2.64	2.62	0.76	3.16	3.18	-0.63
BM	3.10	3.10	0.00	3.56	3.53	0.84
KG	5.46	5.46	0.00	5.73	5.73	0.00
GM	0.28	0.26	7.14	0.99	0.99	0.00
GM_T	0.024	0.024	1.43	0.071	0.071	0.00

4.7 Cost Module

In this thesis the acquisition cost is calculated by using the 2N Program Cost Model [12]. A description of this cost model and the basis for determining the acquisition cost are provided by Smith [17]. Table 29 presents the flow chart for the cost module. This section only presents the inputs and the outputs of the "weight" based cost model. The results assume 2005 inflation rates. ESCET's cost model inputs are:

- Lead ship change orders percentage
- Follow ship change orders percentage
- Profit
- Lead ship T unit
- Follow ship T unit
- Learning curve percentage
- SWBS groups calculated by the weight module

While calculating the outputs for the cost model, ESCET uses Cost Estimating Relationships (CERS), in conjunction with the SWBS groups to produce cost estimates. CERs are an extremely useful tool as they provide a basic means for estimating costs despite dealing with a number of material products, parts and components in addition to multiple labor processes and support services.

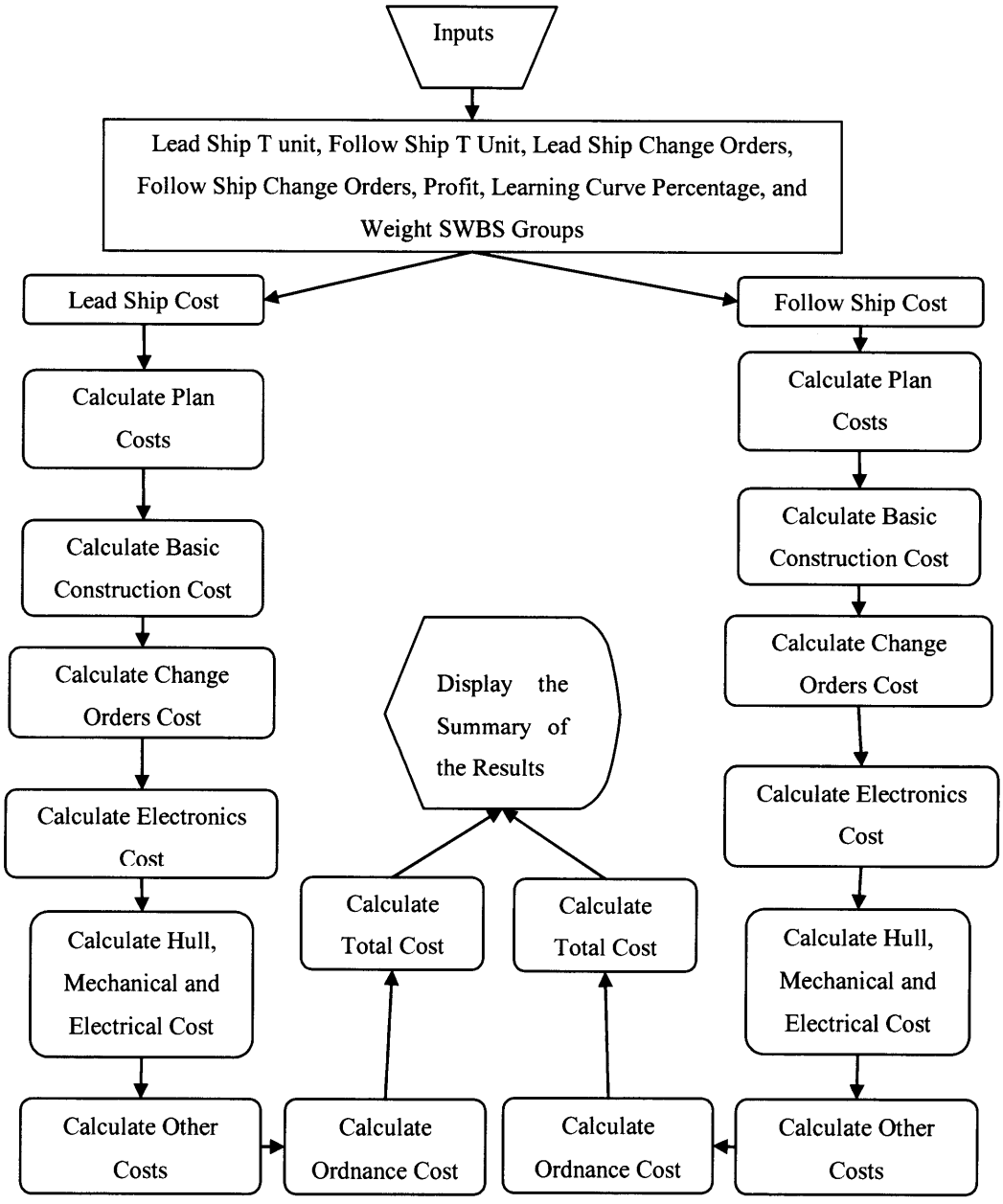
In addition to the seven main groups that breakdown a ship's weight, there are two other SWBS groups that are used in the cost estimation process: W_{800} and W_{900}.

W_{800} (Integration/Engineering) - The integration and engineering element refers to the engineering effort and related materials associated with the design and development of the ship. The work covered in this group includes the development and maintenance of drawings, production engineering, mass properties engineering, design support, quality assurance, integrated logistic support engineering, repair planning, and preparation and planning for special purpose items and systems.

W_{900} (Ship Assembly and Support Services) - The ship assembly element refers to work associated with ship construction and testing which is not included in the aforementioned groups. The elements in this group covers staging, scaffolding and cribbing, temporary utilities and services, molds, patterns, templates, jigs, fixtures, special production special tools and test

equipment, dry-docking, contractual and production support services, insurance, trials, tests and inspection, and delivery.

Table 29 Cost Module Flow Chart



Both for lead ship cost and follow ship cost, the outputs of the cost model are:

- Plan cost
- Basic construction cost
- Change orders cost
- Electronics cost
- Hull, mechanical and Electrical cost
- Other costs
- Ordnance
- Total cost

4.8 Summary of the Results

In this section, the summary of the results of ESCET are presented. Summary of the each module could be simply reviewed by selecting the pushbuttons on the *Home* page of ESCET. These pushbuttons are named on the *Home* page.

Figure 51 shows the summary of the hull module, which presents the basic hull dimensions and the characteristics of the ship.

Figure 52 shows the summary of the machinery module, which presents the name of the selected power plant for a given maximum speed, machinery space dimensions and BHPs.

Figure 53 shows the summary of the space module, which presents the estimations of the areas and volume.

Figure 54 shows the summary page for the weight module, which presents the SWBS groups, margins, light ship weight, full loads and full ship displacement.

Figure 55 shows the summary page for the stability module, which shows whether the ship is stable or not.

Figure 56 shows the summary of the cost module, which presents the basic construction costs for the lead ship and the follow ship based on 2005 inflation rates.

All of the summary pages have a printing option to help the user to have a hard copy of the data. The user could always select the *Home* pushbutton, then change the customer requirements and start analysis again for another run.

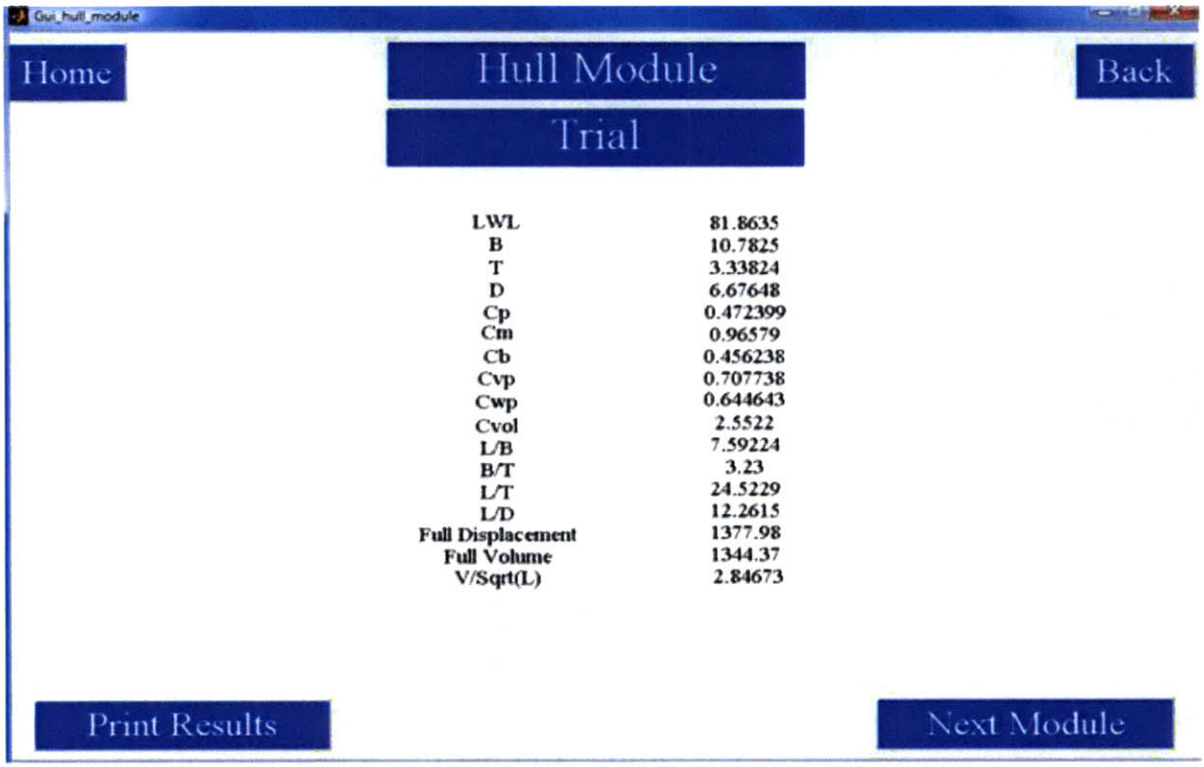


Figure 51 Hull Module; Summary of the Results

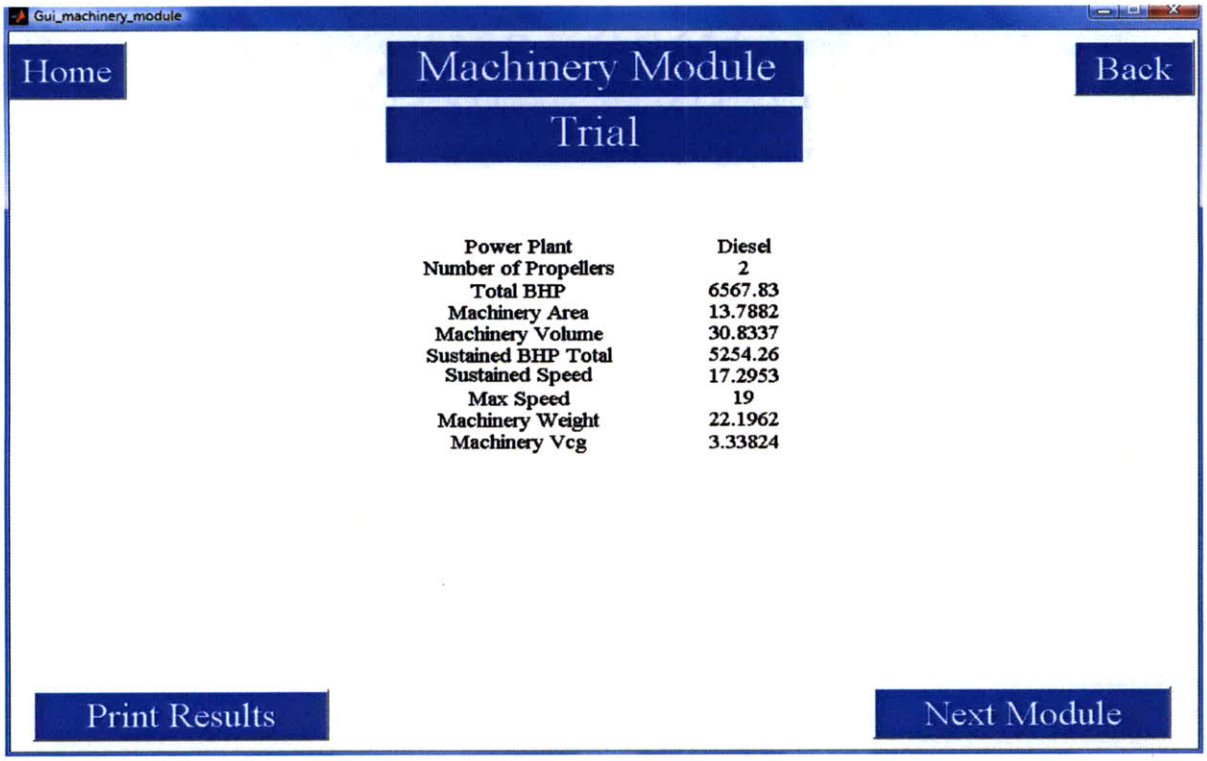
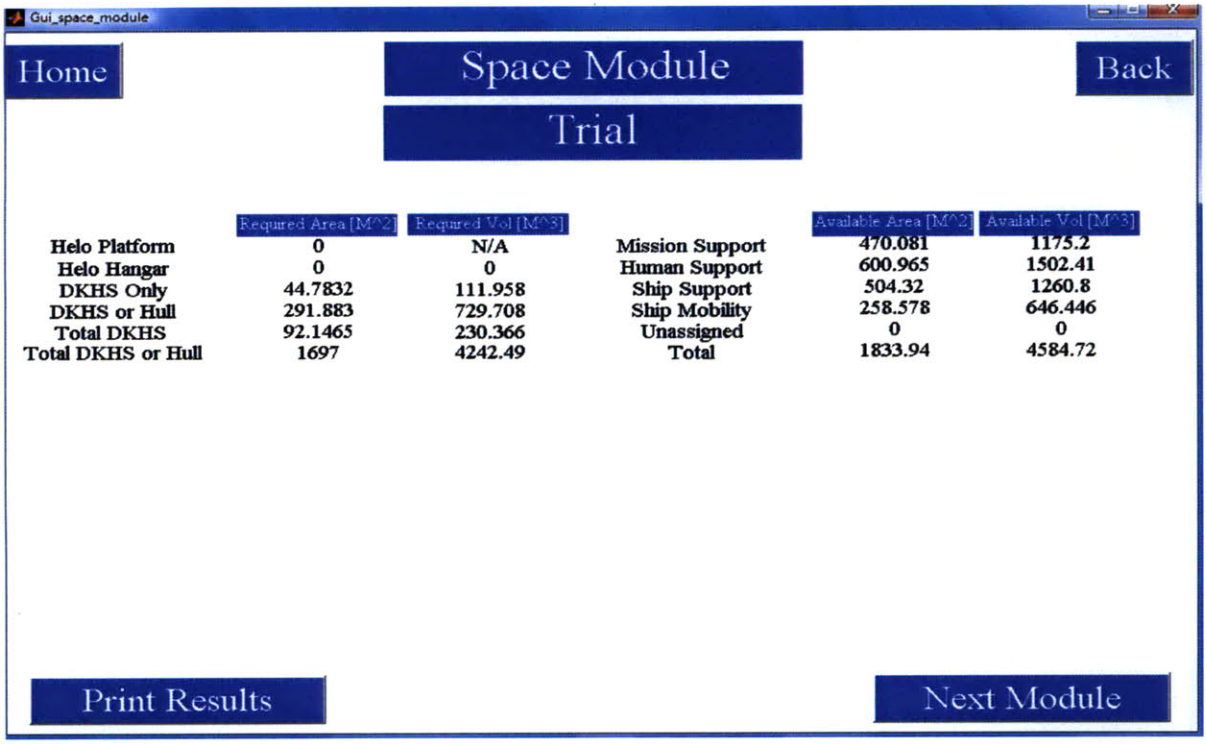
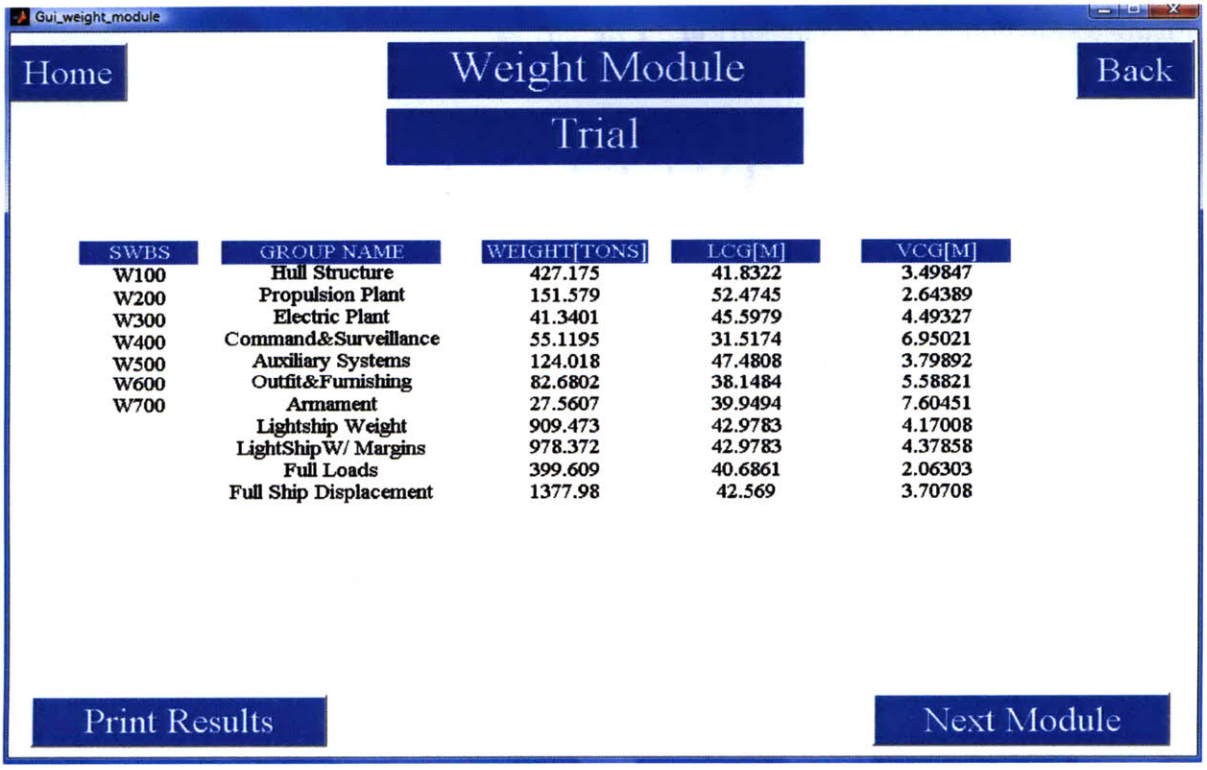


Figure 52 Machinery Module; Summary of the Results



	Required Area [M^2]	Required Vol [M^3]		Available Area [M^2]	Available Vol [M^3]
Helo Platform	0	N/A	Mission Support	470.081	1175.2
Helo Hangar	0	0	Human Support	600.965	1502.41
DKHS Only	44.7832	111.958	Ship Support	504.32	1260.8
DKHS or Hull	291.883	729.708	Ship Mobility	258.578	646.446
Total DKHS	92.1465	230.366	Unassigned	0	0
Total DKHS or Hull	1697	4242.49	Total	1833.94	4584.72

Figure 53 Space Module; Summary of the Results



SWBS	GROUP NAME	WEIGHT[TONS]	LCG[M]	VCG[M]
W100	Hull Structure	427.175	41.8322	3.49847
W200	Propulsion Plant	151.579	52.4745	2.64389
W300	Electric Plant	41.3401	45.5979	4.49327
W400	Command&Surveillance	55.1195	31.5174	6.95021
W500	Auxiliary Systems	124.018	47.4808	3.79892
W600	Outfit&Furnishing	82.6802	38.1484	5.58821
W700	Armament	27.5607	39.9494	7.60451
	Lightship Weight	909.473	42.9783	4.17008
	LightShipW/ Margins	978.372	42.9783	4.37858
	Full Loads	399.609	40.6861	2.06303
	Full Ship Displacement	1377.98	42.569	3.70708

Figure 54 Weight Module; Summary of the Results

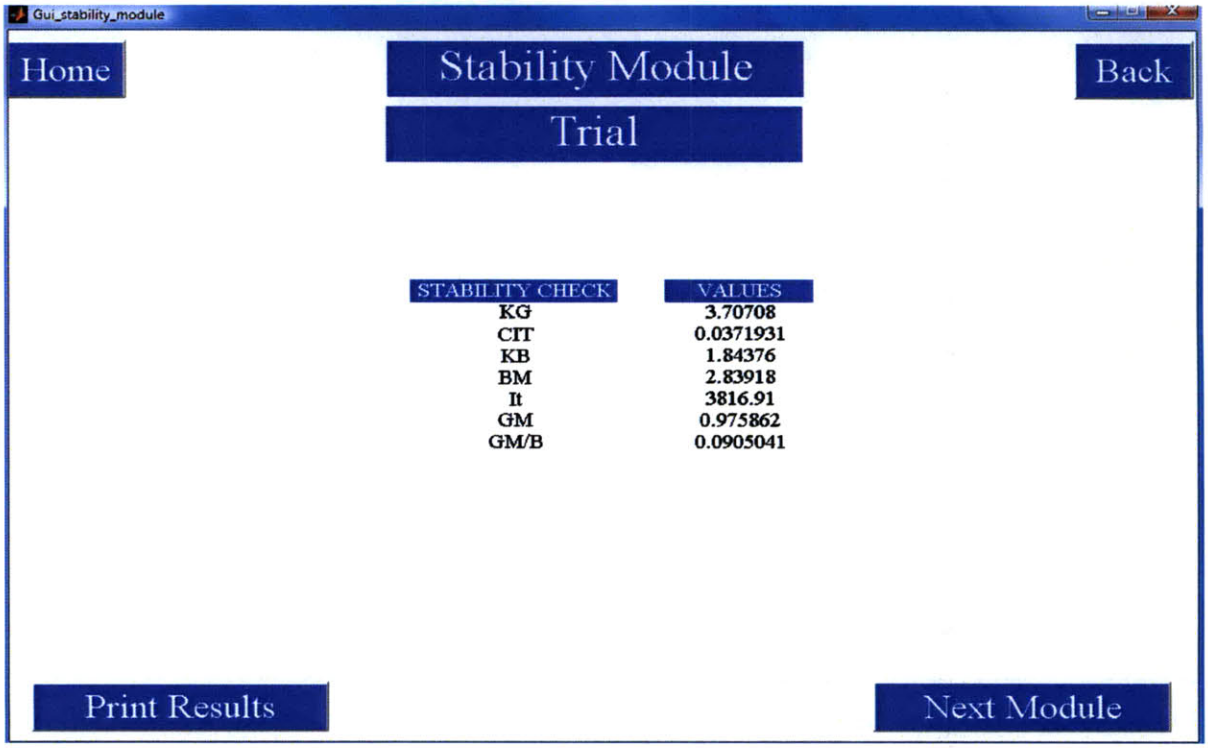


Figure 55 Stability Module; Summary of the Results

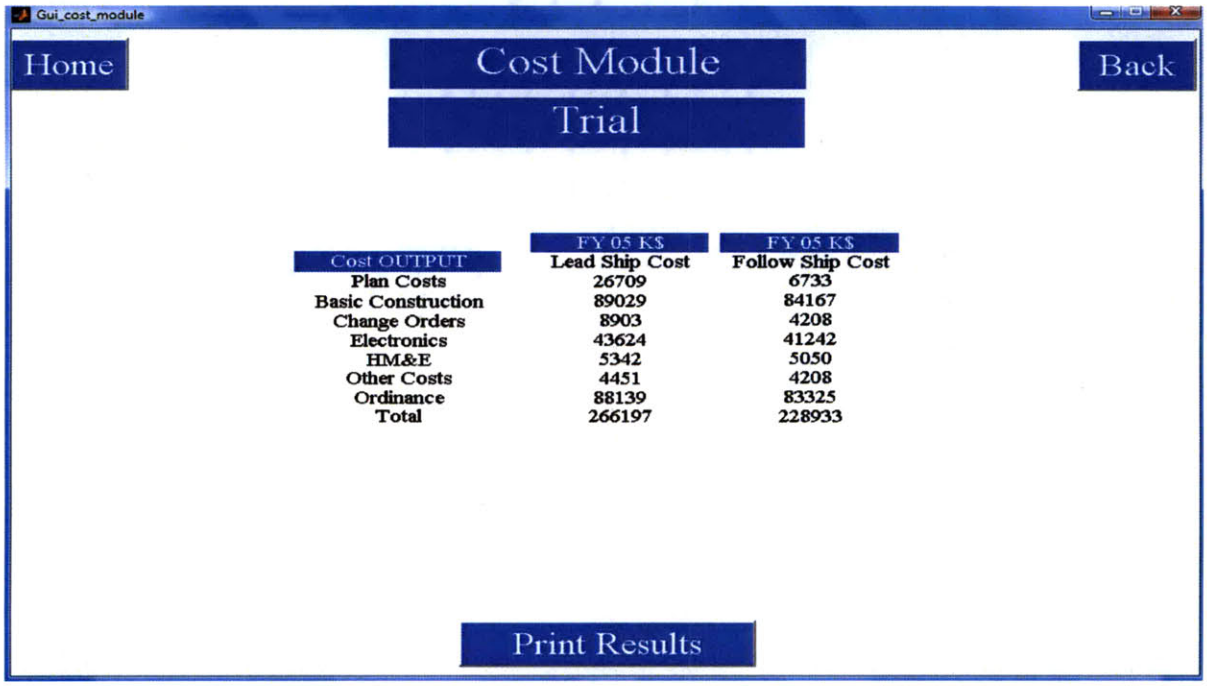


Figure 56 Cost Module; Summary of the Results

CHAPTER 5

5 Validation of the Early-Stage Design Tool

Validation of the early-stage design tool is carried out by using three different ships from the historical database. These ships are Kral J Petar Kresimir, Eilat (SAAR 5) and Robinson. These ships represent a cross section of the full load displacement range from 372 to 1850 tonnes. The actual full load displacements of these ships are:

- Kral J Petar Kresimir = 401 tonnes
- Eilat (SAAR 5) = 1295 tonnes
- Robinson =1836 tonnes

The validation process followed these steps as follows: Firstly, the customer requirements of these ships are entered into ESCET, secondly the historical comparison is carried out and lastly the analysis is held. The summary of the result are tabulated in the following pages and ESCET's screenshots are presented. The assessments of the results are presented at the end of this chapter.

5.1 Validation of ESCET using Kral J Petar Kresimir

"Kral J Petar Kresimir is the first of a 2-strong class of Croatian Kralj ("King") class missile boats (corvette). It is named after the Croatian king Petar Krešimir IV. It was built in the Kraljevica shipyard in 1991 and commissioned in 1992. It is an upgraded version of the Rade Končar missile boat class and is 8.5 meters longer. Kral J Petar Kresimir and its sister ship Kral J Dmitar Zvonimir are the only ships in their class. A potential third ship was under consideration in 1999, but the ship was never commissioned due to budget restraints.

The Kral J class ships are currently the largest warships within the Croatian navy. However, plans exist to purchase or domestically build four large corvettes or frigates. These will supplement existing missile boats and are scheduled to start entering service by 2012" [19] .

