RECONSTRUCTING ROCKETS:
The Politics of Developing Military Technology in Brazil, India, and Israel

by

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ABSTRACT

This thesis is a study of why and how some countries develop the technologies to produce ballistic missiles. I tell that story for three countries--Brazil, India, and Israel. In each case, I follow whatever strands seem important to the story, from fiberglass motor cases and solid propellant binders to organizational rivalries and the broadest philosophical debates of a society.

Theory:
With the end of the Cold War, missile proliferation has achieved greater prominence as a worldwide security problem. Current understandings of proliferation and the development of military technologies in general emphasize security-based or external motivations, giving insufficient attention to the political nature of these technologies. My three case studies raise questions about whether external factors can be a plausible explanation for even the basic existence of missile programs, much less their actual shape. The thesis instead develops and applies a strong methodology for probing the internal motivations for the evolution of indigenous missile technology, based on the history and sociology of technology.

This established body of theory and practice, also known as the social construction of technology, elevates technology to the same status as bureaucracies, nationalism, or security threats as a subject worthy of detailed scrutiny. The theory recognizes that the diverse communities and interests needed to make missiles a reality will never monolithically decide to construct ballistic missiles, with the technical processes then obediently following in the wake of the political decision. Instead, starting small and building on existing resources, a "large technological system" is painstakingly constructed, and if successful, recruits both "social" and "technical" allies along the way. The traces of this process can be revealed by examining technical artifacts as "congealed culture," as embodying the social and political context of their original construction.

Cases:
Brazil: The Brazil chapter argues that a traditional security analysis, looking at threats, rivals, security dilemmas, and military capability, is insufficient to explain this case. As one of the main figures in the research effort, an Air Force colonel, said, "After all, whom will we attack?" A realist perspective has difficulty accounting for even the existence of Brazil's Sonda rockets or VLS satellite launch vehicle, much less their specific history or characteristics.

My analysis instead examines how the detailed construction of Brazilian missiles reflects the empire-building tactics of important engineers, the competition between the leading missile and space research organizations, the prevailing ideas about military technology's role in development, and the place of the military in the Brazilian polity. I conclude that the Brazilian space and missile programs are a result of a temporary convergence of a diverse set of personal, organizational, and ideological interests, a convergence that is now mostly in the past.

India: While there may be little technical difference between the Indian missile and space programs, they are politically quite distinct. The space program is supported by a stable, national consensus based on broad themes that are found throughout Indian politics, such as nation-building, self-reliance or technological autonomy, and international position. The missile program is a less stable and historically contingent alliance of particular interests, such as concerns about brain drain, a small cadre of missile engineers, India's nuclear

"option strategy", and Army-Air Force rivalry. The analysis again examines the detailed construction of the artifacts of the missile programs, especially the intermediate range Agni and short range Prithvi missiles.

The Agni missile, although it did travel a thousand kilometers in its first test, is not a ballistic missile in the usual sense. So far, it has been just two specimens of a hybrid, RV technology test bed, a weak political alliance that is only as strong as the interstage holding together rockets from the space and Prithvi programs. The Prithvi missile, which is far more likely to become a deployed, mass-produced system, has had its political essence defined by its relationships to the Army, to long-range artillery, and by necessity, to conventional, non-nuclear warheads. Each of these conclusions demonstrates that the Indian space and missile programs are far less problematic (from the perspective of risks of war or of U.S. policy) than commonly assumed. Many traditional political analyses, because they ignore so much of the politics of developing military technologies, are not able to reach these same conclusions.

Israel: From the late 1950s through the mid-1970s, four forces in the Israeli political system promote the development of new weapons systems and new military technology: self-reliance, inter-industry rivalry, faith in technology, and secrecy. The primary inhibiting forces are economic limitations, the availability of alternatives to indigenous development, and again secrecy. These forces are structural, in the sense that their power spans more than the single issue of security, and in the sense that they are not likely to change quickly as a result of events only in the security arena.