The validation of ESCET is performed using this ship's customer requirements. In the following pages, the customer requirements are entered into the program, historical comparison results are shown, the summary of the results are displayed and are tabulated.

5.1.1 Customer Requirements for the Kral J Petar Kresimir

Figure 57 shows the payloads and input page for the Kral J Petar Kresimir. The ship has a 30 mm AK/630M for the ship's AAW missions and Kolonka F/C unit for this gun system. The

ship has a Bofors 57 mm/70 Mk 2 gun system for ASuW missions and PEAB 9 LV 249 Mk2 F/C unit. The ship also has eight RBS-15 Mk 2 missiles for ASuW missions and the ship's F/C unit. The ship does not have any torpedoes; however it has RIZ PPM 10 M sonar. For ISR missions, the ship has Decca 1226 navigation radar and Racal Decca 2459 surface radar. The acquisition cost inputs are left default. The ship does not carry any helicopter on board and the ship does not require any helicopter missions. Manning on board follows: Officers =5, CPOs=12, Enlisted=12 and Total=29. The endurance inputs follow: Endurance Speed=18 KTS, Maximum Speed=36 KTS, Storage Days=30 Days, Range =1700 NM.

The customer requirements presented above are entered into the ESCET to run the analysis. Since the data on the F/C units were not available, ASSET's library is used for the required F/C units. The closest design for the required F/C units and the ships' specifications are entered into ESCET. The specifications of the sonar are also assumed to be the same as the SIMRAD 950 specifications. However, the other gun and missile systems' specifications are gathered and they are the exact values.

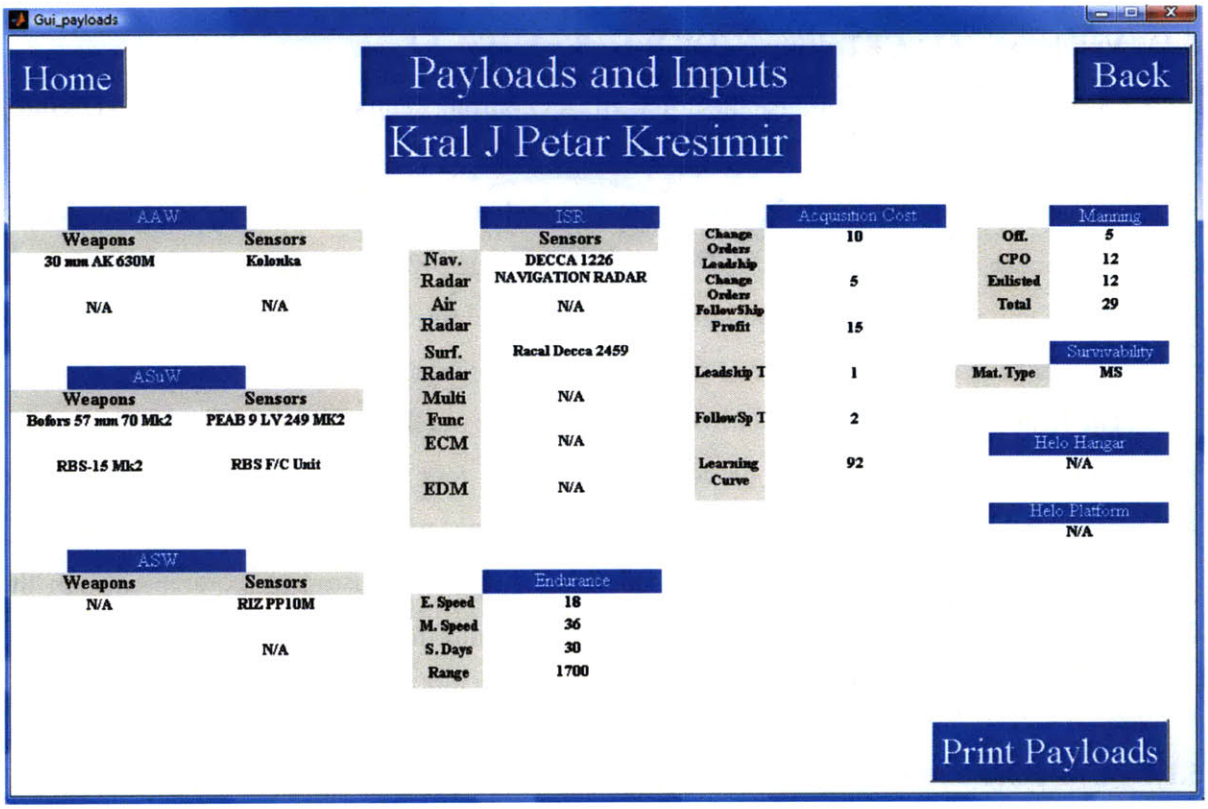


Figure 57 Customer Requirements for the Kral J Petar Kresimir

5.1.2 Validation of the Historical Comparison for Kral J Petar Kresimir

Since historical comparison part is one of the useful tools in ESCET, the validation of this tool was needed. The validation is held using the customer requirements of the ships mentioned in previous sections. Figure 58 shows the validation of historical comparison using the customer requirements of the Kral J Petar Kresimir. As expected, exact match shows the correct result for this ship and close match shows the closer designs for the desired requirements of this ship.

The historical comparison is carried out by just comparing the abilities of the ship. The historical comparison also compares the missions that they are not capable of and counts them. Kral J Petar Kresimir passes the statement of being able to carry out six missions (out of ten) to be the exact match for the desired customer requirements. Since PF 103 Bayandor and Serviola pass the statement of being able to carry out three missions (out of ten) to be close match, they appear at the close match section.

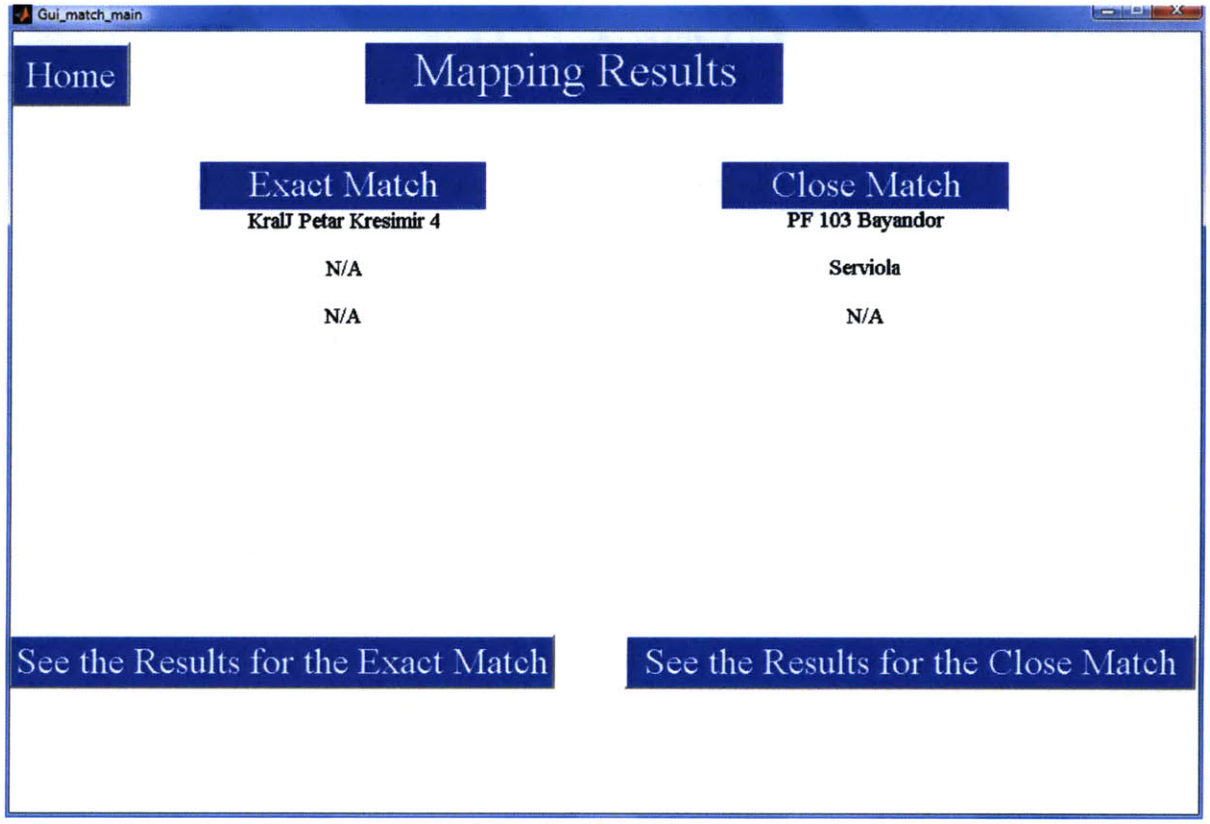


Figure 58 Validation of the Historical Comparison for the Kral J Petar Kresimir

5.1.3 Summary of the ESCET Results for the Kral J Petar Kresimir

The following pages present the summary of the results for the Kral J Petar Kresimir. Figure 59 shows the hull module summary, which is displayed by ESCET. The summary of the results are tabulated in Table 30 as well. As presented in Figure 59 and Table 30, LWL is calculated 52.21 meters. B is 8.38 meters, T is 2.59 meters and C_B is 0.410. As it is presented on Table 30, C_m equals to 0.961 where the actual value equals to 0.959. The hull module estimated the C_m within 1% error. C_{wp} coefficient is also estimated within 1% error. The larger error percentages in the hull module occur in the estimation of D and T, which is shown in the Table 39. The average error for the hull module is 8.26%.

Figure 60 shows the machinery module summary displayed by ESCET. ESCET concludes the power plant of this ship to be a CODOG. However, actual power plant of Kral J Petar Kresimir is Diesel. This error is because of the fact that Kral J Petar Kresimir does not present common power plant type for corvettes. Table 30 presents the other specifications for the machinery of this ship.

Figure 61 presents the space module summary displayed by ESCET. The space module estimations present area, volume requirements and the assignments of these spaces for the Kral J Petar Kresimir. Since the actual allocation of the ship could not be gathered the comparison is not possible on the space module. The space allocation is presented in the Table 31.

Figure 62 displays SWBS groups for the ship. ESCET calculates that the full load displacement of the ship is 478.20 tonnes. This calculation shows an approximate 20% error. The assessment of the ship is described in the following sections. Figure 62 also presents the vertical center of the gravity for each weight group and longitudinal center of gravity. The results of the weight module are also tabulated in Table 31. Figure 63 shows the stability characteristics of the analyzed hull. As it is presented, the GM_T /B ratio is between 0.05 and 0.15, which is the requirement for the corvettes. Figure 64 shows the cost module summary.

The cost module and the stability module results are tabulated in Table 32 as well. The comparison between the actual data and ESCET's outputs are tabulated in section 5.4.

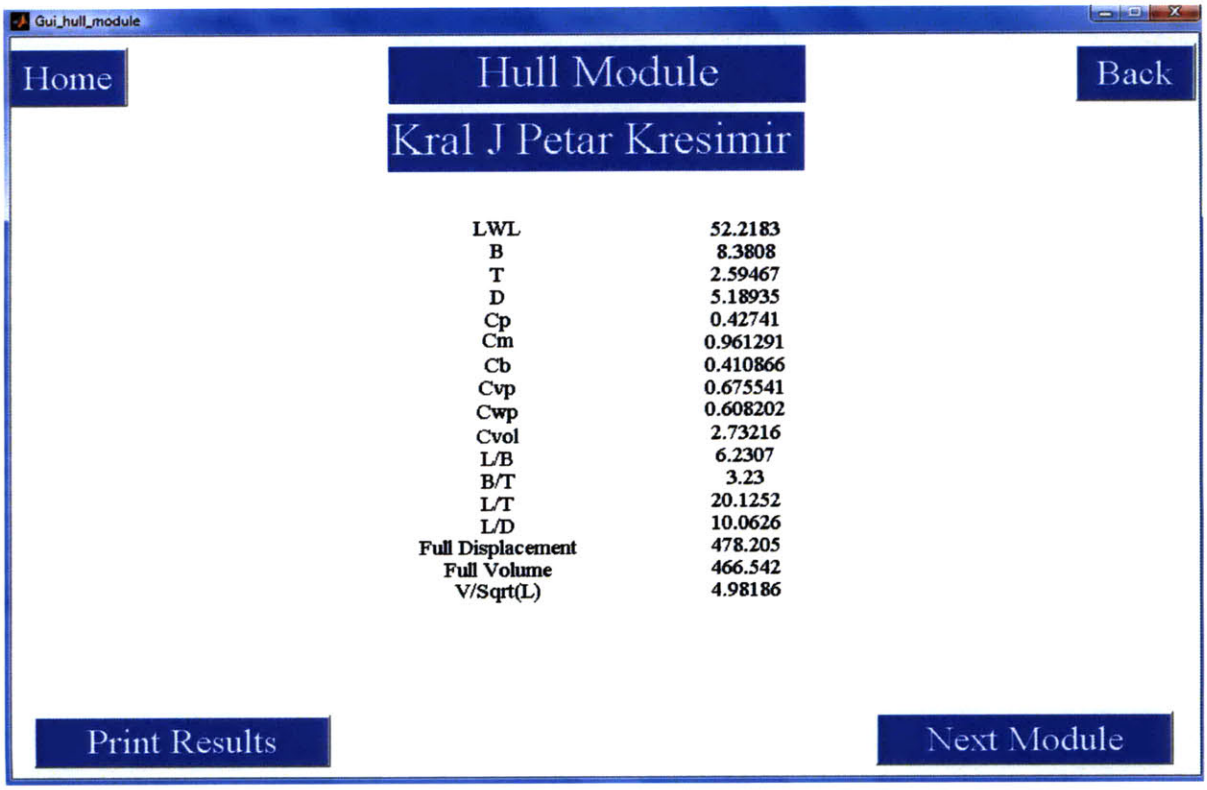
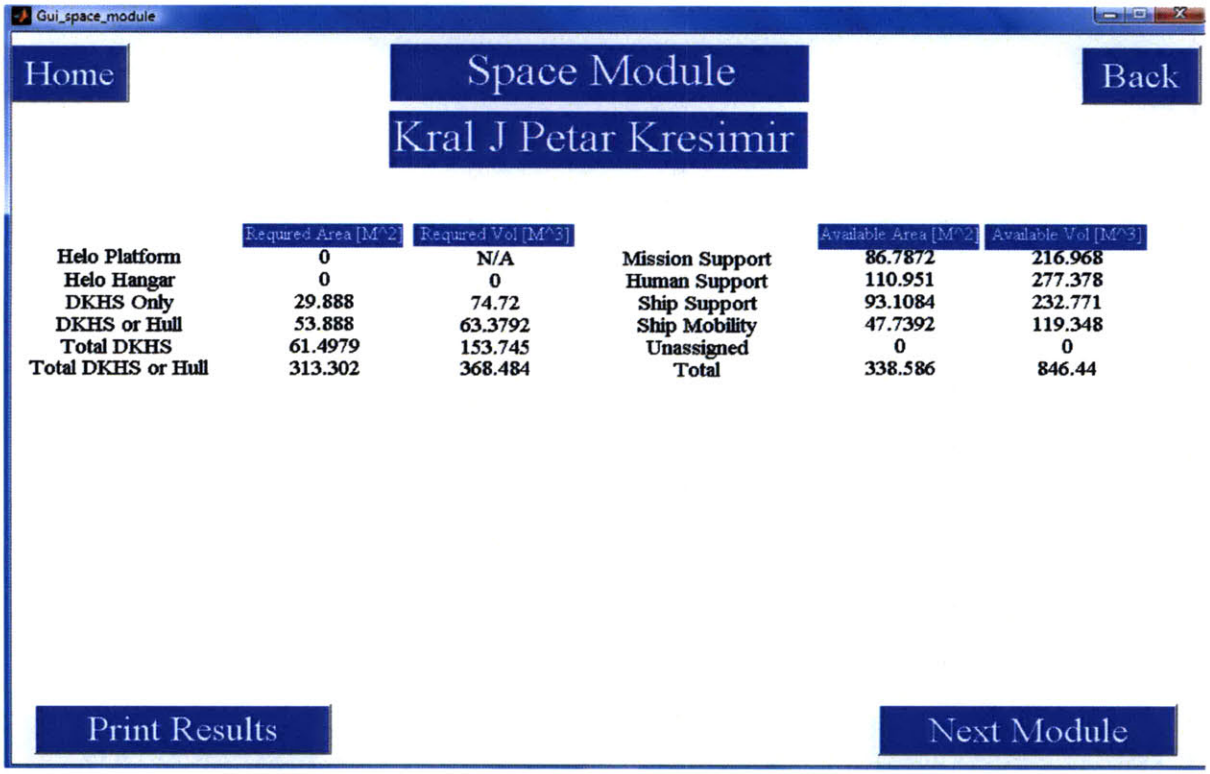


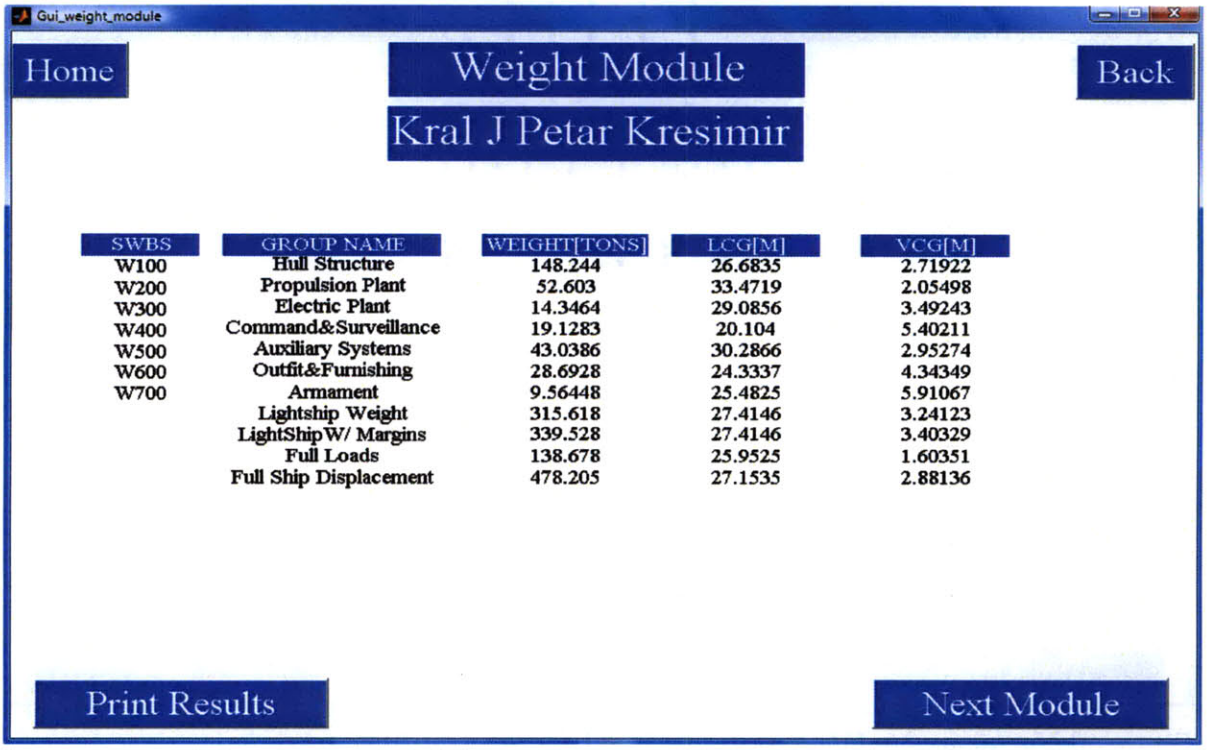
Figure 59 Hull Module Results of ESCET for the Kral J Petar Kresimir

Figure 60 Machinery Module Results of ESCET for the Kral J Petar Kresimir



	Required Area [M^2]	Required Vol [M^3]		Available Area [M^2]	Available Vol [M^3]
Helo Platform	0	N/A	Mission Support	86.7872	216.968
Helo Hangar	0	0	Human Support	110.951	277.378
DKHS Only	29.888	74.72	Ship Support	93.1084	232.771
DKHS or Hull	53.888	63.3792	Ship Mobility	47.7392	119.348
Total DKHS	61.4979	153.745	Unassigned	0	0
Total DKHS or Hull	313.302	368.484	Total	338.586	846.44

Figure 61 Space Module Results of ESCET for the Kral J Petar Kresimir



SWBS	GROUP NAME	WEIGHT[TONS]	LCG[M]	VCG[M]
W100	Hull Structure	148.244	26.6835	2.71922
W200	Propulsion Plant	52.603	33.4719	2.05498
W300	Electric Plant	14.3464	29.0856	3.49243
W400	Command&Surveillance	19.1283	20.104	5.40211
W500	Auxiliary Systems	43.0386	30.2866	2.95274
W600	Outfit&Furnishing	28.6928	24.3337	4.34349
W700	Armament	9.56448	25.4825	5.91067
	Lightship Weight	315.618	27.4146	3.24123
	LightShipW/ Margins	339.528	27.4146	3.40329
	Full Loads	138.678	25.9525	1.60351
	Full Ship Displacement	478.205	27.1535	2.88136

Figure 62 Weight Module Results of ESCET for the Kral J Petar Kresimir

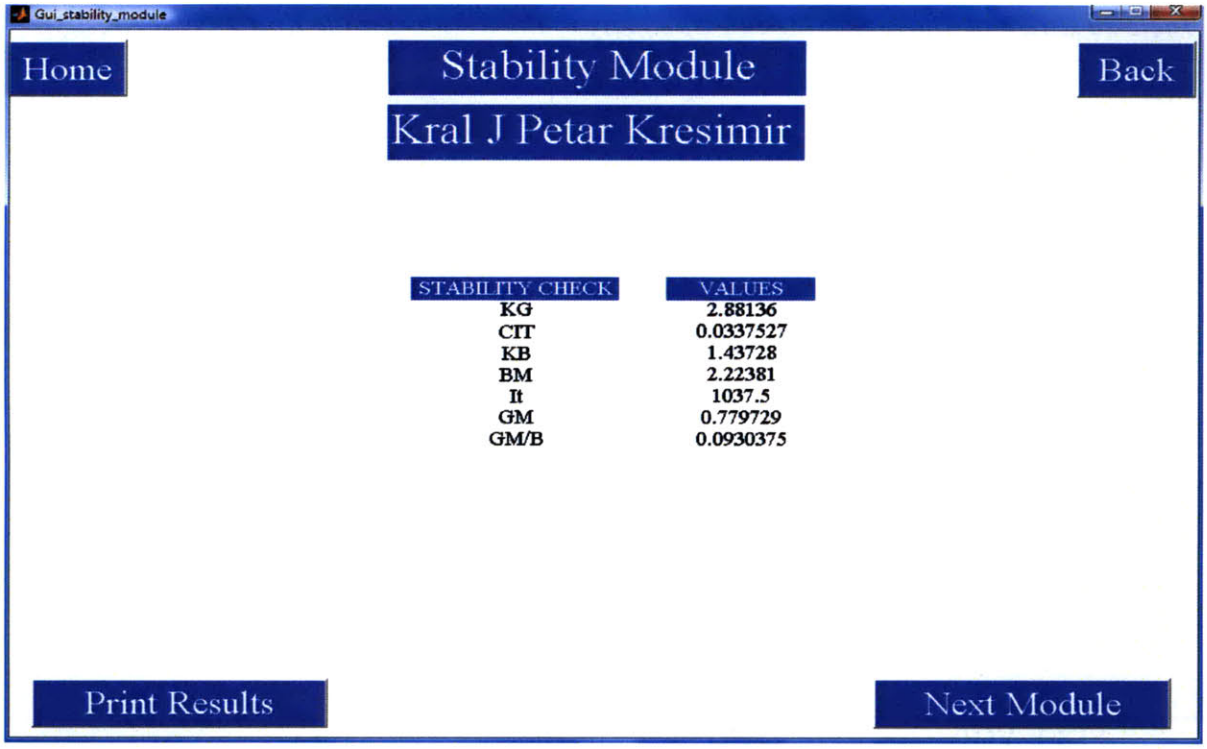


Figure 63 Stability Module Results of ESCET for the Kral J Petar Kresimir

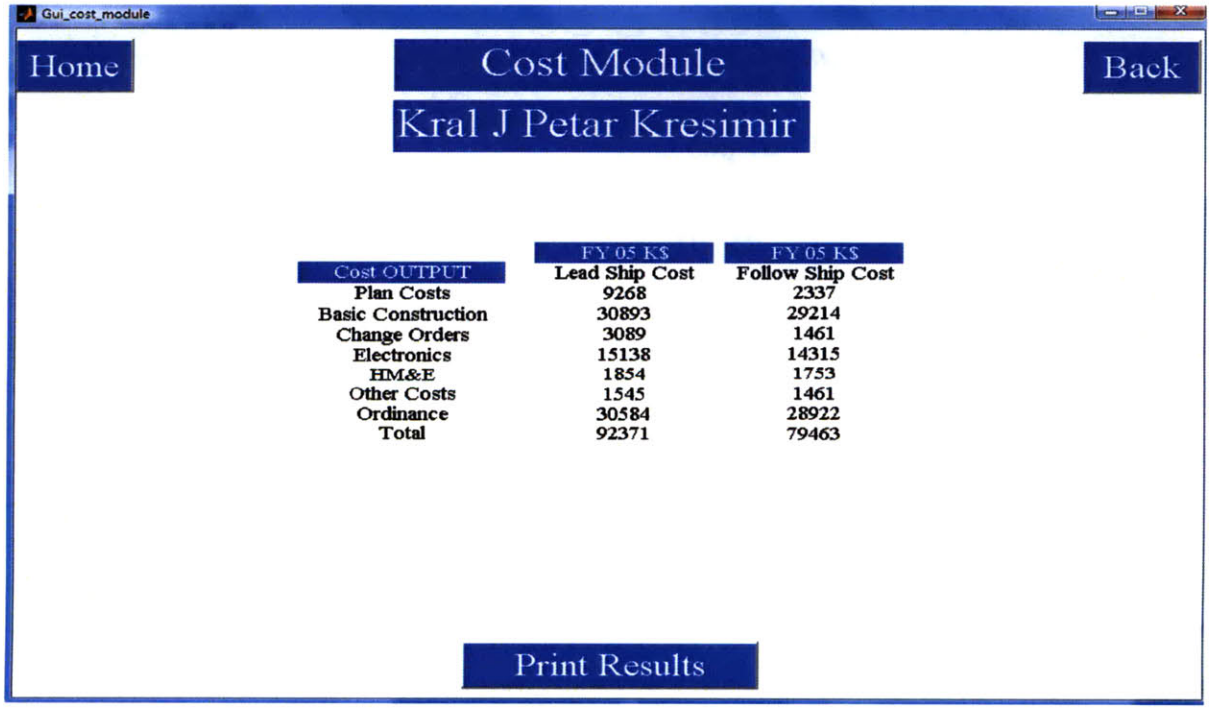


Figure 64 Cost Module Results of ESCET for the Kral J Petar Kresimir

Table 30 Hull and Machinery Module Summary of the Results for the Kral J Petar Kresimir

Hull Module		Machinery Module	
LWL	52.21	**Power Plant**	CODOG
B	8.38	**Number of Prop**	2.00
T	2.59	**Total BHP**	34142.70
D	5.18	**Machinery Area**	41.09
C_P	0.427	**Machinery Volume**	116.92
C_m	0.961	**Sustained BHP Total**	27314.2
C_B	0.41	**Sustained Speed**	31.21
C_{vp}	0.675	**Max Speed**	36
C_{wp}	0.608	**Machinery Vcg**	2.59
C_{vol}	2.73		
L/B	6.23		
B/T	3.23		
L/T	20.12		
L/D	10.06		
Δ_{Full}	478.2		
FULL VOL	466.542		
V/SQRT(LWL)	4.98		

Table 31 Space and Weight Module Summary of the Results for the Kral J Petar Kresimir

Space Module			Weight Module			
	Available Area	**Available Volume**	**SWBS**	**Weight**	**LCG**	**VCG**
Mission Support	86.78	216.97	**100**	148.24	26.68	2.71
Human Support	110.95	277.38	**200**	52.60	33.47	2.05
Ship Support	93.10	232.77	**300**	14.34	29.08	3.49
Ship Mobility	47.73	119.35	**400**	19.12	20.10	5.40
Unassigned	0.00	0.00	**500**	43.03	30.28	2.95
Total	338.59	846.44	**600**	28.69	24.33	4.34
			700	9.56	25.48	5.91
			Light Ship	315.62	27.41	3.24
			Light Ship w/ Margins	339.53	27.41	3.40
			Full Loads	138.68	25.95	1.60
			Full Load Displacement	478.21	27.15	2.88

Table 32 Stability and Cost Module Summary of the Results for the Kral J Petar Kresimir

Stability Module		Cost Module		
			Lead Ship Cost	Follow Ship Cost
KG	2.88	Plan Costs	9268	2337
C_{IT}	0.0337	Basic Construction	30893	29214
KB	1.44	Change Orders	3089	1461
BM	2.22	Electronics	15138	14315
I_t	1037.5	HM&E	1854	1753
GM	0.779	Other Costs	1545	1461
GM_T/B	0.093	Ordnance	30584	28922
		Total	92371	79463

5.2 Validation of ESCET using Eilat (SAAR 5)

"Eilat (SAAR 5) is a class of Israeli navy corvette, designed based on lessons learned from the SAAR 4.5 class ships. Three Sa'ar 5 ships were built by Northrop Grumman Ship Systems (formerly Litton-Ingalls Shipbuilding Corporation of Pascagoula, Mississippi) for the Israeli Navy, based on Israeli designs. Eilat (SAAR 5) ships are the Israeli fleet's most advanced surface ships, costing US$ 260 million each." [20]

"The first of class, INS Eilat (SAAR 5), was launched in February 1993, followed by INS Lahav in August 1993 and INS Hanit in March 1994." [20]

The validation of ESCET is carried out using this ship's customer requirements. In the following pages, the customer requirements are entered into the program, the historical comparison results are shown, the summary of the results are displayed and are tabulated.

5.2.1 Customer Requirements for the Eilat (SAAR 5)

Figure 65 shows the payloads and input page for the Eilat (SAAR 5). As presented, the ship has three different mission capabilities. The ship has Sea Vulcan CIWS 20 mm for its AAW missions and Mk 16 F/C unit for this gun system. The ship also has Barak 1 surface to air missiles for AAW missions. For ASuW missions, the ship has Oto Melara 76/62 mm Mod 7 Compact gun and Oto Melara F/C unit. The ship also has eight Harpoon RGM 84A surface to surface missiles for ASuW missions and its F/C unit. The Eilat (SAAR 5) uses Honeywell Mk 46 Mod 5 torpedoes, and its sonar system is EDO Type 796 Mod 1. ASW F/C unit specifications are also assumed to be as same as ASSET's ASW F/C unit. For ISR missions, it has FFG type navigation radar, Elta ELM 2218 S air radar, Cardion SPS-55 surface radar, Elisra NS 9003

ECM and Rafael 1010 EDM. Manning on board follows: Officers =20, CPOs=25, Enlisted=29 and Total=74. The acquisition cost inputs are left default. The ship can conduct helicopter missions on board; however it cannot carry any helicopter on board. The endurance inputs follow: Endurance Speed=17 KTS, Maximum Speed=33 KTS, Storage Days=45 Days and Range =3500 NM.

The customer requirements mentioned above are entered into the ESCET to run the analysis. Since the data on the F/C units were not available, ASSET's library is used to find the required F/C units. The closest design is searched for the required F/C unit and its specifications are entered into the program. The specifications of the sonar are also assumed to be the same as the SIMRAD 950 specifications. However, the other gun and missile systems' specifications are gathered and they are the exact values.

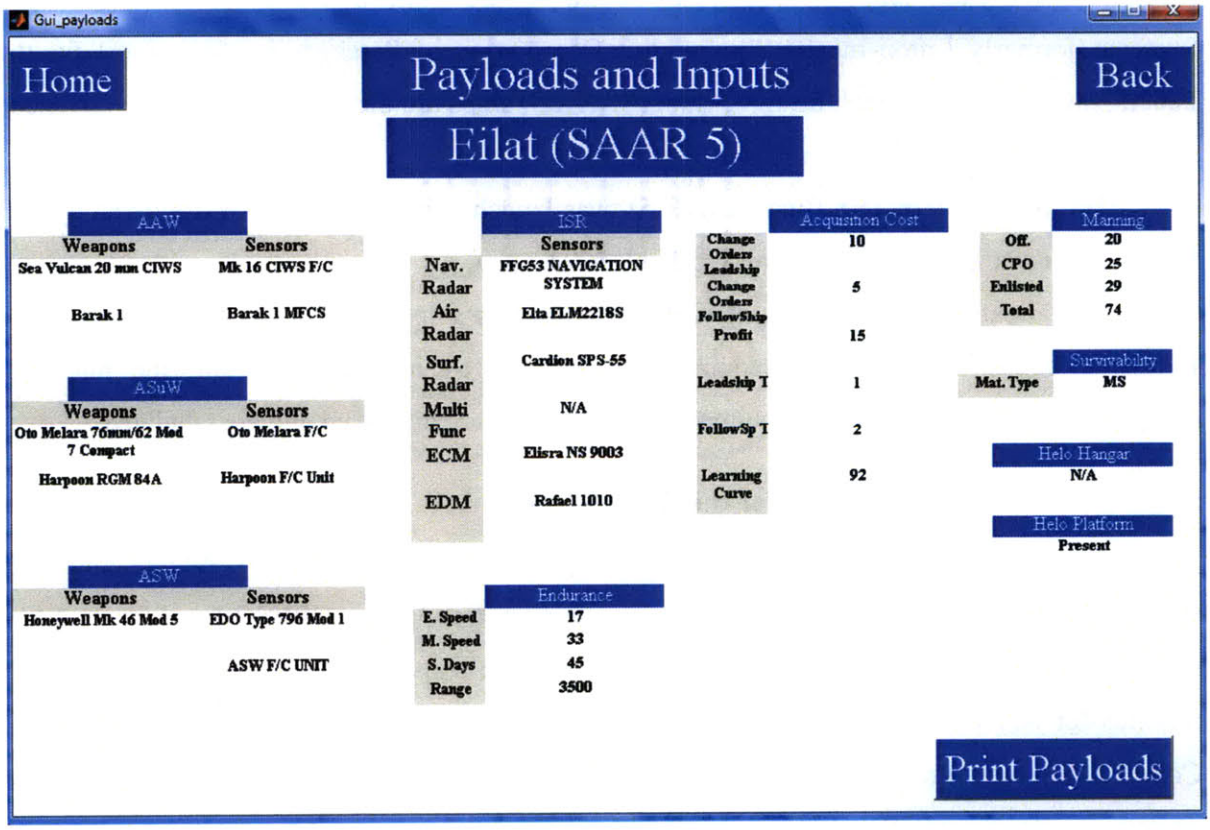


Figure 65 Customer Requirements for the Eilat (SAAR 5)

5.2.2 Validation of the Historical Comparison for Eilat (SAAR 5)

Figure 66 shows the validation of historical comparison tool using the parameters of the Eilat (SAAR 5). As presented, exact match presents the correct result for this ship and close match shows the closer designs for the desired requirements of this ship.

Eilat (SAAR 5) passes the statement of being able to carry out eight missions (out of ten) to be the exact match for the desired customer requirements. Since HTMS Rattanakosin, Pohang and Descubierta have the same gun systems and the same torpedo systems as the Eilat (SAAR 5); they are presented as the closer design for these customer requirements. They pass the statement of being able to carry out three missions (out of ten) to be close match, they appear at the close match section.

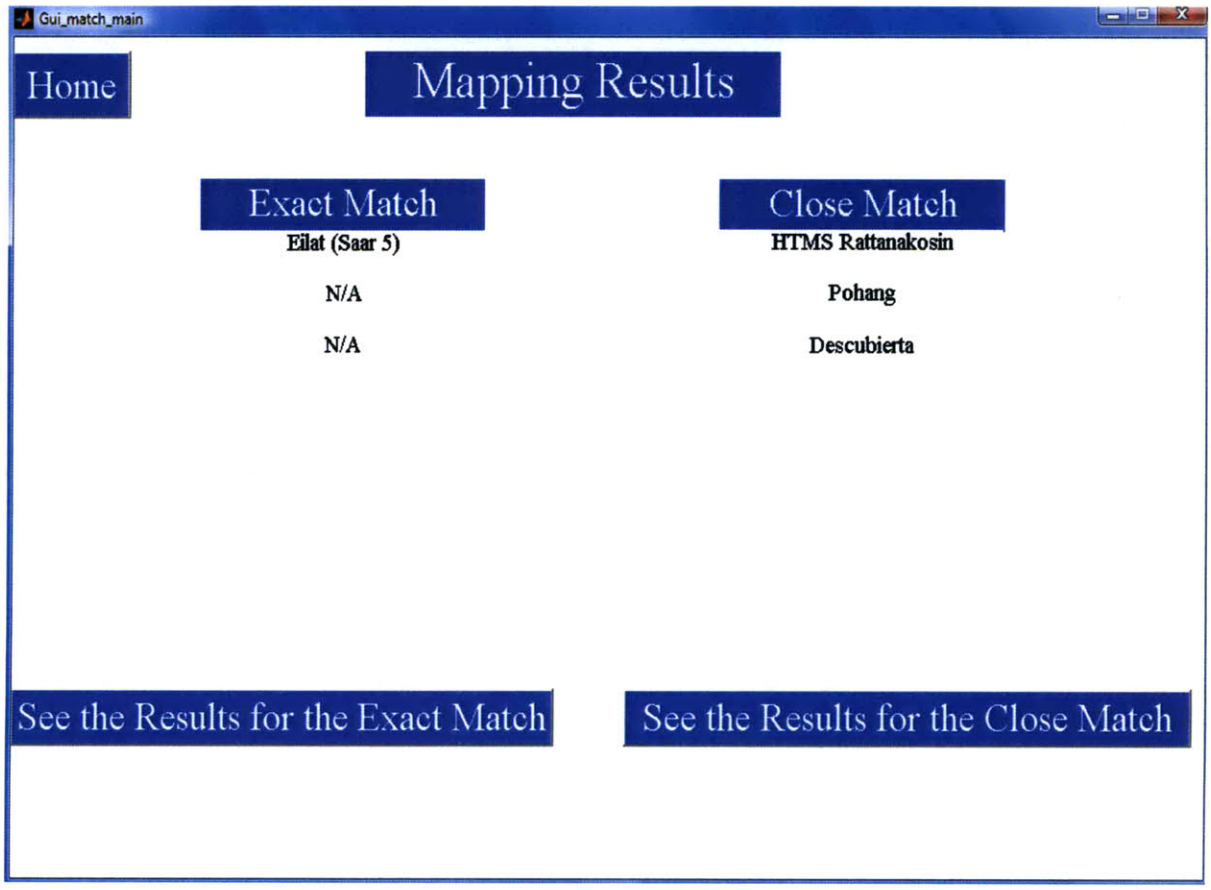


Figure 66 Validation of the Historical Comparison for the Eilat (SAAR 5)

5.2.3 Summary of the ESCET Results for the Eilat (SAAR 5)

The following pages present the summary of the results for the Eilat Saar 5. Figure 67 shows the hull module summary, which is the screenshot from ESCET's hull module. As tabulated in Table 33, LWL is calculated 78.93 meters. B is calculated 10.50 meters, T is calculated 3.25 meters and C_B is calculated 0.449. C_m is calculated as 0.965 where the actual data in the historical database is 0.960. The hull module estimated the C_m within 1% error. However, the LWL is estimated within 4% error, while D and T are calculated within 2% error. The summary of the results is tabulated in Table 33.

Figure 68 shows the machinery module summary, displayed by ESCET, which concludes the power plant of this ship to be a CODAG. However, the actual power plant of this ship is CODOG. This error is because of the fact that this ship falls into the same lane for the CODAG and CODOG power plant. Table 33 summarizes the other specifications for the machinery of this ship.

Figure 69 displays the space module summary screenshot from ESCET. These space module estimations present area allocations, volume requirements for the Eilat Saar 5. Since the actual data on allocation of the ship's areas could not be gathered, the comparison of this module could not be carried out. The space allocations are tabulated in Table 34 as well.

Figure 70 displays SWBS groups for the ship. ESCET calculates that the full load displacement of the ship is 1241.21 tonnes. This calculation shows an approximate 5% error. The assessment of the remaining SWBS group is described in the following sections. The summary of the weight module is tabulated in Table 34. Figure 70 also presents the vertical center of the gravity and longitudinal center of gravity for each weight group.

Figure 71 presents the stability characteristics of the analyzed hull. As presented in the figure, the GM_T/B ratio is between 0.05 and 0.15, which is the requirement for corvettes. Figure 72 shows the cost module summary.

The stability and the cost module summary of the results are tabulated in Table 35 as well. The comparison between the actual data and ESCET's outputs are tabulated in section 5.4.

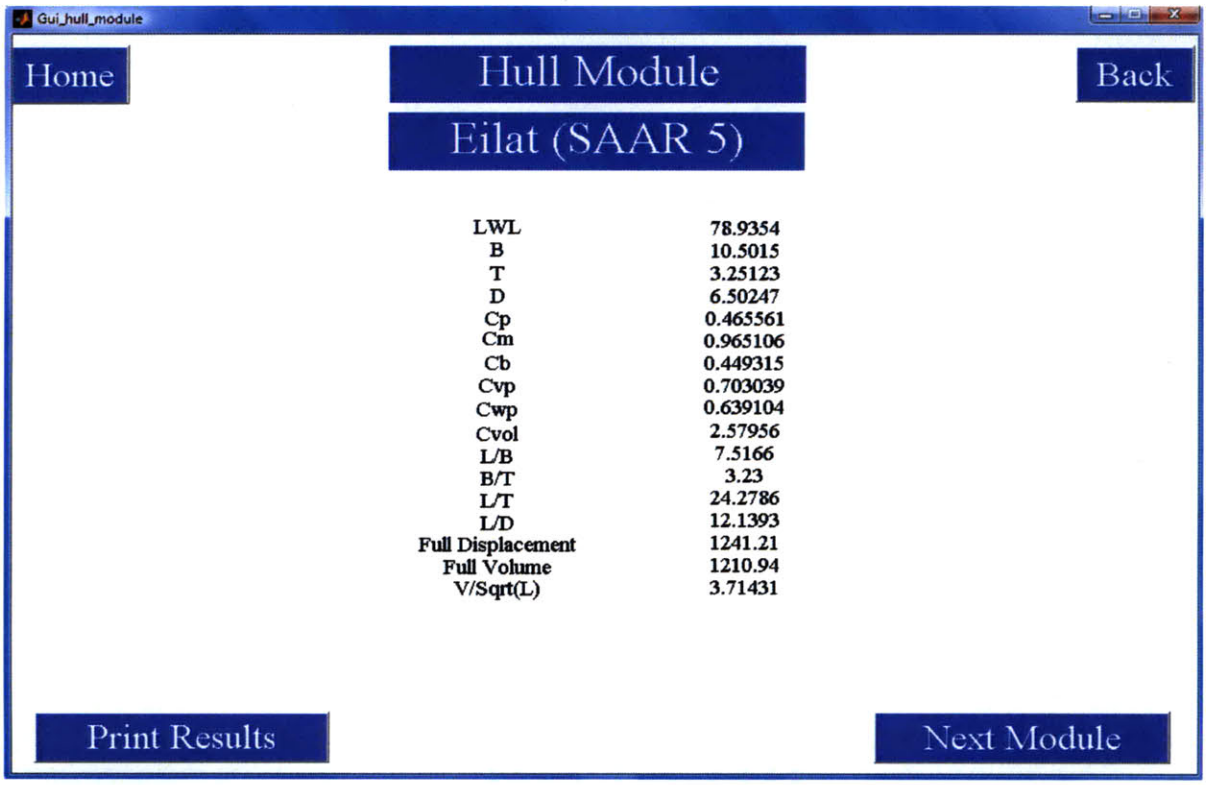


Figure 67 Hull Module Results of ESCET for the Eilat (SAAR 5)

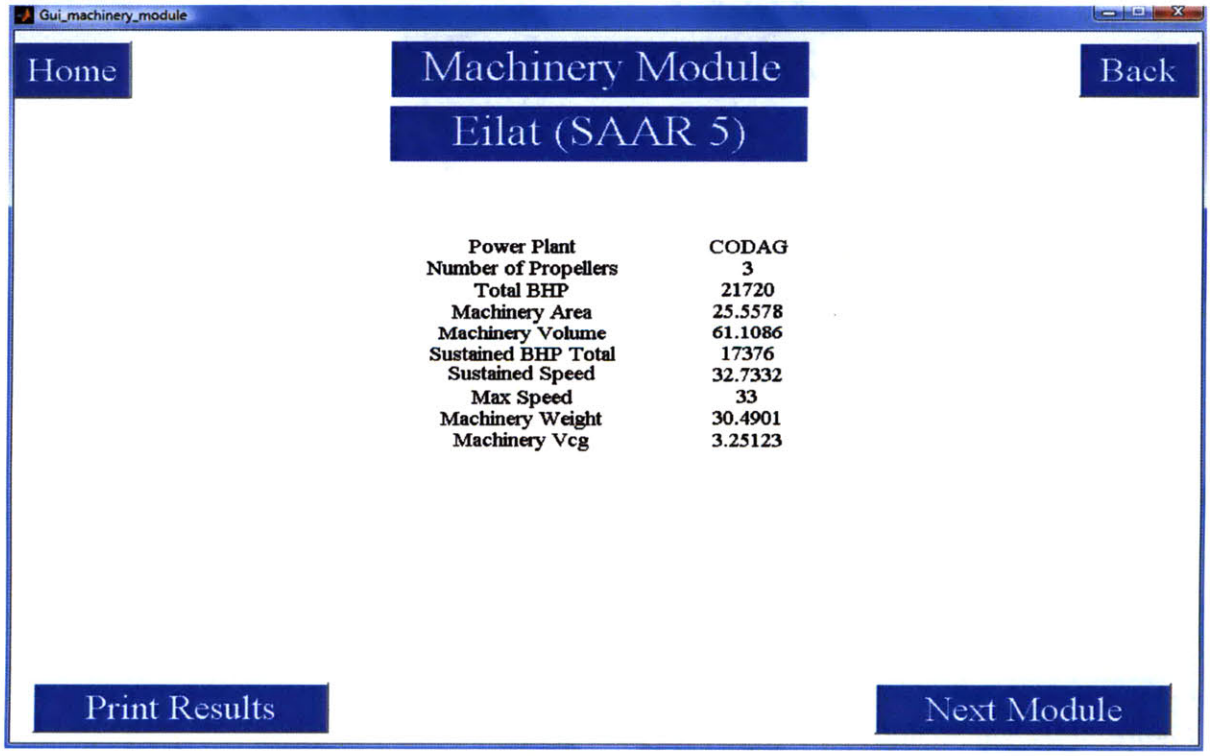
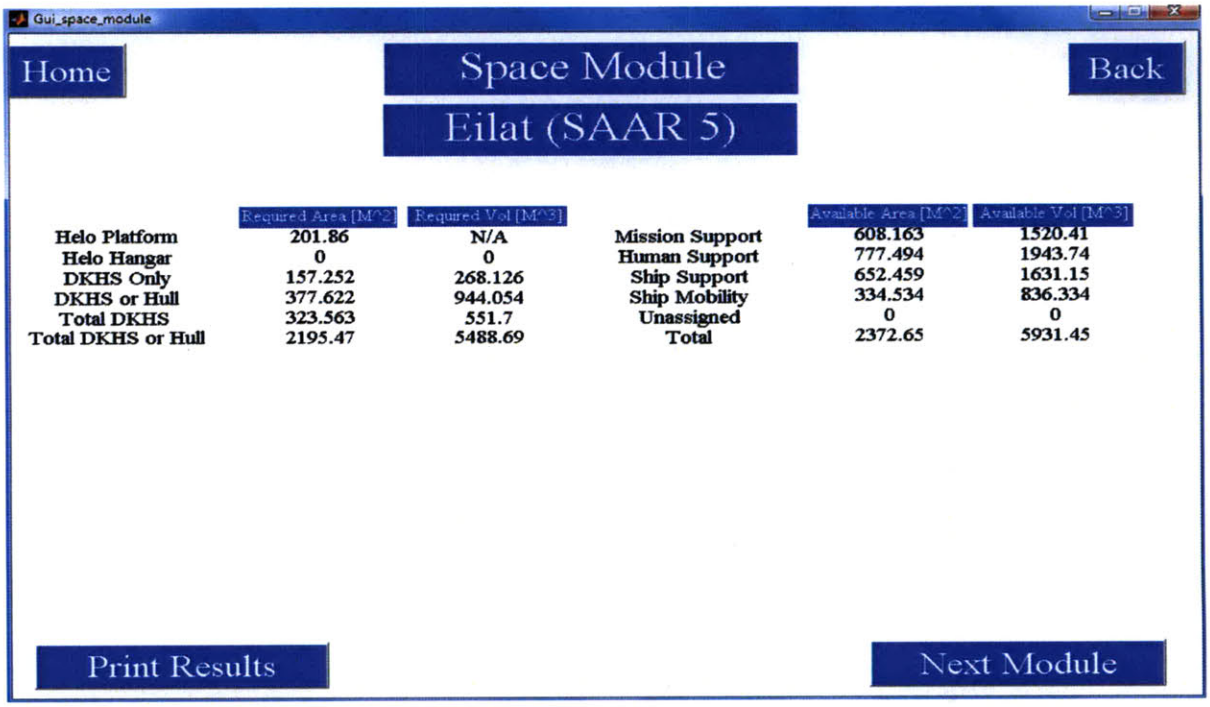
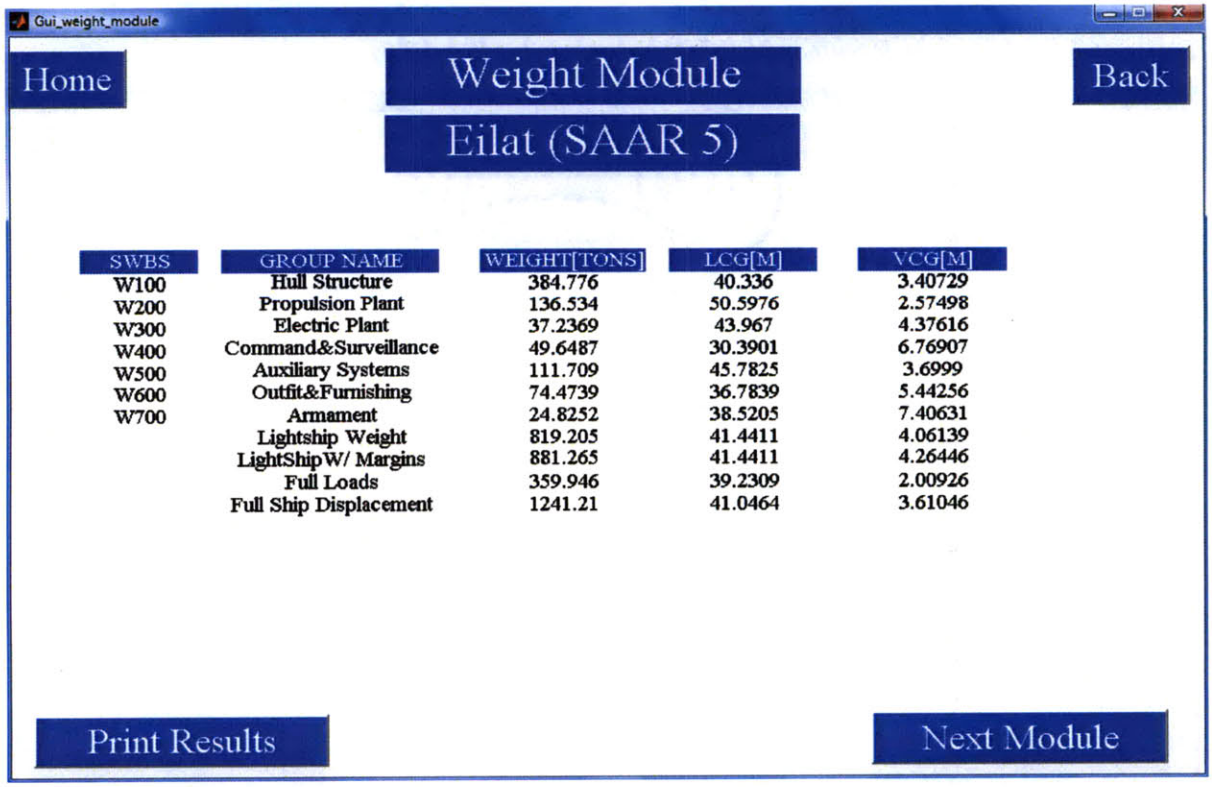


Figure 68 Machinery Module Results of ESCET for the Eilat (SAAR 5)



	Required Area [M^2]	Required Vol [M^3]		Available Area [M^2]	Available Vol [M^3]
Helo Platform	201.86	N/A	Mission Support	608.163	1520.41
Helo Hangar	0	0	Human Support	777.494	1943.74
DKHS Only	157.252	268.126	Ship Support	652.459	1631.15
DKHS or Hull	377.622	944.054	Ship Mobility	334.534	836.334
Total DKHS	323.563	551.7	Unassigned	0	0
Total DKHS or Hull	2195.47	5488.69	Total	2372.65	5931.45

Figure 69 Space Module Results of ESCET for the Eilat (SAAR 5)



SWBS	GROUP NAME	WEIGHT[TONS]	LCG[M]	VCG[M]
W100	Hull Structure	384.776	40.336	3.40729
W200	Propulsion Plant	136.534	50.5976	2.57498
W300	Electric Plant	37.2369	43.967	4.37616
W400	Command&Surveillance	49.6487	30.3901	6.76907
W500	Auxiliary Systems	111.709	45.7825	3.6999
W600	Outfit&Furnishing	74.4739	36.7839	5.44256
W700	Armament	24.8252	38.5205	7.40631
	Lightship Weight	819.205	41.4411	4.06139
	LightShipW/ Margins	881.265	41.4411	4.26446
	Full Loads	359.946	39.2309	2.00926
	Full Ship Displacement	1241.21	41.0464	3.61046

Figure 70 Weight Module Results of ESCET for the Eilat (SAAR 5)

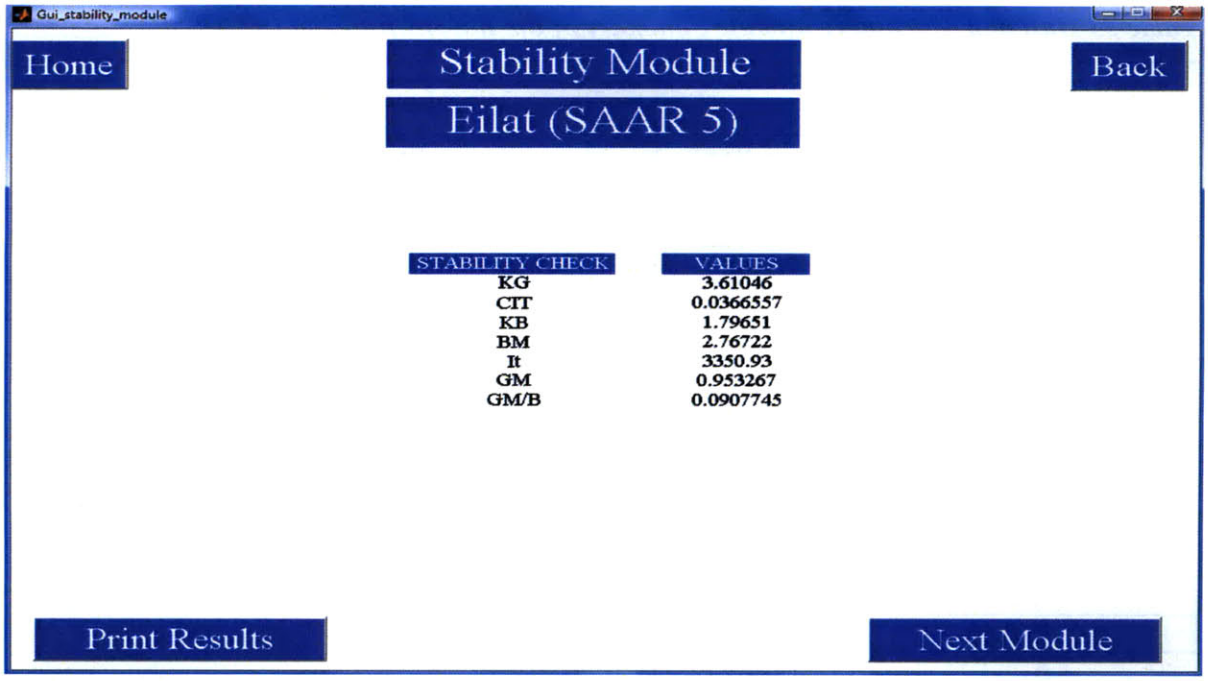


Figure 71 Stability Module Results of ESCET for the Eilat (SAAR 5)

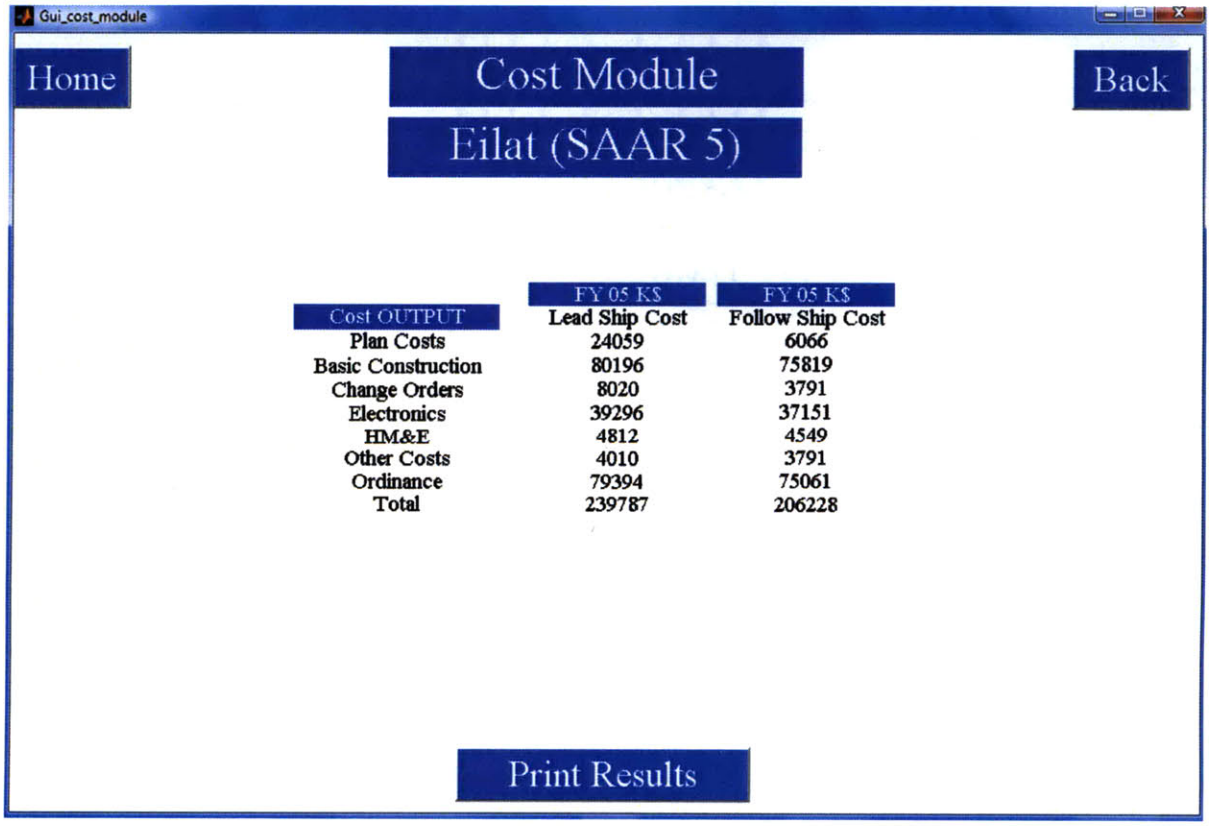


Figure 72 Cost Module Results of ESCET for the Eilat (SAAR 5)

Table 33 Hull and Machinery Module Summary of the Results for Eilat (SAAR 5)

Hull Module		Machinery Module	
LWL	78.93	**Power Plant**	CODAG
B	10.50	**Number of Prop**	3.00
T	3.25	**Total BHP**	21720.00
D	6.50	**Machinery Area**	25.55
C_P	0.465	**Machinery Volume**	61.1
C_m	0.965	**Sustained BHP Total**	17376
C_B	0.449	**Sustained Speed**	32.733
C_{vp}	0.703	**Max Speed**	33
C_{wp}	0.639	**Machinery Vcg**	3.25
C_{vol}	2.57		
L/B	7.51		
B/T	3.23		
L/T	24.27		
L/D	12.13		
Δ_{Full}	1241.21		
FULL VOL	1210.94		
V/SQRT(LWL)	3.71		

Table 34 Space and Weight Module Summary of the Results for the Eilat (SAAR 5)

Space Module			Weight Module			
	Available Area	**Available Volume**	**SWBS**	**Weight**	**LCG**	**VCG**
Mission Support	608.16	1520.41	**100**	384.78	40.33	3.40
Human Support	777.49	1943.74	**200**	136.53	50.59	2.57
Ship Support	653.45	1631.15	**300**	37.23	43.96	4.37
Ship Mobility	334.53	836.33	**400**	49.64	30.39	6.76
Unassigned	0.00	0.00	**500**	111.7	45.78	3.69
Total	2372.65	5931.45	**600**	74.47	36.78	5.44
			700	24.82	38.52	7.40
			Light Ship	819.21	41.44	4.06
			Light Ship w/ Margins	881.27	41.44	4.26
			Full Loads	359.95	39.23	2.00
			Full Load Displacement	1241.21	41.04	3.61

Table 35 Stability and Cost Module Summary of the Results for the Eilat (SAAR 5)

Stability Module		Cost Module		
			Lead Ship Cost	Follow Ship Cost
KG	3.61	Plan Costs	24059	6066
C_{IT}	0.0366	Basic Construction	80196	75819
KB	1.79	Change Orders	8020	3791
BM	2.76	Electronics	39296	37151
I_t	3350.93	HM&E	4812	4549
GM	0.95	Other Costs	4010	3791
GM_T/B	0.090	Ordnance	79394	75061
		Total	239787	206228

5.3 Validation of ESCET using the Robinson

"ARA Robinson (P-45) is the fifth ship of the MEKO 140A16 Espora series of six corvettes built for the Argentine Navy. The ship is the second ship to bear the name of Captain Carlos Robinson, who fought in the Argentine Navy during the Argentina-Brazil Warand died commanding a squadron of gunboats during the Battle of La Colonia." [21]

"Robinson and her sister ships were part of the 1974 Naval Constructions National Plan, an initiative by the Argentine Navy to replace old World War II-vintage ships with more advanced warships. The original plan called for six MEKO 360H2 destroyers, four of them to be built in Argentina, but the plan was later modified to include four MEKO destroyers and six corvettes for anti-surface warfare and patrol operations."[21]

The validation of ESCET is carried out using this ship's customer requirement. In the following pages, the customer requirements are entered into the program, historical comparison results are shown, the summary of the results are displayed and are tabulated.

5.3.1 Customer Requirements for the Robinson

Figure 73 shows the payloads and input page for the Robinson. As presented in the figure, the ship has three different mission capabilities. The ship has two Oto Breda 40mm/70 Twin guns for its AAW missions and Signaal SEWACO F/C unit for this gun system. The ship does not have any surface to air missiles for AAW missions. For ASuW missions, the ship has Oto Melara 76mm/62 Mod 7 Compact gun and Oto Melara F/C unit. The ship also has eight Exocet MM38 surface to surface missiles for ASuW missions and its F/C unit. Robinson uses

Whitehead A244/SPS torpedoes, and its sonar system is Atlas ASO 4. ASW F/C unit specifications are also assumed to be as same as ASSET's ASW F/C unit. For ISR, it has Decca 1226 type navigation radar, Signaal DA 05 multi-functional radar, Racal RQN-3-B ECM and Racal TQN-2X EDM. Manning on board follows: Officers =11, CPOs=20, Enlisted=60 and Total=91.The acquisition cost inputs are left default. The ship can conduct helicopter missions on board; however it cannot carry any helicopter on board. The endurance inputs follow: Endurance Speed=18 KTS, Maximum Speed=27 KTS, Storage Days=30 Days and Range =4000 NM.

The customer requirements mentioned above are entered into the ESCET in order to run the analysis. Since the data on the F/C units were not available, we used the ASSET's library for the required F/C units. The closest design for the required F/C unit is searched and its specifications are entered into the program. The specifications of the sonar are also assumed to be the same as the SIMRAD 950 specifications. However, the other gun and missile systems' specifications are gathered and they are the exact values.

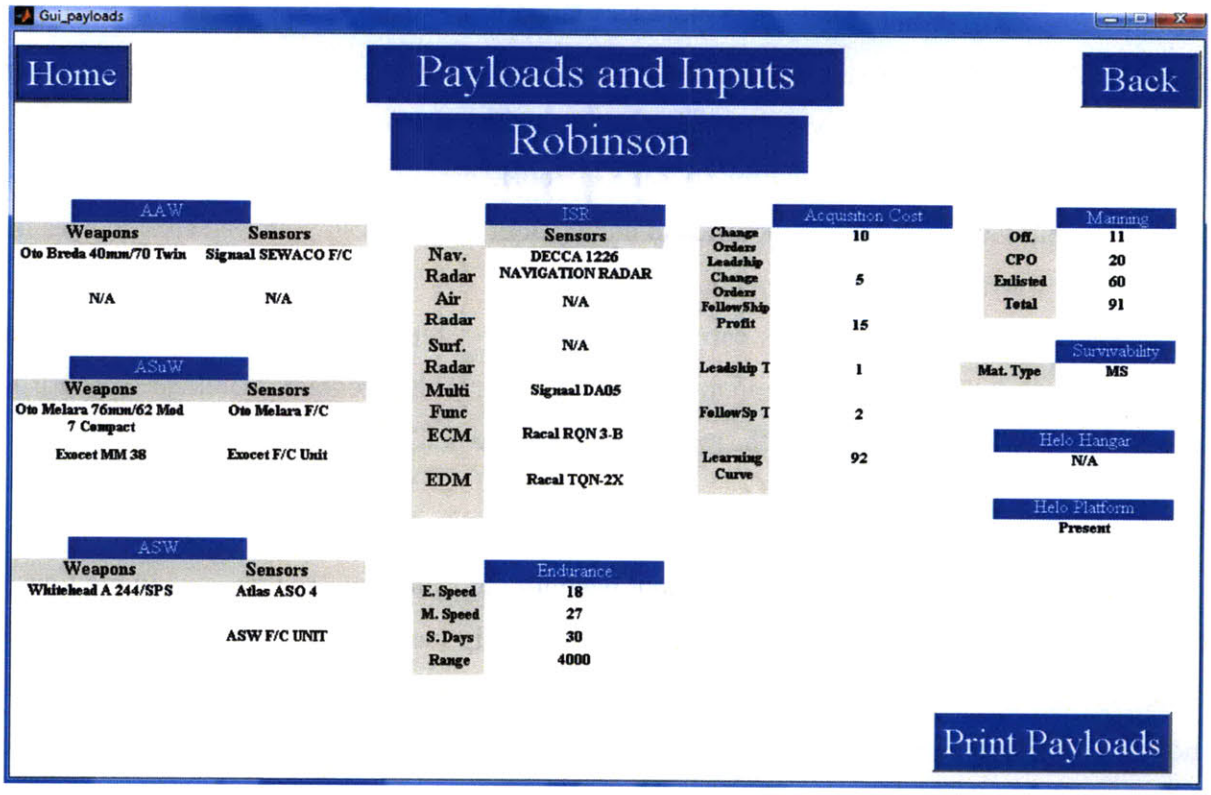


Figure 73 Customer Requirements for the Robinson

5.3.2 Validation of the Historical Comparison for Robinson

Figure 74 shows the validation of historical comparison tool using the parameters of the Robinson. As it is shown in the figure, exact match presents the correct result for this ship and close match presents the closer designs for the desired requirements of this ship. However, Figure 74 also shows the Eilat (SAAR 5) as the exact match, this is because of the fact that historical comparison is carried out by just comparing the abilities of the ship. Historical comparison also compares the missions that they are not capable of and counts them. This is the fact that these two ships pass the statement of being able to carry out six missions (out of ten) to be the exact match for the desired customer requirements. Since Pohang and Descubierta have the same gun systems and the same torpedo systems as the Robinson has, they are presented as the closer design for these customer requirements.

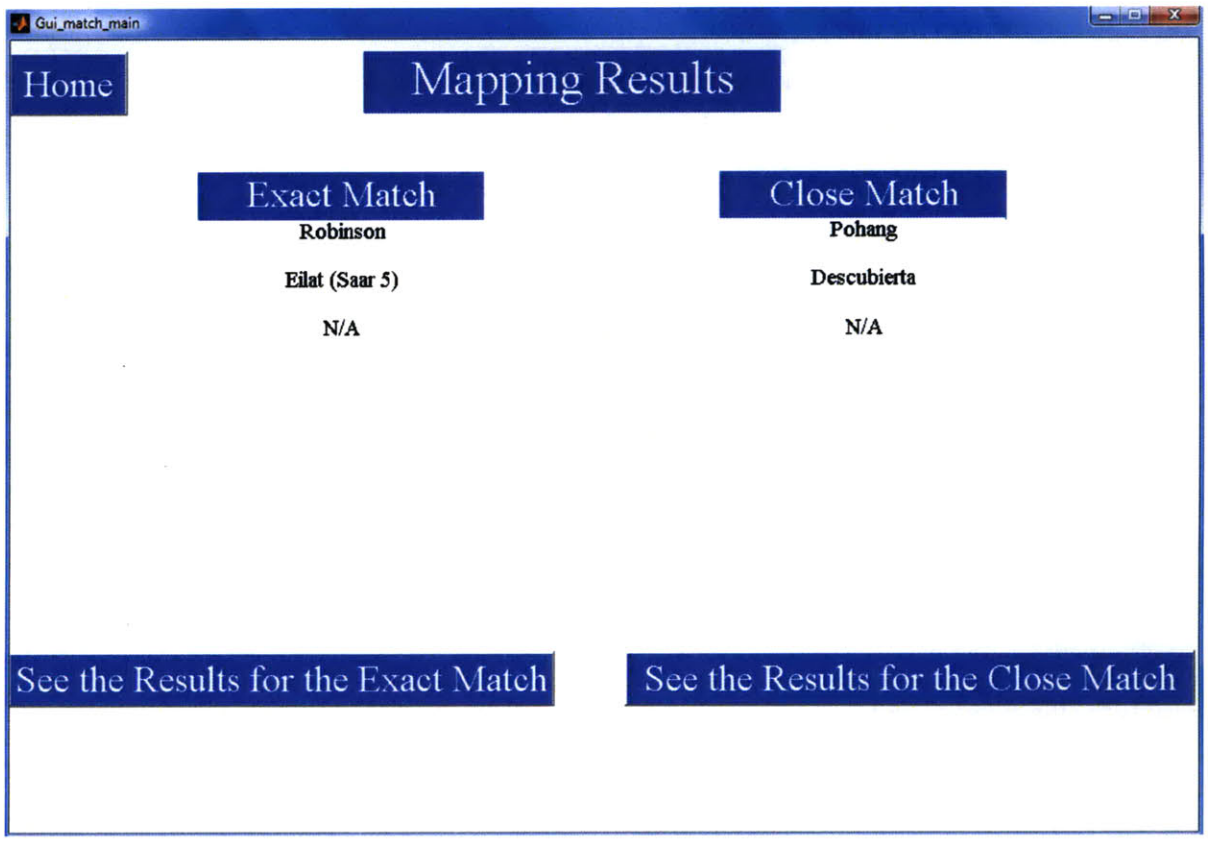


Figure 74 Validation of the Historical Comparison for the Robinson

5.3.3 Summary of the ESCET Results for the Robinson

The following pages present the summary of the results for the Robinson. Figure 75 shows the hull module summary screenshot from ESCET. As presented in Figure 75, LWL is calculated 89.95 meters. B is 11.59 meters, T is 3.58 meters and C_B is 0.495. As shown in Table 36, C_m is estimated 0.968 where the actual value equals to 0.972. ESCET estimated C_m within 1% error. However, the LWL of the ship is calculated as 89.95 meters where the actual value equals to 86.60. This result shows an approximate 4% error. The summary of the results are tabulated in Table 36.

Figure 76 shows the machinery module screenshot from ESCET, which concludes the power plant of this ship to be a CODAD. However, the actual power plant is Diesel. This error occurs because of the fact that Robinson is excluded from design lanes since its engine do not represent current technology, common power plant and common number of shafts for corvettes. Table 36 summarizes the other specifications for the machinery module.

Figure 77 presents the space module summary screenshot from ESCET. Since the actual data on the allocation of the spaces could not be gathered, the comparison of the results could not be carried out. Table 37 presents the summary of the space module results.

Figure 78 displays SWBS groups for the ship. ESCET estimated that the full load displacement of the ship is 1839.63 tonnes, where the actual full load displacement of the ship equals to 1850. This result shows a significant convergence to the actual data. The error percentage is only 1%. The assessment of the weight module is described in the following sections. Figure 78 also presents the vertical center of the gravity and the longitudinal center of gravity for each weight group. The summary of the results is tabulated in Table 37.

Figure 79 shows the stability characteristics of the analyzed hull. As presented, the analyzed hull's GM_T /B ratio is between 0.05 and 0.15, which is the requirement for the corvettes. Figure 80 presents the screen shot for the cost module summary. The summary of the results for the stability and cost module is tabulated in Table 38.

The assessments of these three ships are described in the following pages. The error percentages and the difference between the actual data and ESCET results are shown in section 5.4.

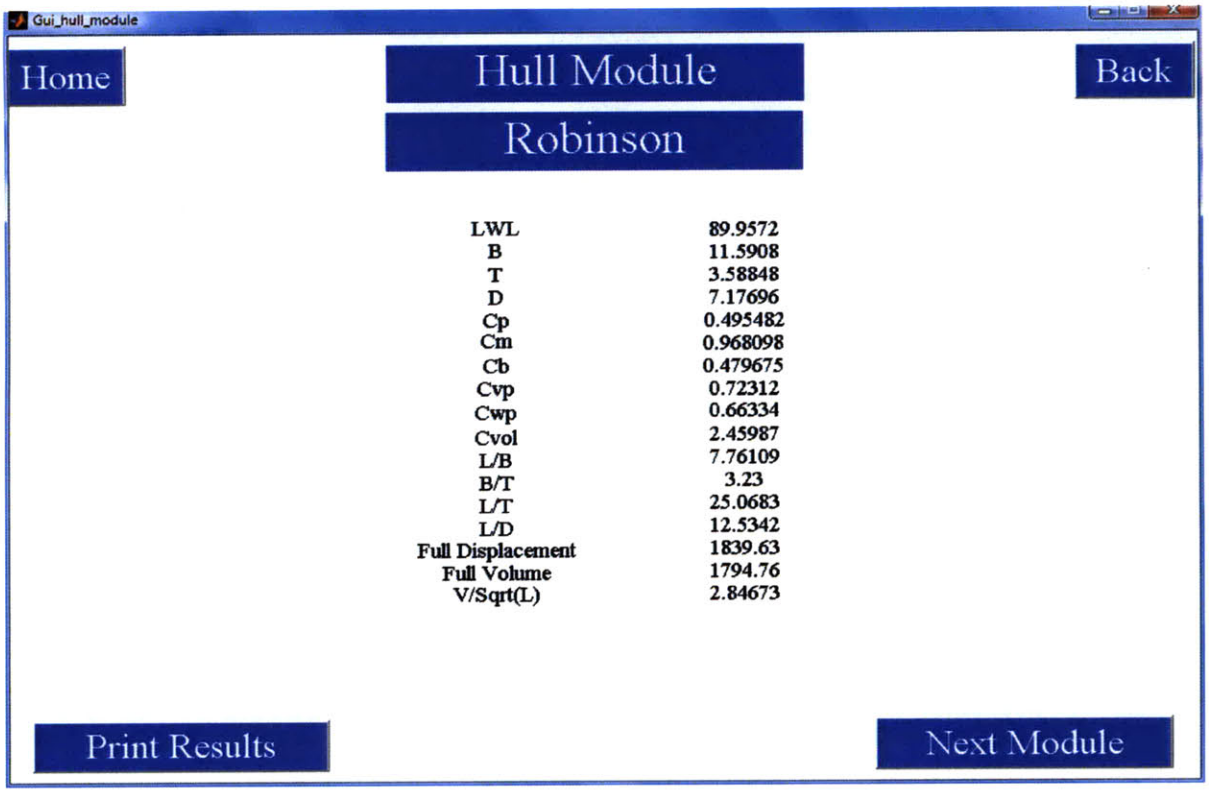


Figure 75 Hull Module Results of ESCET for the Robinson

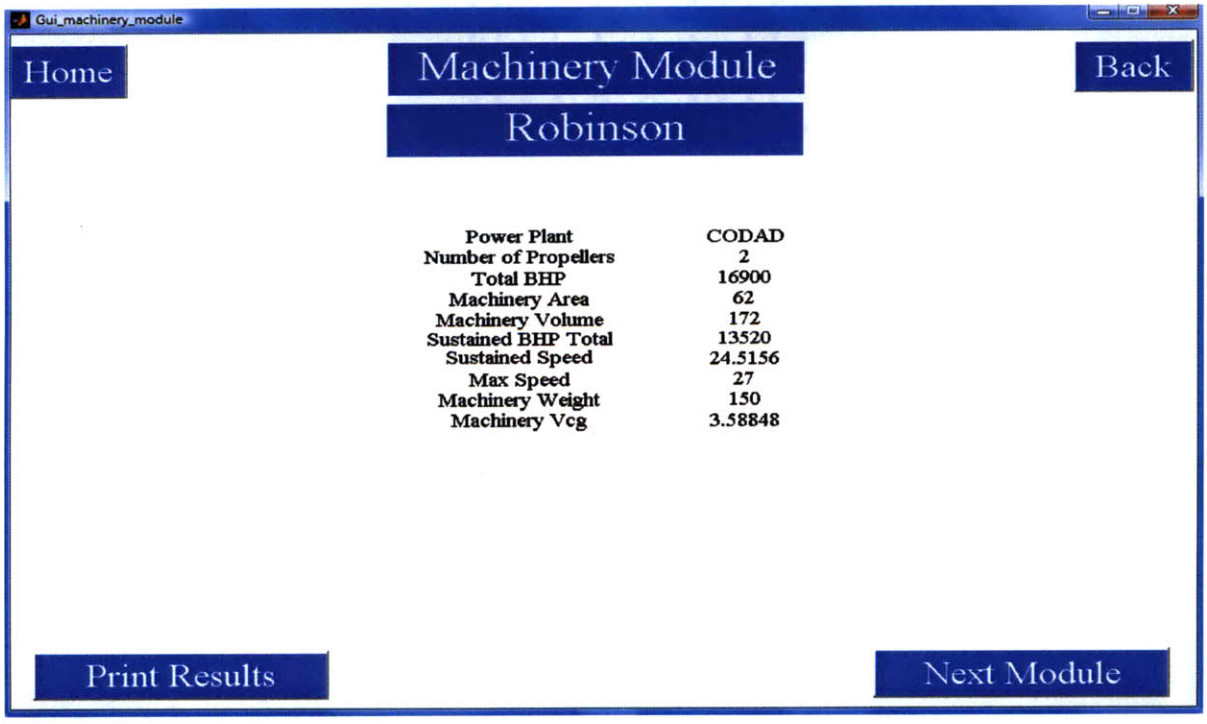
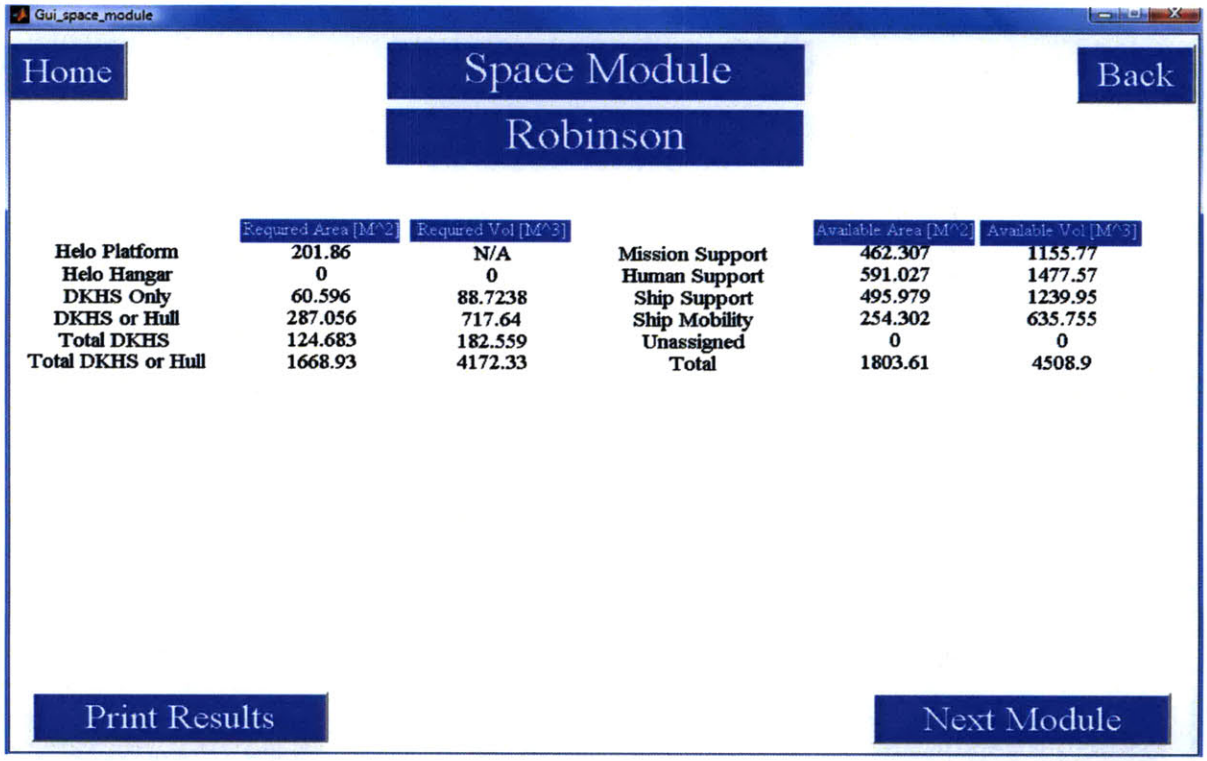
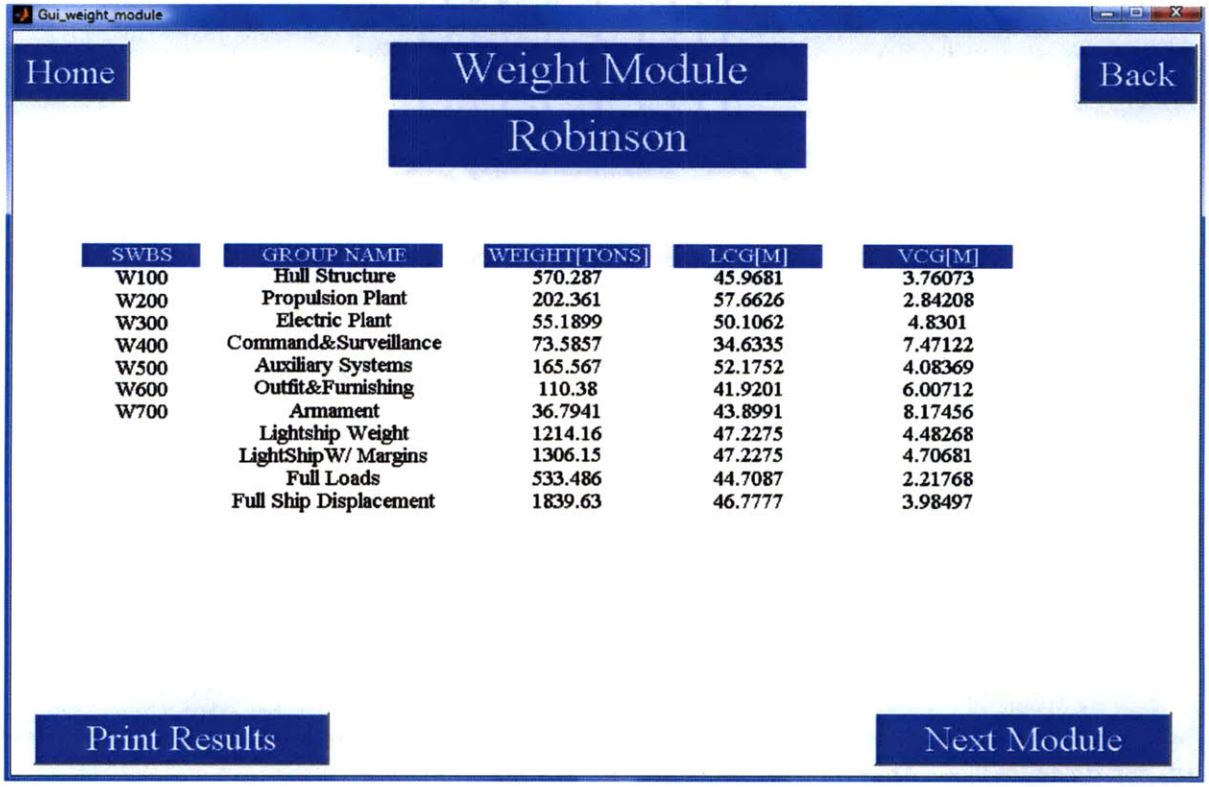


Figure 76 Machinery Module Results of ESCET for the Robinson



	Required Area [M^2]	Required Vol [M^3]		Available Area [M^2]	Available Vol [M^3]
Helo Platform	201.86	N/A	Mission Support	462.307	1155.77
Helo Hangar	0	0	Human Support	591.027	1477.57
DKHS Only	60.596	88.7238	Ship Support	495.979	1239.95
DKHS or Hull	287.056	717.64	Ship Mobility	254.302	635.755
Total DKHS	124.683	182.559	Unassigned	0	0
Total DKHS or Hull	1668.93	4172.33	Total	1803.61	4508.9

Figure 77 Space Module Results of ESCET for the Robinson



SWBS	GROUP NAME	WEIGHT[TONS]	LCG[M]	VCG[M]
W100	Hull Structure	570.287	45.9681	3.76073
W200	Propulsion Plant	202.361	57.6626	2.84208
W300	Electric Plant	55.1899	50.1062	4.8301
W400	Command&Surveillance	73.5857	34.6335	7.47122
W500	Auxiliary Systems	165.567	52.1752	4.08369
W600	Outfit&Furnishing	110.38	41.9201	6.00712
W700	Armament	36.7941	43.8991	8.17456
	Lightship Weight	1214.16	47.2275	4.48268
	LightShipW/ Margins	1306.15	47.2275	4.70681
	Full Loads	533.486	44.7087	2.21768
	Full Ship Displacement	1839.63	46.7777	3.98497

Figure 78 Weight Module Results of ESCET for the Robinson

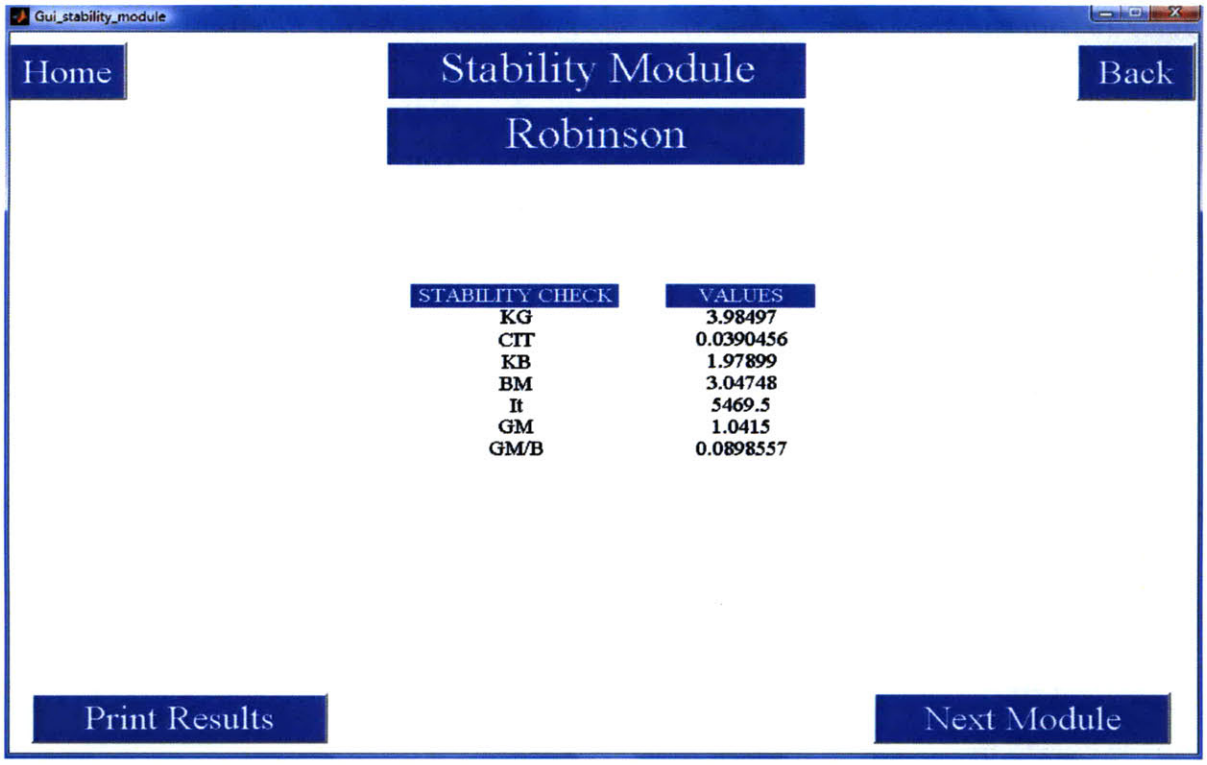


Figure 79 Stability Module Results of ESCET for the Robinson

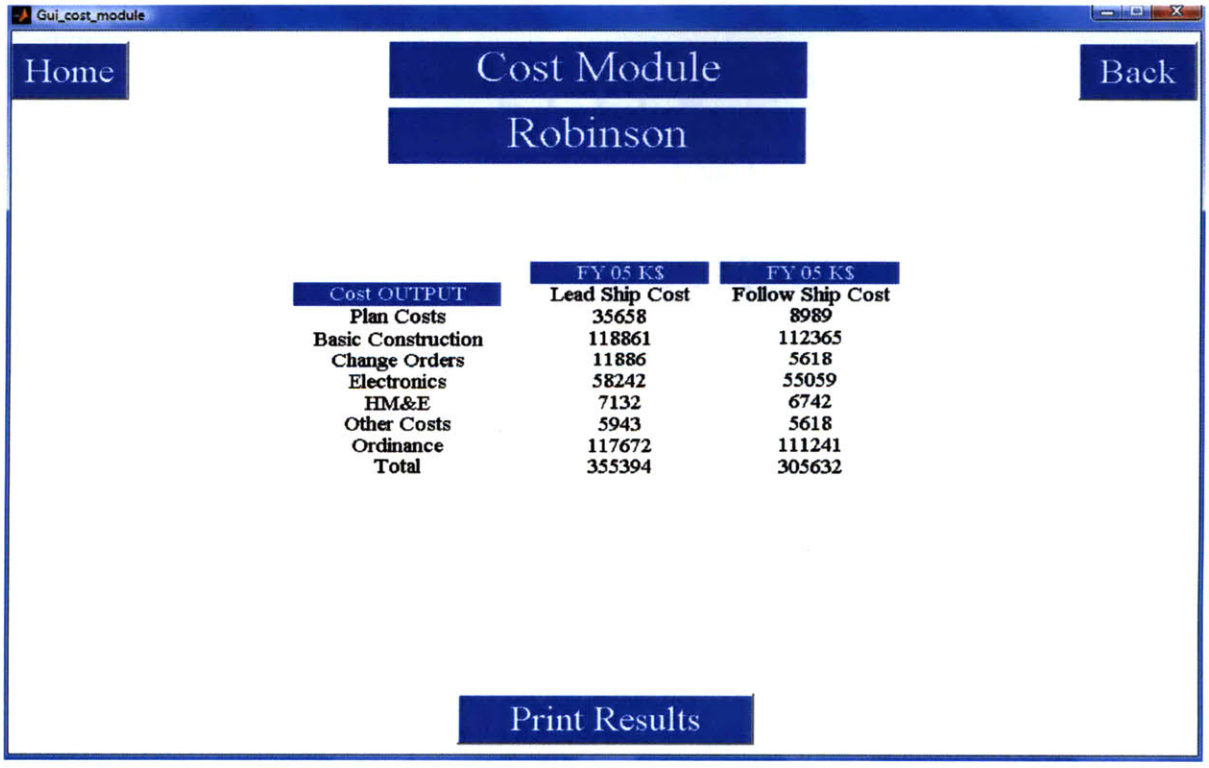


Figure 80 Cost Module Results of ESCET for the Robinson

Table 36 Hull and Machinery Module Summary of the Results for the Robinson

Hull Module		Machinery Module	
LWL	89.95	**Power Plant**	CODAD
B	11.59	**Number of Prop**	2.00
T	3.58	**Total BHP**	16900.00
D	7.17	**Machinery Area**	62.00
C_P	0.495	**Machinery Volume**	172
C_m	0.968	**Sustained BHP Total**	13520
C_B	0.479	**Sustained Speed**	24.51
C_{vp}	0.723	**Max Speed**	27
C_{wp}	0.663	**Machinery Vcg**	3.58
C_{vol}	2.459		
L/B	7.761		
B/T	3.23		
L/T	25.06		
L/D	12.53		
Δ_{Full}	1839.63		
FULL VOL	1794.76		
V/SQRT(LWL)	2.85		

Table 37 Space and Weight Module Summary of the Results for the Robinson

Space Module			Weight Module			
	Available Area	**Available Volume**	**SWBS**	**Weight**	**LCG**	**VCG**
Mission Support	462.30	1155.77	**100**	570.29	45.96	3.76
Human Support	591.02	1477.57	**200**	202.36	57.66	2.84
Ship Support	495.97	1239.95	**300**	55.18	50.10	4.83
Ship Mobility	254.20	635.75	**400**	73.58	34.63	7.47
Unassigned	0.00	0.00	**500**	165.56	52.17	4.08
Total	1803.61	4508.90	**600**	110.38	41.92	6.00
			700	36.79	43.89	8.17
			Light Ship	1214.16	47.22	4.48
			Light Ship w/ Margins	1306.15	47.22	4.70
			Full Loads	533.49	44.70	2.21
			Full Load Displacement	1839.63	46.77	3.98

Table 38 Stability and Cost Module Summary of the Results for the Robinson

Stability Module		Cost Module		
			Lead Ship Cost	Follow Ship Cost
KG	3.98	**Plan Costs**	35658	8989
C_{IT}	0.0390	**Basic Construction**	118861	112365
KB	1.97	**Change Orders**	11886	5618
BM	3.04	**Electronics**	58242	55059
I_t	5469.5	**HM&E**	7132	6742
GM	1.0415	**Other Costs**	5943	5618
GM_T/B	0.089	**Ordnance**	117672	111241
		Total	355394	305632

5.4 Assessment of the Results

The results of the selected ships show some accuracy for the developed program. Table 39 tabulates the validation of the hull module. As presented in the table, ESCET could estimate the hull parameters with low error percentages. The average error percentage on the hull parameters varies from 5% to 9%. The conclusions are:

- ESCET estimates LWL within 5% error for corvettes, while it estimates B, T, and D within 13% error.
- ESCET estimates C_m within 1% error, while it estimates the C_p, C_B, C_{vol}, C_{wp}, and C_{vp} within 13% error for corvettes.
- The L/B, B/T, L/T and L/D are estimated within 14% error for corvettes.
- The full load displacement of the ships is calculated within approximately 20% error for corvettes.

The errors on the basic hull parameters arise because of the fact that ESCET uses the constant B/T ratio, which is the average for the entire historical database. However, the estimations of LWL correspond well with the actual data. This fact is true for some of the coefficients (C_p, C_B, C_{vol}, C_{wp}, and C_{vp}) as well.

ESCET estimates have error greater than 10% for the parametric ratios; however the larger ships show small error percentages. Robinson's error percentages vary from 0.5% to 1.65% while Kral J Petar Kresimir's error percentages on parametric ratios vary from 3.7% to 22.37%.

Table 39 Validation of ESCET Hull Module Comparing Three Different Ships

	KRAL J PETAR KRESIMIR			EILAT(SAAR 5)			ROBINSON		
	ESCET	ACTUAL	ERROR %	ESCET	ACTUAL	ERROR %	ESCET	ACTUAL	ERROR %
LWL	52.21	51.46	1.46	78.93	81.60	-3.27	89.95	86.60	3.87
B	8.38	8.50	-1.41	10.50	11.90	-11.76	11.59	11.10	4.41
T	2.59	2.30	12.61	3.25	3.20	1.56	3.58	3.40	5.29
D	5.18	4.60	12.61	6.50	6.40	1.56	7.17	6.80	5.44
C_P	0.427	0.405	5.43	0.465	0.423	9.93	0.495	0.563	-12.08
C_m	0.961	0.959	0.21	0.965	0.96	0.52	0.968	0.972	-0.41
C_B	0.41	0.388	5.67	0.449	0.406	10.59	0.479	0.548	-12.59
C_{vp}	0.675	0.658	2.58	0.703	0.672	4.61	0.723	0.762	-5.12
C_{wp}	0.608	0.59	3.05	0.639	0.604	5.79	0.663	0.718	-7.66
C_{vol}	2.73	2.87	-4.88	2.57	2.32	10.78	2.459	2.75	-10.58
L/B	6.23	6.05	2.98	7.51	6.86	9.48	7.761	7.8	-0.50
B/T	3.23	3.7	-12.70	3.23	3.72	-13.17	3.23	3.26	-0.92
L/T	20.12	22.37	-10.06	24.27	25.5	-4.82	25.06	25.47	-1.61
L/D	10.06	11.19	-10.10	12.13	12.75	-4.86	12.53	12.74	-1.65
$\Delta_{Full\ Load}$	478.2	401	19.25	1241.21	1295	-4.15	1839.63	1850	-0.56
Volume	466.54	391.22	19.25	1210.94	1263.41	-4.15	1794.76	1804.88	-0.56
V/Sqrt (LWL)	4.98	5.02	-0.75	3.71	3.65	1.67	2.85	2.90	-1.91
		Avg. Error %	8.26		Avg. Error %	6.67		Avg. Error %	4.91

Table 40 shows the comparison of the machinery specifications for selected ships. This table shows that there is a significant difference between the actual data and ESCET data. The conclusions are:

- ESCET estimates total BHP within 173% error for Kral J Petar Kresimir, while it estimates total BHP within 30% error for Eilat (SAAR 5) and the Robinson.
- ESCET estimates machinery area within an approximate 101% error for Kral J Petar Kresimir, while it estimates machinery area within 4% error for Eilat (SAAR 5) and the Robinson.
- ESCET estimates machinery volume with an approximate 124% error for Kral J Petar Kresimir, while it estimates machinery volume within 18% error for Eilat (SAAR 5) and the Robinson.

- ESCET estimates machinery weight with an approximate 98% error for Kral J Petar Kresimir, while it estimates machinery weight within 17% error for Eilat (SAAR 5) and the Robinson.

The difference on the power plants occurs because of the fact that ESCET excludes these ships from the design lanes that it uses while calculating the machinery module. As mentioned in section 4.3.1, Kral J Petar Kresimir is excluded from the design lanes for Diesel Power Plants. Robinson is excluded from design lanes as well.

The average error percentage on the machinery module for Kral J Petar Kresimir is 124%, while it is 16% for Eilat (Saar 5) and 12% for Robinson. This result shows that the machinery module is more reliable for the larger corvettes.

Table 40 Validation of ESCET Machinery Module Comparing Three Different Ships

	KRAL J PETAR KRESIMIR			EILAT(SAAR 5)			ROBINSON		
	ESCET	**ACTUAL**	**ERROR %**	**ESCET**	**ACTUAL**	**ERROR %**	**ESCET**	**ACTUAL**	**ERROR %**
Power Plant	CODOG	Diesel	Wrong	CODAG	CODOG	Wrong	CODAD	Diesel	Wrong
Number of Propellers	2.00	3.00	Wrong	3.00	2.00	Wrong	2.00	2.00	Correct
Total BHP	34142	12500	-173.14	21720	30000	27.60	16900	20400	17.16
Machinery Area	41.09	20.42	-101.22	25.55	25.81	1.01	62.00	60.60	-2.31
Machinery Volume	116.92	52.38	-123.21	61.1	74.5	17.99	172	206.6	16.75
Machinery Weight	59.77	30.3	-97.26	30.49	36.41	16.26	150	166	9.64
		Avg. Error %	123.71		**Avg. Error %**	15.71		**Avg. Error %**	11.46

Table 41 presents the validation of the weight module comparing three different ships. As shown in the table, the smaller-sized ships show an approximate 20% error, while the moderate-sized ships show up to a 4% error. However, the larger-sized ships present only 0.2% errors.

The results are:

- ESCET estimates SWBS groups with an approximate 20% error for the smaller-sized corvettes.
- ESCET estimates SWBS groups with an approximate 5% error for the moderate-sized corvettes.

- ESCET estimates SWBS groups with an approximate 1% error for the larger-sized corvettes.
- ESCET estimates have an error less than 20% for the full load displacement of the corvettes.

Since the estimation on the weight groups performed by using the parametric ratios in SAWE [11] for each ship, the error percentages change linearly.

The cost parameters for each ship could not be gathered, thus the validation of the cost module is not presented. However, in the online reference [20] it is mentioned that each ship for the Eilat SAAR cost 260 million dollars, where ESCET calculated the estimated price for the lead ship cost approximately 240 million dollars. Forecast International [22] shows that Visby costs 65 million dollars and Magdeburg costs 181 million dollars. ESCET estimates the cost of Visby as 81 million dollars and the cost of Magdeburg as 230 million dollars. This result also shows that ESCET estimates the cost of the ship within 8% error.

Table 41 Validation of ESCET Weight Module Comparing Three Different Ships

	KRAL J PETAR KRESIMIR			EILAT(SAAR 5)			ROBINSON		
	ESCET	ACTUAL	ERROR %	ESCET	ACTUAL	ERROR %	ESCET	ACTUAL	ERROR %
W_{100}	148.24	124.31	-19.25	384.78	401.45	4.15	570.29	569.16	-0.20
W_{200}	52.60	44.11	-19.25	136.53	142.45	4.15	202.36	201.96	-0.20
W_{300}	14.34	12.03	-19.20	37.23	38.85	4.17	55.18	55.08	-0.18
W_{400}	19.12	16.04	-19.20	49.64	51.80	4.17	73.58	73.44	-0.19
W_{500}	43.03	36.09	-19.23	111.7	116.55	4.16	165.56	165.24	-0.19
W_{600}	28.69	24.06	-19.24	74.47	77.7	4.16	110.38	110.16	-0.20
W_{700}	9.56	8.02	-19.20	24.82	25.90	4.17	36.79	36.72	-0.19
$\Delta_{Lightship}$	315.62	264.66	-19.25	819.21	854.70	4.15	1214.16	1211.76	-0.20
Lightship w/ Margins	339.53	284.00	-19.55	881.27	910.00	3.16	1306.15	1300.00	-0.47
Full Loads	138.68	116.29	-19.25	359.95	375.55	4.15	533.49	532.44	-0.20
Δ_{Full}	478.21	401.00	-19.25	1241.21	1295.00	4.15	1839.63	1850.00	0.56
		Avg. Error %	19.26		Avg. Error %	4.07		Avg. Error %	0.25

CHAPTER 6

6 Conclusions

The goals of this study were:

"The first goal of this thesis is to present the parametric relationships using graphs and trend lines in the historical database.

The second goal of this thesis is to develop a Matlab™ model, which evaluates the early-stage design of corvettes."

These goals were met, though there are several areas in which ESCET could be improved.

6.1 Summary of the Results

There are two areas in which ESCET shows promise for more accuracy, and more robust results: the hull module and the weight module.

- ESCET estimates the LWL within 5% error for corvettes.
- ESCET estimates C_m with an approximate 1% error, while it estimates the C_p, C_B, C_{vol}, C_{wp}, and C_{vp} within 13% error for corvettes.
- The full load displacement of the ships is calculated within approximately 20% error for corvettes.
- ESCET mostly estimates total BHP with an approximate 30% error for corvettes.
- ESCET mostly estimates machinery area with an approximate 4% error for corvettes.
- ESCET mostly estimates machinery volume with an approximate 18% error for corvettes.
- ESCET mostly estimates machinery weight with an approximate 17% error for corvettes.
- ESCET estimates the full load displacement of the ships within approximately 1% error for larger sized corvettes.
- ESCET estimates SWBS weight groups with an approximate 1% error for the larger sized corvettes.

The results show that an early-stage design tool could be developed for corvettes. The modules estimate values within 20% error. The improvement of this developed model could

decrease these error percentages gradually. Thus, follow-on recommendations are described in the following pages.

6.2 Follow-on Work Recommendations

These follow-on recommendations are described module by module to make the program more robust and accurate. Add-on features/improvements could be developed by adding new code to the program or editing the written code.

6.2.1 Customer Requirements

The customer requirements page in ESCET could be improved by gathering several new data. Here are some suggestions:

- In ESCET; most of the payloads are estimated due to lack of data availability. So, gathering more data on payloads would make the calculations more robust and reliable. This improvement could be added by studying with one of the shipyards that has already been designing warships.
- Most of the payloads in ESCET are old technology and out-dated, so the new technology weapons could be added to the customer requirements page.
- Most of the mission requirements are covered in ESCET; however some of them are still not developed. The development of the other missions could make ESCET work for other warships as well.

6.2.2 Hull Module

The hull module in ESCET could be improved by adding several new features. Here are some suggestions:

- Adding a parent hull feature;

This feature will improve the ability of the hull module. After adding this feature, the hull module could allocate the hull subdivision, define the geometry of the molded hull and set the off sets, and even it could regenerate the hull for a new design.

- Adding subdivisions to the hull;

This feature will improve the allocation of the spaces on board. It will also use the inputs that are not directly used in ESCET for now. This will open the path to make endurance

calculations and allocate the tankage on board. This feature also will define the decks, platforms, transverse bulkheads, longitudinal bulkheads and inner bottoms if present.

- Adding deckhouse module;

This feature will improve the space module. It could be added by using parent ships super structure. This feature will define new models for the desired ship.

- Adding a hull structure module;

This feature will calculate the scantlings of the ships elements for the desired ship. This will also improve the weight module while doing its calculations. This feature could be added by using the Lloyds's instructions and formulations for surface combatants.

- Adding more ships in the historical database;

The calculations in hull module are restricted by the historical database. The assumptions made in this module are mostly average values (B/T ratio assumed to be 3.23, which is the average value) in the historical database and the data on the surface combatants. Since the historical database is limited by the number of the ships, the hull module could be improved by increasing the number of the ships in the historical database.

- Gathering actual coefficient values and some missing parameters for the hull module from ship building companies;

ESCET uses the estimation methods to calculate most of the coefficients. The program writer could come up with better results, if he could gather the actual coefficients and some missing parameters for the ships.

- Gathering actual LWL values;

ESCET has most of the ships actual LWL; however the missing LWL values are estimated to complete the historical database. Gathering LWL for all of the ships will improve the sensitivity of the program.

6.2.3 Machinery Module

The machinery could be improved by adding several new features. Here are some suggestions:

- Developing better parametric relationships;

ESCET has 30 ships in the historical database so the parametric relationships are limited by the number of the ships. Thus, developing better relationships could increase the efficiency of

this module. This improvement could be added by gathering the actual machinery area, volume and weight data without making any assumptions.

- Adding a machinery catalogue for customers;

This feature will improve the space module and help the programmer to make better estimations for the required space for machinery.

- Adding electrical requirements;

This feature will help the programmer to calculate the auxiliary machinery specifications for the desired ship.

- Adding main propulsion machinery and auxiliary propulsion machinery;

This feature will help the programmer to make better estimations for the space module.

6.2.4 Space Module

The space module is depending on the US ships allocations and just making estimations. Thus, it could be improved by adding several new features. Here are some suggestions:

- Developing parametric relationships;

ESCET has 30 ships in the historical database so the parametric relationships are limited by the number of the ships. Thus, developing relationships for the space module could increase the efficiency of this module. This improvement could be added by gathering the actual SSCS groups, volume data without making any assumptions.

- Using the inputs for the officers on board;

This feature will improve the calculation of the mission support area allocations. However, the other features mentioned in the previous pages for the other modules will also contribute to improve the space module.

- Adding a deck height input;

This feature will improve the calculations of the required volume for the ship. This could be also added by the hull module if the parent hull feature is added.

6.2.5 Weight Module

The weight module is based on the ratiocination method described in SAWE [11]. Thus, it could be improved by adding several new features. Here are some suggestions:

- Using the outputs from the hull structure module;

This feature will help the calculations of the W_{100} group and it will output more reliable results.

- Developing better parametric relationships;

ESCET has 30 ships in the historical database, so the parametric relationships are limited by the number of the ships. Also, these parametric relationships for the weight module are based on the ratiocination method for corvettes. Since these parametric relationships could not be developed from the actual weights of the ships in the historical database, gathering these weights for each ship will lead to better parametric relationships for the weight module. Thus, developing these parametric relationships could increase the efficiency of this module.

6.2.6 Stability Module

Since ESCET is just checking the GM_T/B ratio, this module could be improved by doing iterations. For instance, if analyzed ship's GM_T/B ratio is not in the range ($0.05 \leq GM_T/B \leq 0.15$) the program could recalculate the hull module and change the parent hull in order to make the desired ship float upright. Now, ESCET uses a static stability check for this module. The design lanes and the formulas of the stability module could also be revised.

The stability module could also include a free surface factor to the calculations to have better results.

6.2.7 Cost Module

ESCET uses surface combatant's CER data. However, these CERs are not suitable for corvettes. This module could be improved by developing the corvette's CERs. Since this CER data could not be developed, ESCET estimates the cost module depending on surface combatant's CERs. This module also could be improved by using a different approach if it is applicable to corvettes.

6.2.8 Final Thoughts

The results show that ESCET could be a good estimation tool for corvettes at the early-stage design. However, it would be naïve to say that ESCET gives the exact results for the desired ship. ESCET is not robust enough to present the optimum design analysis for the desired ship; however it can put the naval architect in the ball park of the design. This tool could become more robust by implementing recommended changes discussed previously.

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APPENDIX 1 Historical Database A-1

No	Ship Class	Ship No	Country	Builder	Year(Launched)	LOA	LWL	B	D	T
1	Stockholm	K11	Sweden	Karlskronavarvet	1984	50.00	48.00	7.50	6.60	3.30
2	Goteborg	K21	Sweden	Karlskronavarvet	1989	57.00	54.72	8.00	4.00	2.00
3	KralJ Petar Kresimir 4	RTOP 11	Crotia	Kraljevica SY	1992	53.60	51.46	8.50	4.60	2.30
4	Victory	P 88	Singapore	Lürssen-Werft	1988	62.40	58.00	8.50	6.20	3.10
5	Visby	K31	Sweden	Karlskronavarvet	2000	72.00	69.12	10.40	5.00	2.50
6	Khamronsin	531	Thailand	Ithal Thai Marine	1988	62.00	56.70	8.20	5.00	2.50
7	Roussen	P-67	Greece	Elefsis Shipyard	2002	61.90	59.42	9.50	5.20	2.60
8	Eleftheria	P-64	Greece	Rolandwerft	1962	70.00	67.20	8.20	5.40	2.70
9	HTMS Rattanakosin	FS 441	Thailand	Tacoma Boatbuilders	1986	80.00	76.80	9.60	4.80	2.40
10	Parchim	MPK-99	Russia	Wolgast	1985	75.20	69.70	9.80	8.80	4.40
11	Dong Hae	PCC-751	South Korea	KSEC Pusan	1982	78.10	74.30	9.60	5.20	2.60
12	PF 103(Bayandor)	81	Iran	Levingstone Ship Building. TX	1963	84.00	79.00	10.10	6.20	3.10
13	Serviola	P-71	Spain	Bazan, Ferrol	1990	68.70	63.00	10.40	6.80	3.40
14	Lutsk	U 200	Ukraine	Leninskaya Kuznitsa	1993	74.17	71.20	9.80	7.40	3.70
15	Kaszub	240	Poland	Northern Shipyard,Gdansk	1986	82.30	79.01	10.00	6.20	3.10
16	Pohang	PCC-756	South Korea	Korea SEC,Pusan	1985	88.30	82.40	10.00	5.80	2.90
17	Minerva	F551	Italy	Fincantieri	1986	86.00	82.56	10.50	6.40	3.20
18	Eilat (Saar 5)	501	Israel	Northrop Grumman	1993	85.00	81.60	11.90	6.40	3.20
19	Niels Juel	F 354	Denmark	Aalborg Vaerft A/S	1978	84.00	80.64	10.30	7.30	3.10
20	Vosper Mk5(Alvand)	F-71	Iran	Vosper Thornycroft,Woolston	1968	94.50	88.00	11.10	6.50	3.25
21	Baptisda De Andrade Class	F 486	Portugal	Empresa National Bazan	1973	84.60	81.22	10.30	6.20	3.10
22	Joao Coutinho	F 475	Portugal	Blohm Voss	1969	84.60	81.22	10.30	6.60	3.30
23	Khukri	P49	India	Mazagon Dock Ltd	1986	91.10	84.20	10.50	8.00	4.00
24	Fatahillah	FTH-361	Indonesia	Wilton Fijenoord	1977	84.00	80.20	11.10	6.60	3.30
25	Ishikari	DE 226	Japan	Mitsui,Tamano	1980	91.00	85.00	10.80	7.20	3.60
26	Cassiopea	P 401	Italy	Fincantieri	1988	80.00	72.60	11.80	7.00	3.50
27	Magdeburg	F 261	Germany	Lürssen- Vegesak	2006	88.30	84.77	13.20	9.60	4.80
28	Descubierta	P-75	Spain	Bazan, Ferrol & Cartagena	1975	88.80	85.25	10.40	7.60	3.80
29	Robinson(Meko 140)	P-45	Argentine	Blohm Voss	1985	91.20	86.60	11.10	6.80	3.40
30	Kasturi	F25	Malaysia	Howaldtswerke,Kiel	1983	97.30	89.60	11.30	7.00	3.50

APPENDIX 2 Historical Database A-2

Ship Class	Super Structure (%)	T_{Screw}	L/B	B/T	L/T	B/D	L/D	Displacement Standard	Displacement Full	W_{100}	W_{200}
Stockholm			6.40	2.27	14.55	1.14	7.27	350	372	115.32	40.92
Goteborg			6.84	4.00	27.36	2.00	13.68	300	399	123.69	43.89
KralJ Petar Kresimir 4			6.05	3.70	22.37	1.85	11.19	385	401	124.31	44.11
Victory			6.82	2.74	18.71	1.37	9.35		595	184.45	65.45
Visby			6.65	4.16	27.65	2.08	13.82		620	192.2	68.2
Khamronsin			6.91	3.28	22.68	1.64	11.34	362	630	195.3	69.3
Roussen			6.26	3.65	22.86	1.83	11.43	580	660	204.6	72.6
Eleftheria			8.20	3.04	24.89	1.52	12.44	575	732	226.92	80.52
HTMS Rattanakosin			8.00	4.00	32.00	2.00	16.00		960	297.6	105.6
Parchim			7.11	2.23	15.84	1.11	7.92	769	990	306.9	108.9
Dong Hae			7.74	3.69	28.58	1.85	14.29		1076	333.56	118.36
PF 103(Bayandor)			7.82	3.26	25.48	1.63	12.74	900	1135	351.85	124.85
Serviola			6.06	3.06	18.53	1.53	9.26		1147	355.57	126.17
Lutsk			7.27	2.65	19.24	1.32	9.62	950	1150	356.5	126.5
Kaszub			7.90	3.23	25.49	1.61	12.74	1051	1183	366.73	130.13
Pohang			8.24	3.45	28.41	1.72	14.21		1220	378.2	134.2
Minerva			7.86	3.28	25.80	1.64	12.90	1029	1285	398.35	141.35
Eilat (Saar 5)			6.86	3.72	25.50	1.86	12.75	1075	1295	401.45	142.45
Niels Juel	59.00	4.80	7.83	3.32	26.01	1.41	11.05		1320	409.2	145.2
Vosper Mk5(Alvand)		4.30	7.93	3.42	27.08	1.71	13.54	1250	1350	418.5	148.5
Baptisda De Andrade Class			7.89	3.32	26.20	1.66	13.10	1203	1380	427.8	151.8
Joao Coutinho			7.89	3.12	24.61	1.56	12.31	1203	1380	427.8	151.8
Khukri			8.02	2.63	21.05	1.31	10.53		1423	441.13	156.53
Fatahillah			7.23	3.36	24.30	1.68	12.15	1200	1450	449.5	159.5
Ishikari			7.87	3.00	23.61	1.50	11.81	1290	1450	449.5	159.5
Cassiopea			6.15	3.37	20.74	1.69	10.37	1002	1475	457.25	162.25
Magdeburg			6.42	2.75	17.66	1.38	8.83		1662	515.22	182.82
Descubierta			8.20	2.74	22.43	1.37	11.22	1233	1666	516.46	183.26
Robinson(Meko 140)			7.80	3.26	25.47	1.63	12.74	1470	1836	569.16	201.96
Kasturi			7.93	3.23	25.60	1.61	12.80	1500	1850	573.5	203.5

APPENDIX 3 Historical Database A-3

Ship Class	W_{300}	W_{400}	W_{500}	W_{600}	W_{700}	$W_{payload}$	pf	$W_{Lightship}$	W_{Margin}	$W_{Full\ Loads}$	Displacement Check
Stockholm	11.16	14.88	33.48	22.32	7.44	22.32	0.06	245.52	18.6	107.88	372
Goteborg	11.97	15.96	35.91	23.94	7.98	23.94	0.06	263.34	19.95	115.71	399
KralJ Petar Kresimir 4	12.03	16.04	36.09	24.06	8.02	24.06	0.06	264.66	20.05	116.29	401
Victory	17.85	23.8	53.55	35.7	11.9	35.7	0.06	392.7	29.75	172.55	595
Visby	18.6	24.8	55.8	37.2	12.4	37.2	0.06	409.2	31	179.8	620
Khamronsin	18.9	25.2	56.7	37.8	12.6	37.8	0.06	415.8	31.5	182.7	630
Roussen	19.8	26.4	59.4	39.6	13.2	39.6	0.06	435.6	33	191.4	660
Eleftheria	21.96	29.28	65.88	43.92	14.64	43.92	0.06	483.12	36.6	212.28	732
HTMS Rattanakosin	28.8	38.4	86.4	57.6	19.2	57.6	0.06	633.6	48	278.4	960
Parchim	29.7	39.6	89.1	59.4	19.8	59.4	0.06	653.4	49.5	287.1	990
Dong Hae	32.28	43.04	96.84	64.56	21.52	64.56	0.06	710.16	53.8	312.04	1076
PF 103(Bayandor)	34.05	45.4	102.15	68.1	22.7	68.1	0.06	749.1	56.75	329.15	1135
Serviola	34.41	45.88	103.23	68.82	22.94	68.82	0.06	757.02	57.35	332.63	1147
Lutsk	34.5	46	103.5	69	23	69	0.06	759	57.5	333.5	1150
Kaszub	35.49	47.32	106.47	70.98	23.66	70.98	0.06	780.78	59.15	343.07	1183
Pohang	36.6	48.8	109.8	73.2	24.4	73.2	0.06	805.2	61	353.8	1220
Minerva	38.55	51.4	115.65	77.1	25.7	77.1	0.06	848.1	64.25	372.65	1285
Eilat (Saar 5)	38.85	51.8	116.55	77.7	25.9	77.7	0.06	854.7	64.75	375.55	1295
Niels Juel	39.6	52.8	118.8	79.2	26.4	79.2	0.06	871.2	66	382.8	1320
Vosper Mk5(Alvand)	40.5	54	121.5	81	27	81	0.06	891	67.5	391.5	1350
Baptisda De Andrade Class	41.4	55.2	124.2	82.8	27.6	82.8	0.06	910.8	69	400.2	1380
Joao Coutinho	41.4	55.2	124.2	82.8	27.6	82.8	0.06	910.8	69	400.2	1380
Khukri	42.69	56.92	128.07	85.38	28.46	85.38	0.06	939.18	71.15	412.67	1423
Fatahillah	43.5	58	130.5	87	29	87	0.06	957	72.5	420.5	1450
Ishikari	43.5	58	130.5	87	29	87	0.06	957	72.5	420.5	1450
Cassiopea	44.25	59	132.75	88.5	29.5	88.5	0.06	973.5	73.75	427.75	1475
Magdeburg	49.86	66.48	149.58	99.72	33.24	99.72	0.06	1096.92	83.1	481.98	1662
Descubierta	49.98	66.64	149.94	99.96	33.32	99.96	0.06	1099.56	83.3	483.14	1666
Robinson(Meko 140)	55.08	73.44	165.24	110.16	36.72	110.16	0.06	1211.76	91.8	532.44	1836
Kasturi	55.5	74	166.5	111	37	111	0.06	1221	92.5	536.5	1850

APPENDIX 4 Historical Database A-4

Ship Class	Crew	Max. Speed	Power Plant	SHP(metric)	Range	Range Speed	Cubic Number	C_B	BHP
Stockholm	33	32	CODAG				4.85	0.3055	5440
Goteborg	36	30	Diesel				7.06	0.4446	8700
KralJ Petar Kresimir 4	29	36	Diesel		1700	18	6.18	0.3889	12500
Victory	49	35	Diesel		4000	18	6.03	0.3798	15020
Visby	43	35	CODOG				5.35	0.3366	21760
Khamronsin	57	25	Diesel		2500	15	8.40	0.5288	9980
Roussen	45	34	Diesel		1800	12	6.97	0.4387	23170
Eleftheria	48	20	Diesel		2760	15	7.63	0.4800	6800
HTMS Rattanakosin	87	26	Diesel		3000	16	8.41	0.5293	14730
Parchim	70	26	Diesel		2500	12	5.11	0.3214	14250
Dong Hae	95	31	CODOG		4000	15	8.99	0.5661	26820
PF 103(Bayandor)	140	20	Diesel		2400	18	7.11	0.4477	5250
Serviola	42	19	Diesel		8000	12	7.98	0.5023	7500
Lutsk	70	34	CODAG		2500	14	6.90	0.4346	38000
Kaszub	82	27	CODAD		3500	14	7.49	0.4712	16900
Pohang	95	32	CODOG		4000	15	7.91	0.4981	26820
Minerva	106	24	Diesel		3500	18	7.18	0.4519	11000
Eilat (Saar 5)	64	33	CODOG		3500	17	6.46	0.4066	30000
Niels Juel	94	28	CODOG	18400	2500	18	6.75	0.5002	24600
Vosper Mk5(Alvand)	135	39	CODOG		3650	18	6.59	0.4149	40000
Baptisda De Andrade Class	71	22	Diesel		5900	18	8.25	0.5192	12000
Joao Coutinho	70	22	Diesel		5900	18	7.75	0.4877	12000
Khukri	112	24	Diesel		4000	16	6.24	0.3926	14400
Fatahillah	89	30	CODOG		4250	16	7.65	0.4815	25440
Ishikari	95	25	CODOG				6.80	0.4281	24700
Cassiopea	65	20	Diesel		3300	17	7.62	0.4799	7940
Magdeburg	65	26	Diesel		2500	15	4.80	0.3019	19850
Descubierta	118	25	Diesel		4000	18	7.66	0.4824	15000
Robinson(Meko 140)	93	27	Diesel		4000	18	8.71	0.5481	20400
Kasturi	124	28	Diesel		3000	18	8.09	0.5093	23400

APPENDIX 5 Historical Database A-5

Ship Class	C_P	C_{vol}	C_m	C_{wp}	C_{vp}	Number of Shafts	Helicopter Platform	$W_{payload}/ W_{Full}$	$W_{Payload}$	Fr @ V_{Max}
Stockholm	0.3209	3.2817	0.9520	0.5219	0.5853	3	0	0.07	27.78	0.76
Goteborg	0.4613	2.3758	0.9638	0.6357	0.6994	3	0	0.08	32.47	0.67
KralJ Petar Kresimir 4	0.4055	2.8715	0.9591	0.5905	0.6586	3	0	0.06	23.94	0.82
Victory	0.3964	2.9752	0.9583	0.5831	0.6514	4	0	0.03	17.88	0.75
Visby	0.3526	1.8317	0.9546	0.5476	0.6147	2	1	0.04	22.62	0.69
Khamronsin	0.5446	3.3718	0.9709	0.7031	0.7520	2	0	0.02	14.78	0.55
Roussen	0.4554	3.0686	0.9633	0.6309	0.6954	4	0	0.03	20.83	0.72
Eleftheria	0.4965	2.3533	0.9668	0.6642	0.7227	2	0	0.02	15.53	0.39
HTMS Rattanakosin	0.5451	2.0676	0.9710	0.7035	0.7523	2	0	0.03	30.99	0.49
Parchim	0.3371	2.8524	0.9533	0.5351	0.6006	3	0	0.02	23.10	0.51
Dong Hae	0.5811	2.5593	0.9741	0.7327	0.7726	2	0	0.02	21.55	0.59
PF 103(Bayandor)	0.4644	2.2459	0.9641	0.6381	0.7015	2	0	0.03	31.64	0.37
Serviola	0.5186	4.4753	0.9687	0.6820	0.7365	2	1	0.00	4.72	0.39
Lutsk	0.4513	3.1084	0.9629	0.6276	0.6925	3	0	0.03	38.34	0.66
Kaszub	0.4878	2.3402	0.9661	0.6571	0.7171	2	0	0.02	27.48	0.50
Pohang	0.5144	2.1274	0.9683	0.6786	0.7339	2	0	0.02	20.31	0.58
Minerva	0.4686	2.2278	0.9644	0.6416	0.7044	2	0	0.01	17.64	0.43
Eilat (Saar 5)	0.4233	2.3253	0.9606	0.6049	0.6722	2	1	0.02	19.52	0.60
Niels Juel	0.5164	2.4558	0.9685	0.6803	0.7352	2	0	0.01	16.43	0.51
Vosper Mk5(Alvand)	0.4316	1.9327	0.9613	0.6116	0.6784	2	0	0.03	38.69	0.68
Baptisda De Andrade Class	0.5352	2.5132	0.9701	0.6955	0.7465	2	1	0.02	24.40	0.40
Joao Coutinho	0.5041	2.5132	0.9675	0.6703	0.7276	2	1	0.02	23.56	0.40
Khukri	0.4092	2.3257	0.9594	0.5935	0.6615	2	1	0.02	34.20	0.43
Fatahillah	0.4980	2.7423	0.9669	0.6654	0.7237	2	0	0.03	44.43	0.55
Ishikari	0.4448	2.3035	0.9624	0.6223	0.6879	2	0	0.01	20.38	0.45
Cassiopea	0.4964	3.7606	0.9668	0.6641	0.7227	2	1	0.01	8.51	0.39
Magdeburg	0.3172	2.6620	0.9517	0.5190	0.5817	2	1	0.02	27.25	0.46
Descubierta	0.4989	2.6236	0.9670	0.6661	0.7243	2	0	0.02	28.92	0.44
Robinson(Meko 140)	0.5635	2.7580	0.9726	0.7184	0.7628	2	1	0.01	20.21	0.48
Kasturi	0.5255	2.5091	0.9693	0.6876	0.7407	2	1	0.01	24.26	0.49

APPENDIX 6 Historical Database A-6

Ship Class	Froude Number @ V_{Range}	A_{wp}	$W_{Total\ Machinery}$	Machinery Volume	Machinery Footprint	Machinery Vol./Machinery Area
Stockholm	N/A	187.90	12.96	16.44	10.66	1.54
Goteborg	N/A	278.27	18.42	22.55	14.09	1.60
KralJ Petar Kresimir 4	0.41	258.25	30.30	52.38	20.42	2.57
Victory	0.39	287.44	31.12	57.35	22.89	2.51
Visby	N/A	393.64	9.29	13.80	11.37	1.21
Khamronsin	0.33	326.91	31.73	56.75	15.01	3.78
Roussen	0.26	356.15	52.00	75.85	26.43	2.87
Eleftheria	0.30	365.97	27.31	33.86	13.28	2.55
HTMS Rattanakosin	0.30	518.71	45.96	67.25	17.77	3.79
Parchim	0.24	365.47	22.50	38.67	23.37	1.66
Dong Hae	0.29	522.61	36.41	74.51	25.82	2.89
PF 103(Bayandor)	0.33	509.17	66.00	55.35	42.58	1.30
Serviola	0.25	446.87	27.31	33.86	13.28	2.55
Lutsk	0.27	437.88	45.70	99.85	38.48	2.59
Kaszub	0.26	519.16	150.00	172.64	61.39	2.81
Pohang	0.27	559.21	26.48	54.32	24.37	2.23
Minerva	0.33	556.16	48.60	45.85	19.27	2.38
Eilat (Saar 5)	0.31	587.35	36.41	74.51	25.82	2.89
Niels Juel	0.33	565.05	20.91	47.45	21.00	2.26
Vosper Mk5(Alvand)	0.32	597.40	60.36	115.72	40.59	2.85
Baptisda De Andrade Class	0.33	581.79	160.00	142.10	46.06	3.09
Joao Coutinho	0.33	560.75	160.00	142.10	46.06	3.09
Khukri	0.29	524.67	68.00	78.13	25.85	3.02
Fatahillah	0.29	592.34	58.15	93.76	32.53	2.88
Ishikari	N/A	571.25	41.39	74.30	22.73	3.27
Cassiopea	0.33	568.92	37.00	35.52	15.79	2.25
Magdeburg	0.27	580.68	45.60	73.30	20.28	3.62
Descubierta	0.32	590.56	54.61	67.24	26.37	2.55
Robinson(Meko 140)	0.32	690.61	166.00	206.06	60.61	3.40
Kasturi	0.31	696.20	84.20	146.60	40.55	3.62

APPENDIX 7 Historical Database A-7

Ship Class	Machinery Weight/Machinery Vol.	Machinery Vol./Ship Vol.	(Machinery Weight/Ship Disp)*100	Machinery Area/A_{wp}
Stockholm	0.79	0.05	3.48	0.06
Goteborg	0.82	0.06	4.62	0.05
KralJ Petar Kresimir 4	0.58	0.13	7.56	0.08
Victory	0.54	0.10	5.23	0.08
Visby	0.67	0.02	1.50	0.03
Khamronsin	0.56	0.09	5.04	0.05
Roussen	0.69	0.12	7.88	0.07
Eleftheria	0.81	0.05	3.73	0.04
HTMS Rattanakosin	0.68	0.07	4.79	0.03
Parchim	0.58	0.04	2.27	0.06
Dong Hae	0.49	0.07	3.38	0.05
PF 103(Bayandor)	1.19	0.05	5.81	0.08
Serviola	0.81	0.03	2.38	0.03
Lutsk	0.46	0.09	3.97	0.09
Kaszub	0.87	0.15	12.68	0.12
Pohang	0.49	0.05	2.17	0.04
Minerva	1.06	0.04	3.78	0.03
Eilat (Saar 5)	0.49	0.06	2.81	0.04
Niels Juel	0.44	0.04	1.58	0.04
Vosper Mk5(Alvand)	0.52	0.09	4.47	0.07
Baptisda De Andrade Class	1.13	0.11	11.59	0.08
Joao Coutinho	1.13	0.11	11.59	0.08
Khukri	0.87	0.06	4.78	0.05
Fatahillah	0.62	0.07	4.01	0.05
Ishikari	0.56	0.05	2.85	0.04
Cassiopea	1.04	0.02	2.51	0.03
Magdeburg	0.62	0.05	2.74	0.03
Descubierta	0.81	0.04	3.28	0.04
Robinson(Meko 140)	0.81	0.12	9.04	0.09
Kasturi	0.57	0.08	4.55	0.06

APPENDIX 8 Corvettes' Payload Breakdown Table A-1

No	Ship Class	Guns Unit	Guns Type	Gun Area	Gun Volume	Gun Power Consumption[KW]	Guns Weight Tons
1	Stockholm	1	Bofors 57 mm 70 Mk2	15	41	8	14
2	Goteborg	1	Bofors 57 mm 70 Mk2	15	41	8	14
		1	Bofors 40 mm 70 (M/48 9 LV Mk 3)	14.72	35.637	N/A	3.85
3	KralJ Petar Kresimir 4	1	Bofors 57 mm 70 RTOP 11	15	41	8	14
		1	30 mm/65 AK 630M			N/A	3.7
4	Visby	1	Bofors 57 mm 70 SAK Mk3	15	41	8	14
5	Khamronsin	1	Oto Melara 76 mm/62 Mod 7 Compact			N/A	8.51
		1	Breda 30 mm/70 Twin (Compact) Model 563			N/A	1.53
6	Roussen	1	Oto Breda 76 mm/62 Super Rapid			N/A	8.51
		2	Oto Melara 30 mm(Single Compact) Model 563			N/A	3.06
7	Elefteria	2	Oto Breda 40 mm/70 Twin			N/A	14.6
		2	Rheinmetall 20 mm S.20			N/A	N/A
8	HTMS Rattanakosin	1	Oto Melara 76 mm/62 (Compact)			N/A	8.51
		2	Rheinmetall 20 mm S.20			N/A	N/A
		1	Breda 40 mm/70 Twin			N/A	7.3
9	Dong Hae	1	Oto Melara 76 mm/62 Compact			N/A	8.51
		2	Emerson Electric 30 mm (Twin)			N/A	3.8
		1	Bofors 40 mm/60 (Twin) US Mk2	4.5	16.024	N/A	1.03
10	PF 103 Bayandor	2	MK 34 US 3 in (76 mm)/50 Mk 34			N/A	19.04
		1	Bofors 40 mm/60 (Twin) US Mk1	4.5	16.024	N/A	11.6
		2	12.7 mm Machine Guns			N/A	N/A
		2	Oerlikon GAM-BO1 20 mm			N/A	1
11	Serviola	1	MK 27 US 3 in (76 mm)/50			N/A	4.72
		2	12.7 mm Machine Guns			N/A	N/A
12	Parchim	1	3 in (76 mm)/ 66 AK 176			54.5	16.8
		1	30 mm/65 AK 630M			N/A	3.7
13	Pohang	1	Oto Melara 76 mm/62 Compact			N/A	8.51
		2	Emerson Electric 30 mm (Twin)			N/A	3.8
		1	Bofors 40 mm/70 (Twin) (Oto Melara Compact)	14.72	35.637	N/A	5.6

APPENDIX 9 Corvettes' Payload Breakdown Table A-2

No	Ship Class	Guns Unit	Guns Type	Gun Area	Gun Volume	Gun Power Consumption[KW]	Guns Weight Tons
14	Lutsk	1	3 in (76 mm)/ 60			N/A	25
		2	57 mm/80(Twin) SM-24-ZIF			N/A	1.238
		1	30 mm/65 AK 630M			N/A	3.7
15	Kaszub	1	3 in (76 mm)/ 66 AK 176			54.5	16.8
		3	ZU-23-2-2M Wrobel 23 mm/87 twin			N/A	2.679
16	Minerva	1	Oto Melara 76 mm/62 Compact			N/A	8.51
17	Eilat (Saar 5)	1	Oto Melara 76 mm/62 (Changeable with Phalanx)			N/A	8.51
		2	Sea Vulcan 20 mm CIWS			N/A	1.59
18	Khukri	1	3 in (76 mm)/ 66 AK 176			54.5	16.8
		2	30 mm/65 AK 630M			N/A	7.4
19	Baptisda De Andrade Class	1	Creusot Loire 3.9 in(100 mm)/55 mod 1968 MK 2			84	21
		2	Bofors 40 mm/ 70			N/A	3.4
20	Joao Coutinho	1	MK 33 US 3 in (76 mm)/50 (Twin)			N/A	16.8
		1	Bofors 40 mm/ 60 (Twin) US Mk 1	4.5	16.024	N/A	6.76
21	Fatahillah	1	Bofors 4.7 in(120 mm) TAK 120L/46			60	28.8
		1	Bofors 40 mm/ 70 (350 AFD WM28/Lirod)	14.72	35.637	N/A	2.89
		2	Rheinmetall 20 mm S.20			N/A	N/A
22	Ishikari	1	Oto Breda 76 mm/62 Compact			N/A	8.51
		1	GE/GD 20 mm Phalanx			N/A	5.42
23	Niels Juel	1	Oto Melara 76 mm/62 Compact			N/A	8.51
		4	12.7 mm Machine Guns			N/A	N/A

APPENDIX 10 Corvettes' Payload Breakdown Table A-3

No	Ship Class	Guns Unit	Guns Type	Gun Area	Gun Volume	Gun Power Consumption[KW]	Guns Weight Tons
24	Cassiopea	1	Oto Melara 3 in 76 mm/62 Compact			N/A	8.51
		2	12.7 mm Machine Guns			N/A	N/A
25	Vosper Mk5(Alvand)	1	Vickers 4.5 in(114 mm)/55 Mk 8			100	26.41
		1	Oerlikon 35 mm/90 (Twin) GDMA			N/A	6.52
		3	Oerlikon GAM-BO1 20 mm			N/A	1.5
26	Victory	1	Oto Melara 3 in (76 mm)/62 Super Rapid			N/A	8.51
		4	12.7 mm Machine Guns			N/A	N/A
27	Magdeburg	1	Oto Breda 76 mm/62 Compact			N/A	8.51
		2	Mauser 27 mm			N/A	4
28	Descubierta	1	Oto Melara 3 in 76 mm/62 Compact			N/A	8.51
		2	Oerlikon 20 mm US Mk 10			N/A	1
		1	Bofors 40 mm/ 70 (Bazan 350)	14.72	35.637	N/A	2.89
29	Robinson	1	Oto Melara 3 in 76 mm/62 Compact			N/A	8.51
		2	Oto Breda 40 mm/70 Twin			N/A	7.3
		2	12.7 mm Machine Guns			N/A	N/A
30	Kasturi	1	Creusot Loire 3.9 in(100 mm)/55 Mk 2 Compact			84	13.5
		2	Emerson Electric 30 mm (Twin)			N/A	3.8
		1	Bofors 375 mm Twin Trainable Launcher			N/A	N/A

APPENDIX 11 Corvettes' Payload Breakdown Table B-1

No	Ship Class	Missile System Unit	Missile Launcher Unit	Missile System	Missile Weight
1	Stockholm	8	4	RBS-15 Mk. III	6.4
2	Goteborg	8	4	RBS-15 Mk. II	6.24
3	KralJ Petar Kresimir 4	8	4	RBS-15 Mk. II	6.24
4	Visby	8	4	RBS-15 Mk. II (Batch 2)	6.24
5	Khamronsin	N/A	N/A	N/A	N/A
6	Roussen	4	2	MBDA Exocet MM 40 Block 2	3.48
		21	1	Mk 31 Mod 1 Launcher with 21 missiles (SAM)(RIM 116)	5.777
7	Elefteria	N/A	N/A	N/A	N/A
8	HTMS Rattanakosin	8	2	McDonnell Douglas Harpoon (2 Quad) RGM 84 A	5.52
		8	1	Selenia Elsag Aspide Octuple Launcher(SAM)	8.2
9	Dong Hae	N/A	N/A	N/A	N/A
10	PF 103 Bayandor	N/A	N/A	N/A	N/A
11	Serviola	N/A	N/A	N/A	N/A
12	Parchim	4	1	SA-N 5 Grail Quad Launchers(SAM)	N/A
13	Pohang	2	2	Aerospatiele MM 38 Exocet	1.47

APPENDIX 12 Corvettes' Payload Breakdown Table B-2

No	Ship Class	Missile System Unit	Missile Launcher Unit	Missile System	Missile Weight
14	Lutsk	2	1	SA-N-4 Gecko Twin Launcher (SAM)	0.4
15	Kaszub	4	1	SA-N-5 Grail Quad Launchers(SAM)	N/A
16	Minerva	N/A	N/A	Fitted for but not with 4 or 6 Teseo Otomat Between Masts	N/A
		8	1	Selenia Elsag Aspide/Albatros Octuple Launcher(SAM)	8.2
17	Eilat (Saar 5)	8	2	McDonnell Douglas Harpoon (2 Quad)	5.52
		32	2	Israeli Industries Barak 1(Vertical Launch)	2.5
18	Khukri	4	2	SS-N-2D Mod 1 STYX (Twin) Launcher	10
		4	1	SA-N 5 Grail Quad Launchers(SAM)	N/A
19	Baptisda De Andrade Class	N/A	N/A	N/A	N/A
20	Joao Coutinho	N/A	N/A	N/A	N/A
21	Fatahillah	4	2	Aerospatiele MM 38 Exocet	2.94
22	Ishikari	8	2	McDonnell Douglas Harpoon (2 Quad)	5.52
23	Niels Juel	8	2	McDonnell Douglas Harpoon (2 Quad)	5.52
		6	2	Raytheon Sea Sparrow Mk 48 Mod 3 VLS (2 Sextuple)	2.4

APPENDIX 13 Corvettes' Payload Breakdown Table B-3

No	Ship Class	Missile System Unit	Missile Launcher Unit	Missile System	Missile Weight
24	Cassiopea	N/A	N/A	N/A	N/A
25	Vosper Mk5(Alvand)	4	2	China C-802(2 Twin)(Saccade)	2.86
26	Victory	8	2	McDonnell Douglas Harpoon	5.52
		16	2	Israeli Industries Barak 1(Vertical Launch)	1.25
27	Magdeburg	4	2	SAAB RBS-15 MK 3	3.2
		21	2	RAM 21 Cell Mk 49 Launcher	11.54
28	Descubierta	8	2	McDonnel Douglas Harpoon (2 Quad) Launcher	5.52
		8	1	Selenia Elsag Aspide/Albatros Octuple Launcher(SAM)	8.2
29	Robinson	4	2	Aerospatiele MM 38 Exocet	2.94
30	Kasturi	8	2	Aerospatiele MM 40 Exocet Block 2	6.96

APPENDIX 14 Corvettes' Payload Breakdown Table C-1

No	Ship Class	Torpedo Unit	Torpedo Type	Torpedo Area	Torpedo Volume	Torpedo Weight
1	Stockholm	4	Type 43/45	1.056	0.4224	1.24
2	Goteborg	4	Type 43/45	1.056	0.4224	1.24
3	KralJ Petar Kresimir 4	N/A	N/A	N/A	N/A	N/A
4	Visby	4	Type 43/45	1.056	0.4224	1.24
5	Khamronsin	6	Plessey PMW 49A	1.056	0.4224	1.86
6	Roussen	N/A	N/A	N/A	N/A	N/A
7	Elefteria	6	324 Mk 32(2 triple Tubes)	N/A	N/A	N/A
		4	Honeywell Mk46 Mod 5	0.83916	0.27188784	0.932
8	HTMS Rattanakosin	6	Honeywell Mk46 Mod 5	0.83916	0.27188784	1.464
9	Dong Hae	6	324 Mk 32(2 triple Tubes)	N/A	N/A	N/A
		4	Honeywell Mk46 Mod 5	0.83916	0.27188784	0.932
10	PF 103 Bayandor	N/A	N/A	N/A	N/A	N/A
11	Serviola	N/A	N/A	N/A	N/A	N/A
12	Parchim	4	21 in(533 mm) (2 twin) Tubes USET-95	2.05205	1.09374265	2.6
13	Pohang	6	324 Mk 32(2 triple Tubes)	N/A	N/A	N/A
		4	Honeywell Mk46 Mod 5	0.83916	0.27188784	0.932

APPENDIX 15 Corvettes' Payload Breakdown Table C-2

No	Ship Class	Torpedo Unit	Torpedo Type	Torpedo Area	Torpedo Volume	Torpedo Weight
14	Lutsk	4	21 in(533 mm) (2 twin) Tubes TYPE 53-56	3.731	1.988623	8
15	Kaszub	4	21 in(533 mm) (2 twin) Tubes TYPE 53-56	3.731	1.988623	8
16	Minerva	6	324 Mk White Head B515(2 triple Tubes)	N/A	N/A	N/A
		4	Honeywell Mk46 Mod 5	0.83916	0.27188784	0.932
17	Eilat (Saar 5)	6	324 Mk White Head B515(2 triple Tubes)	N/A	N/A	N/A
		6	Honeywell Mk46	0.83916	0.27188784	1.398
18	Khukri	N/A	N/A	N/A	N/A	N/A
19	Baptisda De Andrade Class	N/A	N/A	N/A	N/A	N/A
20	Joao Coutinho	N/A	N/A	N/A	N/A	N/A
21	Fatahillah	6	324 mm Mk 32(2 triple Tubes)	N/A	N/A	N/A
		12	Honeywell Mk46 Mod 5	0.83916	0.27188784	2.796
22	Ishikari	6	324 mm Type 68 (2 triple Tubes)	N/A	N/A	N/A
		4	Honeywell Mk46 Mod 5	0.83916	0.27188784	0.932
23	Niels Juel	N/A	N/A	N/A	N/A	N/A

APPENDIX 16 Corvettes' Payload Breakdown Table C-3

No	Ship Class	Torpedo Unit	Torpedo Type	Torpedo Area	Torpedo Volume	Torpedo Weight
24	Cassiopea	N/A	N/A	N/A	N/A	N/A
25	Vosper Mk5(Alvand)	6	324 mm Mk 32(2 triple Tubes)			1.398
26	Victory	6	Whitehead A 244/SPS	0.88825	0.28690475	1.464
27	Magdeburg	N/A	N/A	N/A	N/A	N/A
28	Descubierta	6	324 mm Mk 32(2 triple Tubes)	N/A	N/A	N/A
		12	Honeywell Mk46 Mod 5	0.83916	0.27188784	2.796
29	Robinson	6	324 mm Mk 32(2 triple Tubes)	N/A	N/A	N/A
		6	Whitehead A 244/SPS	0.88825	0.28690475	1.464
30	Kasturi	N/A	N/A	N/A	N/A	N/A

APPENDIX 17 Corvettes' Payload Breakdown Table D-1

No	Ship Class	Radar Unit	Main Radar Type	Radar Area	Radar Volume	Radar Weight
1	Stockholm	1	Sea Giraffe 150HC Air/Surf Search			1.137
2	Goteborg	1	Sea Giraffe 150HC Air/Surf Search			1.137
3	KralJ Petar Kresimir 4	1	Racal BT 502			
4	Visby	1	Ericson Sea Giraffe AMB 3D			1.137
5	Khamronsin	1	Plessey AWS 4			2.875
6	Roussen	1	Thomson-CSF MW 08			
7	Elefteria	1	Thomson-CSF TRS 3001			
8	HTMS Rattanakosin	1	Signaal DA05			
9	Dong Hae	1	Raytheon SPS-64 Surface Search	N/A	N/A	0.274
10	PF 103 Bayandor	1	Westinghouse SPS-6C			
11	Serviola	1	Racal Decca 2459			
12	Parchim	1	Cross Dome Air Surface Radar			
13	Pohang	1	Marconi 1810			

APPENDIX 18 Corvettes' Payload Breakdown Table D-2

No	Ship Class	Radar Unit	Main Radar Type	Radar Area	Radar Volume	Radar Weight
14	Lutsk	1	Half Plate B Air Surface Radar			
15	Kaszub	1	Strut Curve(MR 302)			
16	Minerva	1	Selenia SPS 774(RAN 10S)			
17	Eilat (Saar 5)	1	Elta EL/M-2218S(Air Search)			
		1	Cardion SPS-55(Surf Search)			
18	Khukri	1	Cross Dome Air Surface Radar			
19	Baptisda De Andrade Class	1	KH 5000 Nucleos			
20	Joao Coutinho	1	Kelvin Hughes 1007			
21	Fatahillah	1	Signaal DA05			
22	Ishikari	1	JRC OPS-28B/28-1			
23	Niels Juel	1	DASA TRS 3d Air Search			
		1	Philips 9GR 600 Surf Search			

APPENDIX 19 Corvettes' Payload Breakdown Table D-3

No	Ship Class	Radar Unit	Main Radar Type	Radar Area	Radar Volume	Radar Weight
24	Cassiopea	1	SMA SPS-702(V)2			
25	Vosper Mk5(Alvand)	1	Plessey AWS 1			
26	Victory	1	Ericsson/Radamec Sea Giraffe 150 HC			1.137
27	Magdeburg	1	DASA TRS 3d Air Search			
28	Descubierta	1	Signaal DA05/2			
29	Robinson	1	Signaal DA05			
30	Kasturi	1	Signaal DA08 Air Surface Search			

APPENDIX 20 Corvettes' Payload Breakdown Table E-1

No	Ship Class	Sonar Type	Sonar Area	Sonar Volume	Sonar Weight
1	Stockholm	Simrad SA 950	10	20	5
2	Goteborg	Hydra Multi Sonar System (Simrad SA 950);Thomson Sintra TSM 2643 Salmon	4.15	20	6
3	KralJ Petar Kresimir 4	RIZ PP10M			
4	Visby	Computing Devices Canada (CDC)			
5	Khamronsin	Atlas Elektronik DSQS-21C			
6	Roussen	N/A	N/A	N/A	N/A
7	Elefteria	Atlas Elektronik ELAC 1 BV			
8	HTMS Rattanakosin	Atlas Elektronik DSQS-21C			
9	Dong Hae	Signaal PHS-32 Hull Mounted Sonar			7
10	PF 103 Bayandor	EDO SQS-17A			
11	Serviola	N/A	N/A	N/A	N/A
12	Parchim	Bull Horn			
13	Pohang	Signaal PHS-32 Hull Mounted Sonar			

APPENDIX 21 Corvettes' Payload Breakdown Table E-2

No	Ship Class	Sonar Type	Sonar Area	Sonar Volume	Sonar Weight
14	Lutsk	Bull Nose(Mgk 335 MS)			
15	Kaszub	MG 322 T			
16	Minerva	Raytheon/Elsag DE 1167			
17	Eilat (Saar 5)	EDO Type 796 Mod 1			
18	Khukri	N/A	N/A	N/A	N/A
19	Baptisda De Andrade Class	N/A	N/A	N/A	N/A
20	Joao Coutinho	N/A	N/A	N/A	N/A
21	Fatahillah	Signaal PHS-32 Hull Mounted Sonar			7
22	Ishikari	Nec SQS-36J			
23	Niels Juel	Plessey PMS 26			

APPENDIX 22 Corvettes' Payload Breakdown Table E-3

No	Ship Class	Sonar Type	Sonar Area	Sonar Volume	Sonar Weight
24	Cassiopea	N/A	N/A	N/A	N/A
25	Vosper Mk5(Alvand)	Graseby 174			
26	Victory	Thomson Sintra TSM 2064			
27	Magdeburg	N/A	N/A	N/A	N/A
28	Descubierta	N/A	N/A	N/A	N/A
29	Robinson	Atlas Elektronik ASO 4			
30	Kasturi	Atlas Elektronik DSQS-21C			

APPENDIX 23 Corvettes' Payload Breakdown Table F-1

No	Ship Class	Engines Unit	Engines Type	Total Machinery Area M^2	Total Engine Volume M^3	Total Engine Weight	Total Power HP
1	Stockholm	1	Allied Signal Vericor TF50 A G/T	1.264	1.413	0.675	5440
		2	MTU 16 V 396 TB94 Diesels	9.3942	15.03072	12.28	5277
2	Goteborg	3	MTU 16 V 396 TB94 Diesels	14.0913	22.54608	18.42	8700
3	KralJ Petar Kresimir 4	3	MTU 20V 538 TB 93	20.4225	52.3837125	30.3	12500
4	Visby	4	Allied Signal Vericor TF50 A G/T	5.056	5.652	2.7	21760
		2	MTU 16 V 2000 M90 Diesels	6.314	8.14506	6.59	3536
5	Khamronsin	2	MTU 12 V 1163 TB93 Diesels	15.01368	56.7517104	31.73	9980
6	Roussen	4	MTU 16 V 595 TE 90 Diesels	26.4272	75.846064	52	23170
7	Elefteria	2	MAN V84V Diesels	13.28	33.864	27.306	6800
8	HTMS Rattanakosin	2	MTU 20 V 1163 TB83 Diesels	17.76864	67.2543024	45.96	14730
9	Dong Hae	1	GE LM 2500 G/T	13.3008	27.133632	4.682	26820
		2	MTU 12 V 1163 TB82 Diesels	12.5164	47.374574	31.73	6260
10	PF 103 Bayandor	2	Fairbank Morse 38TD8-1/8-9 Diesels	42.58056	55.354728	66	6800
11	Serviola	2	MTU-Bazan 16 V 956 TB 91 Diesels	13.28	33.864	27.306	7500
12	Parchim	3	ZVEZDA, Type M 504A Diesels	23.36625	38.67114375	22.5	10812
13	Pohang	1	GE LM 2500 G/T	13.3008	27.133632	4.682	26820
		2	MTU 12 V 956 TB82 Diesels	11.072	27.18176	21.8	6260

APPENDIX 24 Corvettes' Payload Breakdown Table F-2

No	Ship Class	Engines Unit	Engines Type	Total Machinery Area M^2	Total Engine Volume M^3	Total Engine Weight	Total Power HP
14	Lutsk	1	M8M G/T UGT 15000	13	36.4	11.5	20000
		2	M 507A Diesels	25.48	63.4452	34.2	18000
15	Kaszub	4	Cegielski-Sulzer AS 16 V 25/30 Diesels	61.394784	172.6421326	150	16900
16	Minerva	2	GMT B 230.20 DVM Diesels (GMT BL230P)	19.26528	45.8513664	48.6	11000
17	Eilat (Saar 5)	1	GE LM 2500 G/T	13.3008	27.133632	4.682	30000
		2	MTU 12 V 1163 TB 82 Diesels	12.5164	47.374574	31.73	6600
18	Khukri	2	SEMT-Pielstick/Kirloskar18 PA6CL V 280 Diesels	25.8453	78.1303419	68	14400
19	Baptisda De Andrade Class	2	OEW Pielstick 12 PC2.2 V 400 Diesels	46.06	142.0951	160	12000
20	Joao Coutinho	2	OEW Pielstick 12 PC2.2 V 400 Diesels	46.06	142.0951	160	12000
21	Fatahillah	1	RR Olympus TM3B G/T	17.1375	53.12625	25.7	25440
		2	MTU 20 V 956 TB 92 Diesels	15.392	40.63488	32.446	11070
22	Ishikari	1	Kawasaki/RR Olympus TM3B G/T	17.1375	53.12625	25.7	24700
		1	Mitsubishi/MAN 6DRV Diesel	5.5942	21.174047	15.685	4700
23	Niels Juel	1	GE LM 2500 G/T	13.3008	27.133632	4.682	24600
		1	MTU 20 V 956 TB 82 Diesel	7.696	20.31744	16.223	5210

APPENDIX 25 Corvettes' Payload Breakdown Table F-3

No	Ship Class	Engines Unit	Engines Type	Total Machinery Area M^2	Total Engine Volume M^3	Total Engine Weight	Total Power HP
24	Cassiopea	2	GMT BL 230.16 DVM Diesels	15.78528	35.51688	37	7940
25	Vosper Mk5(Alvand)	2	RR Olympus TM 2A G/T	34.275	106.2525	50	40000
		2	Paxman 16 YJCM Diesels	6.314	9.471	10.358	3800
26	Victory	4	MTU 16 V 538 TB 93 Diesels (By STX from South Korea)	22.8944	57.350472	31.12	15020
27	Magdeburg	2	MTU 20V 1163 TB 93	20.2765	73.2995475	45.6	19850
28	Descubierta	4	MTU-Bazan 16 V 956 TB 91 Diesels	26.368	67.2384	54.612	15000
29	Robinson	2	SEMT-Pielstick 16 PC2.5 V400 Diesels	60.606	206.0604	166	20400
30	Kasturi	4	MTU 20 V 1163 TB 92 Diesels	40.553	146.599095	84.2	23400

APPENDIX 26 Corvettes' Payload Breakdown Table G-1

No	Ship Class	Shafts	Helicopter Platform	Helicopter Units	Helicopter Type	Remarks
1	Stockholm	3	N/A	N/A	N/A	
2	Goteborg	3	N/A	N/A	N/A	Decommisioned/WaterJet Driven
3	KralJ Petar Kresimir 4	3	N/A	N/A	N/A	
4	Visby	2	Yes	1	Agusta A 109M	WaterJet Driven.No Hangar
5	Khamronsin	2	N/A	N/A	N/A	CPP
6	Roussen	4	N/A	N/A	N/A	
7	Elefteria	2	N/A	N/A	N/A	
8	HTMS Rattanakosin	2	N/A	N/A	N/A	CPP
9	Dong Hae	2	N/A	N/A	N/A	CPP
10	PF 103 Bayandor	2	N/A	N/A	N/A	
11	Serviola	2	Yes	1	AB 212	CPP,No Hangar
12	Parchim	3	N/A	N/A	N/A	
13	Pohang	2	N/A	N/A	N/A	CPP

APPENDIX 27 Corvettes' Payload Breakdown Table G-2

No	Ship Class	Shafts	Helicopter Platform	Helicopter Units	Helicopter Type	Remarks
14	Lutsk	3	N/A	N/A	N/A	MIW Capability
15	Kaszub	2	N/A	N/A	N/A	CPP
16	Minerva	2	N/A	N/A	N/A	CPP
17	Eilat (Saar 5)	2	Yes	1	Sea Panther or Dauphin SA 366G	CPP,Hangar Available
18	Khukri	2	Yes	1	Chetak	CPP,No Hangar
19	Baptisda De Andrade Class	2	Yes	1	Not Specified	No Hangar,Will be retired soon
20	Joao Coutinho	2	Yes	1	Not Specified	No Hangar,Will be retired soon
21	Fatahillah	2	N/A	N/A	N/A	CPP,Hangar Available in Latter Ships
22	Ishikari	2	N/A	N/A	N/A	CPP
23	Niels Juel	2	N/A	N/A	N/A	

APPENDIX 28 Corvettes' Payload Breakdown Table G-3

No	Ship Class	Shafts	Helicopter Platform	Helicopter Units	Helicopter Type	Remarks
24	Cassiopea	2	Yes	1	AB 212	CPP,No Hangar
25	Vosper Mk5(Alvand)	2	N/A	N/A	N/A	CPP
26	Victory	4	N/A	N/A	N/A	
27	Magdeburg	2	Yes	1	NH 90	Helicopter Hangar for 2 Camcopter S-100
28	Descubierta	2	N/A	N/A	N/A	CPP
29	Robinson	2	Yes	1	SA 319 B Alouette or AS 555 Fennec	No Hangar
30	Kasturi	2	Yes	1	AS 555 Fennec or Lynx 300	No Hangar

APPENDIX 29 CRS Structure Variables Breakdown

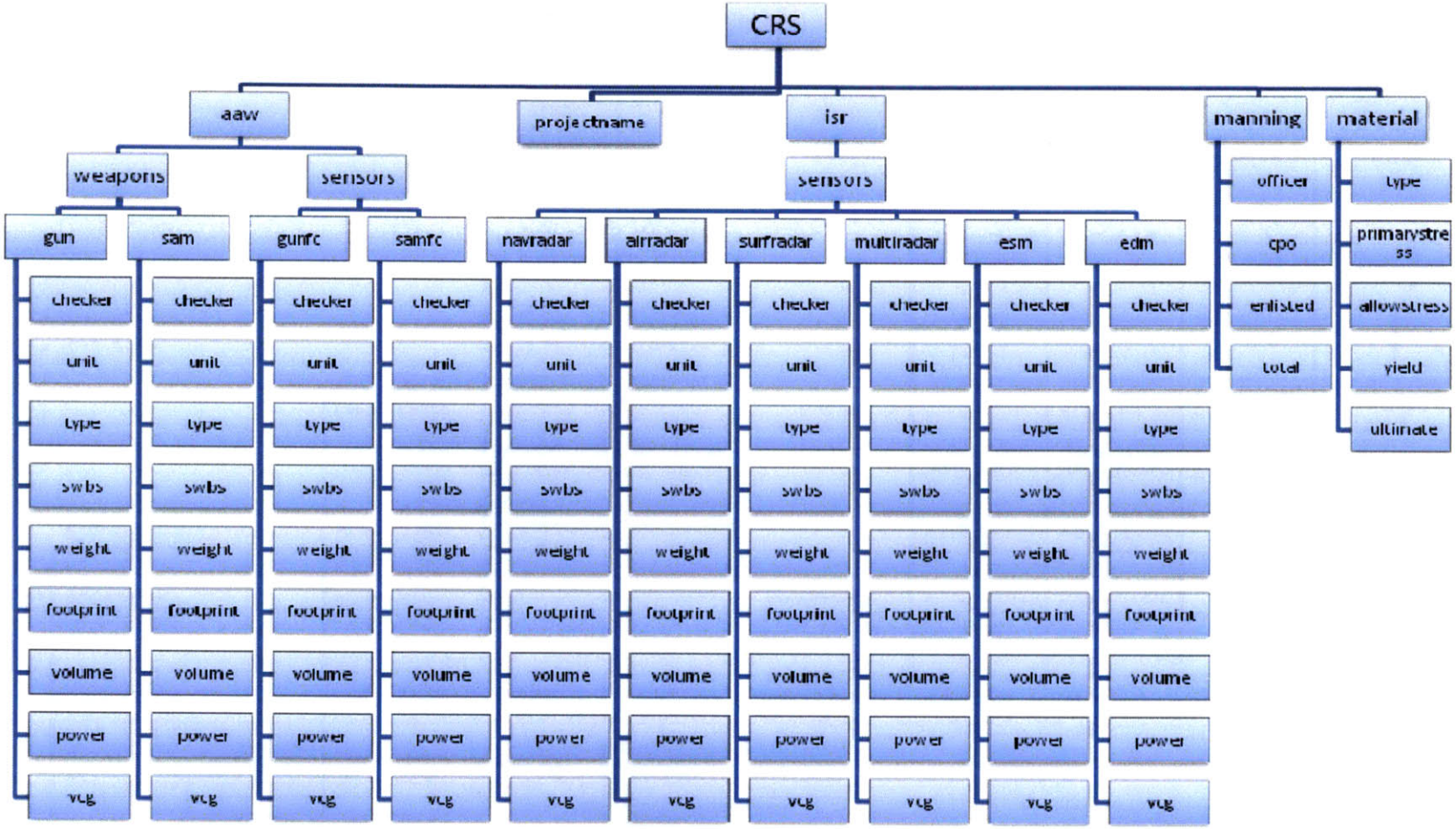

Figure 81 CRS Variables Breakdown 1-A

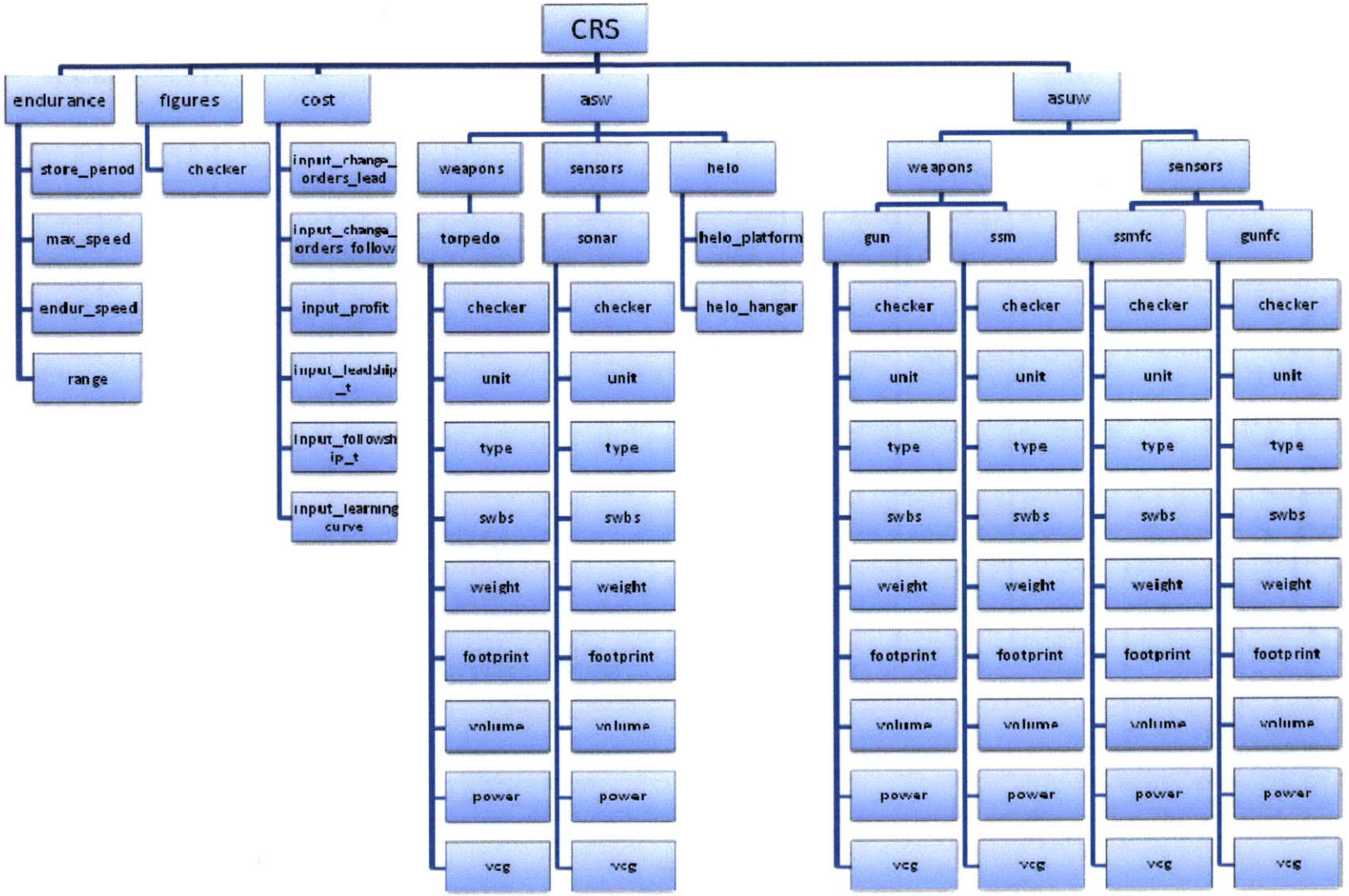

Figure 82 CRS Variables Breakdown 1-B

APPENDIX 30 MODULES Hull Structure Variables Breakdown

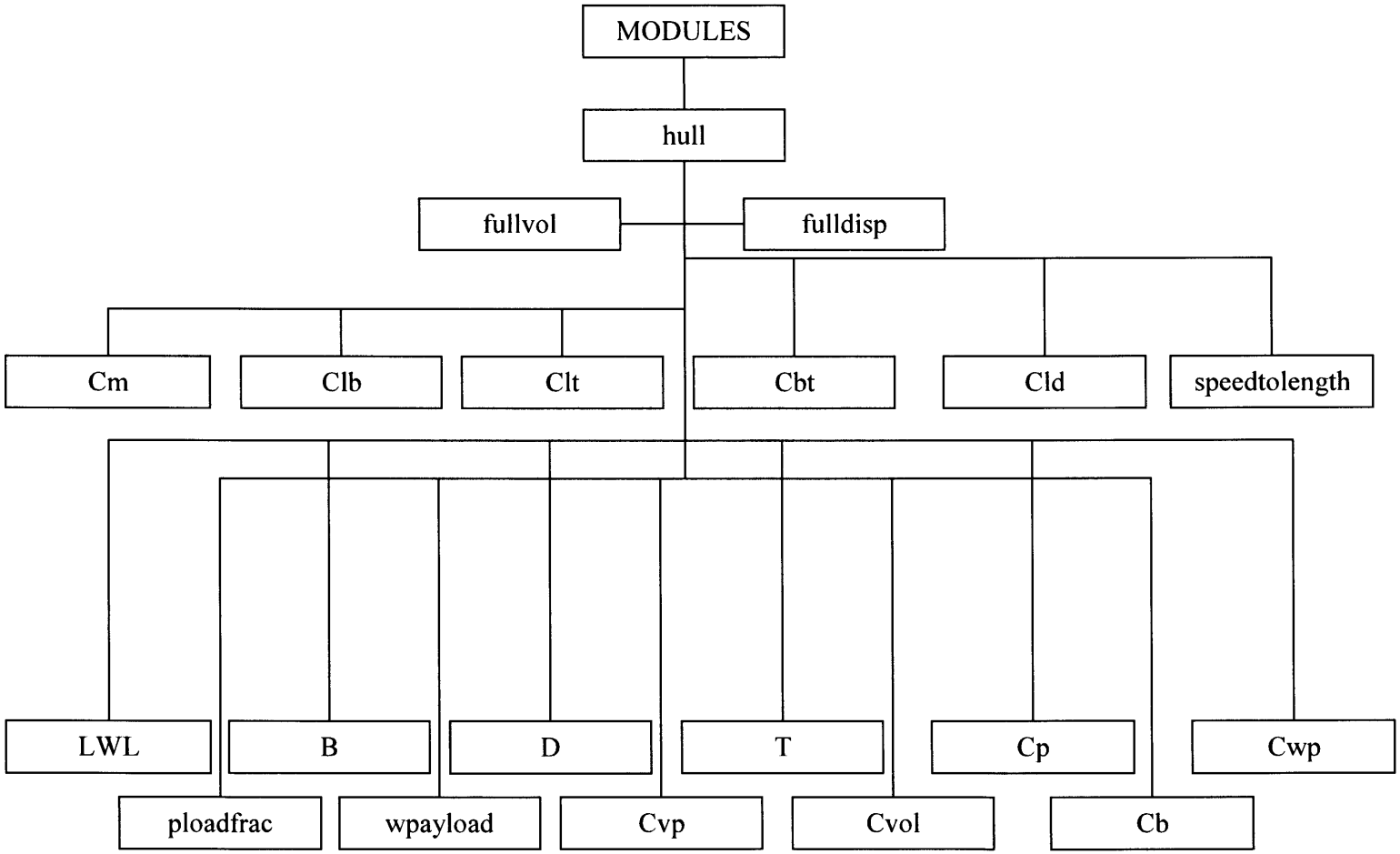

Figure 83 MODULES Hull Structure Variables Breakdown

APPENDIX 31 MODULES Machinery Structure Variables Breakdown

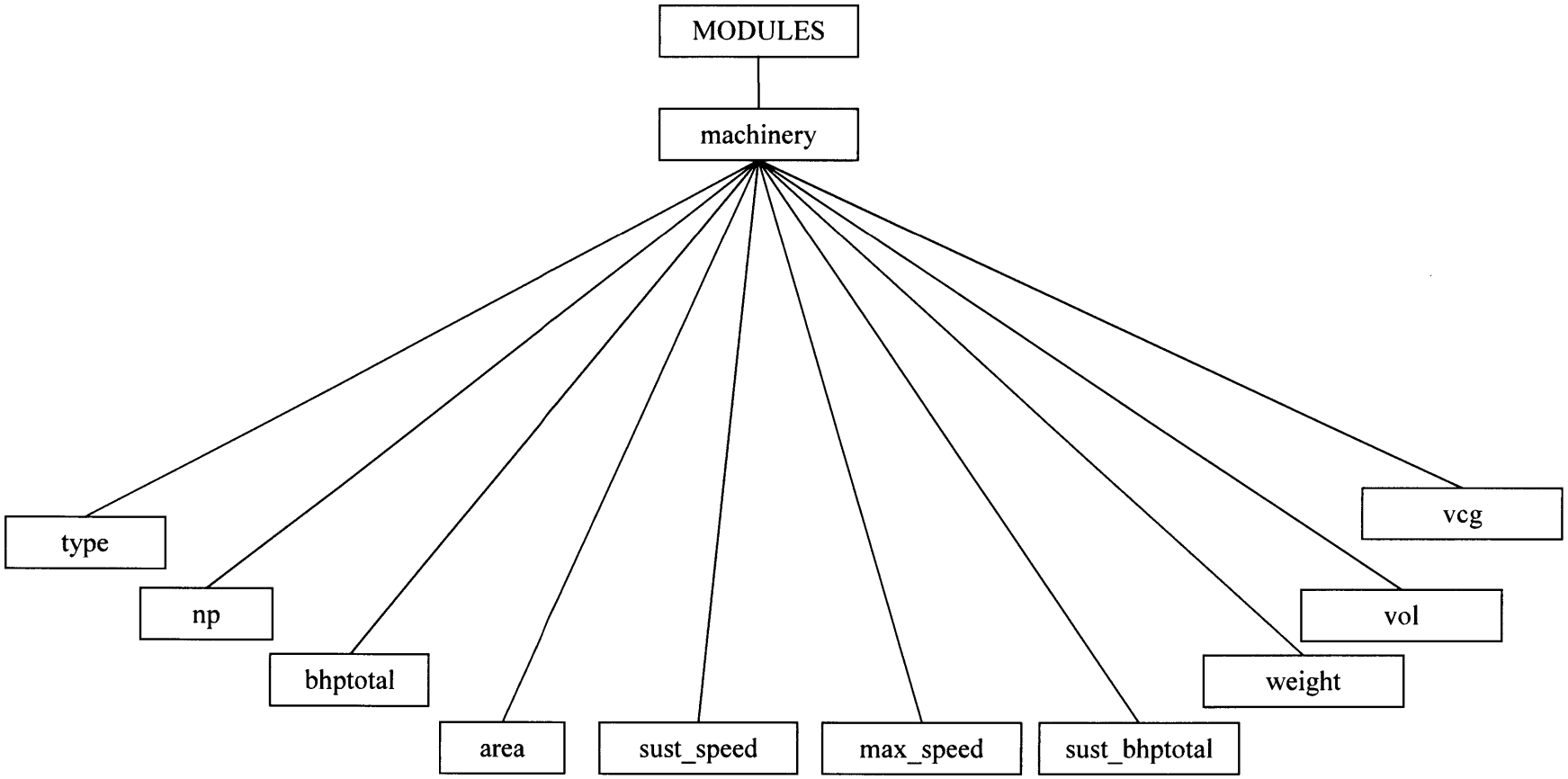

Figure 84 MODULES Machinery Structure Variables Breakdown

APPENDIX 32 MODULES Space Structure Variables Breakdown

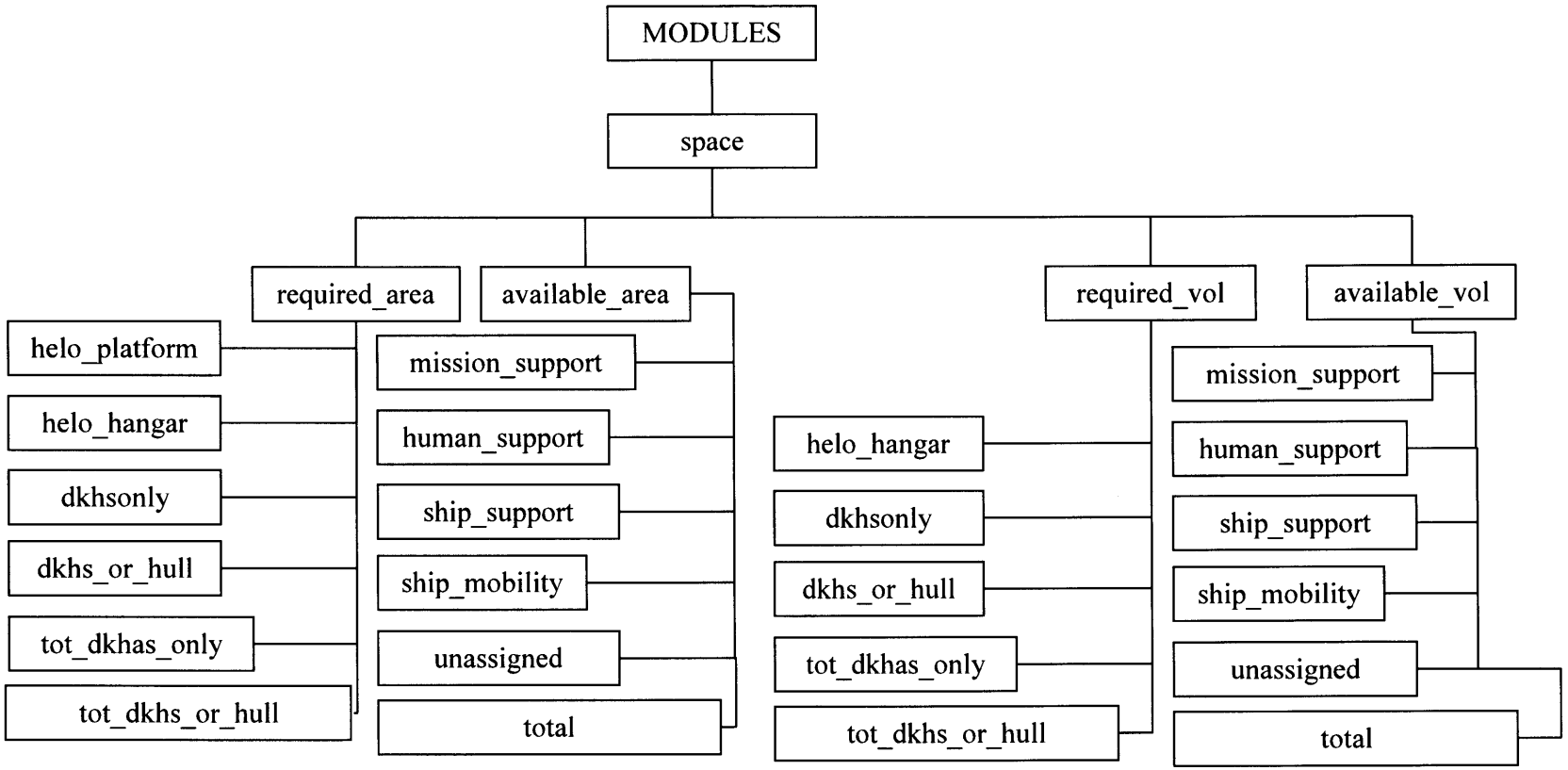

Figure 85 MODULES Space Structure Variables Breakdown

APPENDIX 33 MODULES Weight Structure Variables Breakdown

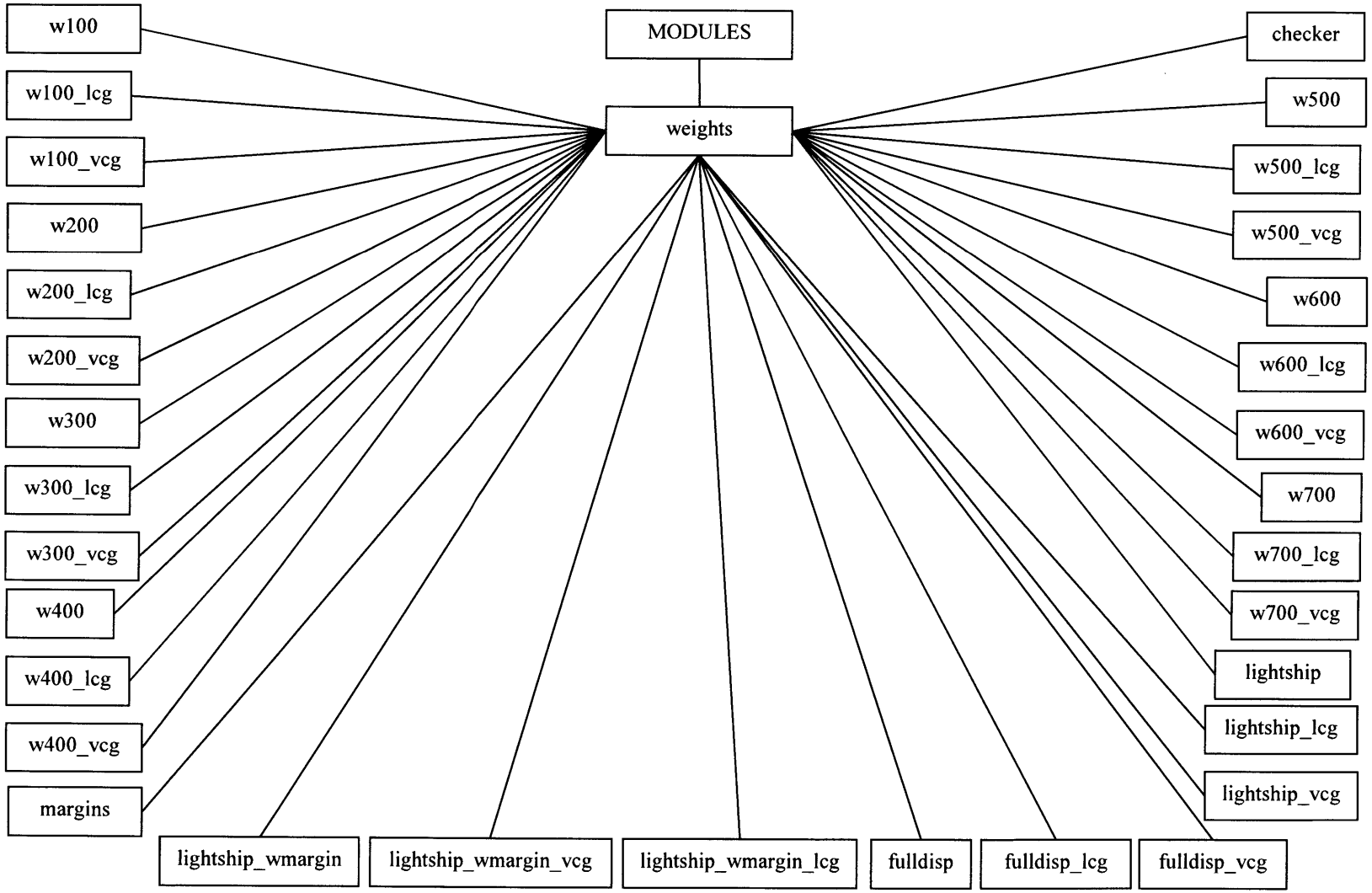

Figure 86 MODULES Weights Structure Variables Breakdown

APPENDIX 34 MODULES Stability Structure Variables Breakdown

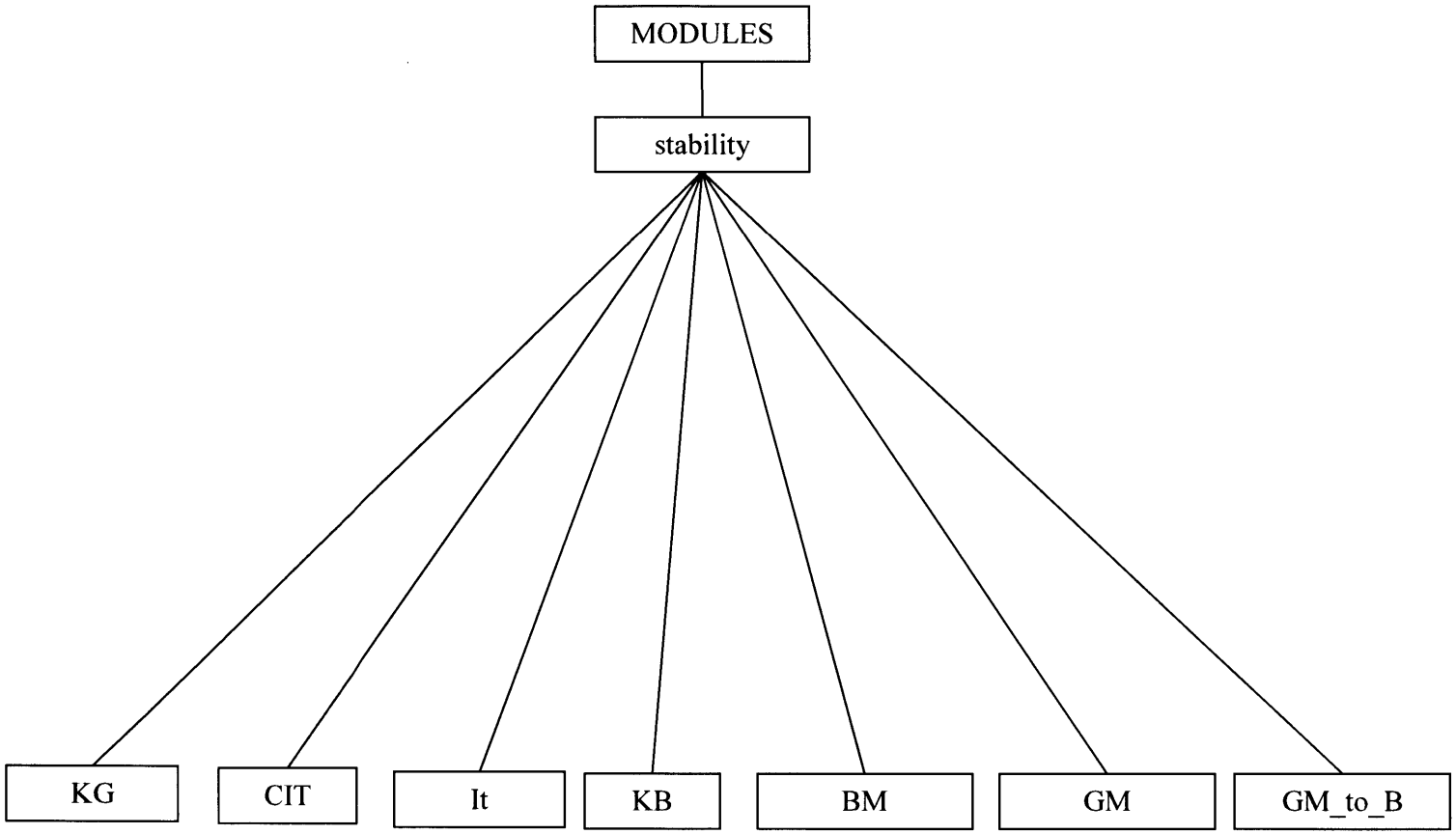

Figure 87 MODULES Stability Structure Variables Breakdown

APPENDIX 35 MODULES Match Structure Variables Breakdown

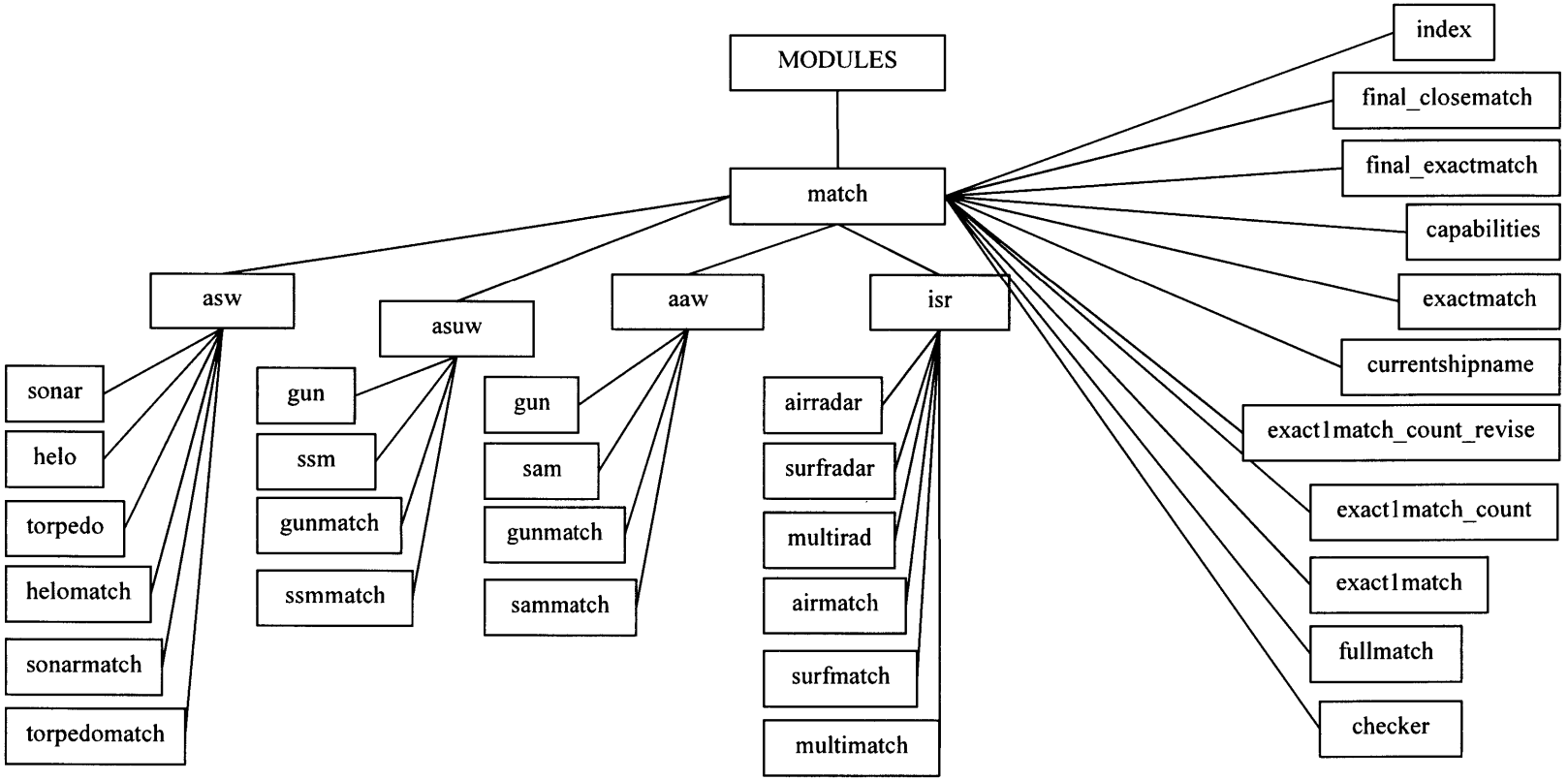

Figure 88 MODULES Match Structure Variables Breakdown