The characteristics of Israeli missiles are determined largely by a synthesis of these conflicting forces, rather than any specific military requirements. The resulting patterns include virtual autonomy, export dependence, and bottom-up technological development. Each is functionally adapted to meeting simultaneously the demands of both the promoting and constraining forces. Even strategic systems such as Jericho missiles or the Shavit satellite launch vehicle fit consistently into these broader patterns of indigenous technology development in Israel. A security-centered analysis, on the other hand, would not be able to explain much beyond the basic fact that Israel will have missiles--not how many, what kind, or whether or not they will be indigenous.
Since the mid-1970s, some of the structural factors enforcing the dialectical pattern in Israel have changed. For example, each test, each use of indigenous technology in combat, increases the acceptance, desirability, and ease of recruiting for new indigenous technologies. The process feeds on itself. Since the mid-1970s, it has become progressively harder to challenge the idea that Israel can and should develop its own weapons systems. Nonetheless, even now the internal contradictions highlighted by this analysis continue to plague Israeli military industry.

Conclusions:
Beyond the specific conclusions of these three case narratives, this thesis evaluates the utility of the history and sociology of technology in understanding the development of military technologies. I conclude that the methodology is capable of generating conclusions different from those of other, more traditional, methodologies; that those conclusions are "interesting," in an academic or aesthetic sense; and that they are useful, in a policy sense.

In a more tentative way, this thesis also points to patterns in the seamless web of large military technological systems, including ballistic missile and nuclear weapons programs. These patterns may inform important aspects of international relations theory, such as the relatively minor role of traditional security motivations in all three of the case studies. Others can offer lessons for development theory, such as the significant role of the Westernized norms of indigenous engineering and scientific communities. Finally, these analyses could improve policy formulation, for example by highlighting the role of scientific and engineering communities or the close relationships between security and development policies in these countries.

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Much of the research and writing for this thesis was made possible by dissertation fellowships from the Center for Science and International Affairs (CSIA), at Harvard University's Kennedy School of Government, and from the Institute for the Study of World Politics. CSIA has also provided the working environment that any graduate student longs for: helpful colleagues, interesting if distracting projects and seminars, time for one's own research, and best of all, access to an excellent library at any time of the day or night. My thanks to Ash Carter and Steve Miller for all of their support at CSIA. My initial research was part of a summer's work in 1991 at the Lawrence Livermore National Laboratory, when I was also a visiting scholar at Stanford University's Center for International Security and Arms Control. My thanks to Bill Domke and John Harvey for making that productive time possible. I only survived to reach the dissertation phase thanks to four years of generous support from the MIT Defense and Arms Control Studies program, and its former and current directors, Jack Ruina and Harvey Sapolsky.

I owe a debt both personal and professional to numerous colleagues for opening new intellectual vistas, for helping me pass my classes, and for keeping me excited about this work: Eric Higginbotham, David Mussington, Jeffrey Sands, Judyth Twigg; Lisbeth Gronlund, George Lewis, David Wright; Sybil Francis, Hugh Gusterson, and Peter Lavoy.

David Guston deserves more than just a paragraph of his own, but here it is: friend and colleague, who has survived sharing offices and apartments with me, and who knows what I'm trying to say (even when I don't). Without him, both this thesis and my life the past six years would have been much the worse.

Chapter One benefits from comments and valuable suggestions from Avner Cohen, Sybil Francis, Ben Frankel, Hugh Gusterson, David Guston, Thomas Hughes, Peter Lavoy, and George Rathjens. David Guston bears at least some of the responsibility for originally introducing me to the history and sociology of technology. An article based on this chapter will appear in the Fall 1993 issue of *Security Studies*. My thanks to David Mussington for the title.

I presented earlier versions of Chapter Two in November 1991, at a joint session of the Research and Technical Seminars at Stanford University's Center for International Security and Arms Control and at the 1991 Annual Meeting of the Society for the Social Studies of Science. I thank both audiences for offering valuable comments and suggestions, which I have attempted to address. I also thank Ron Kerst, Scott Tollefson, Antonio Botelho, and Ken Conca for helping me to become more familiar with the Brazilian defense industries and with Brazilian politics in general.

For Chapter Three, I thank Peter Lavoy for his extensive comments and for helping to orient me in the literature on Indian security. Raju Thomas, Cheenu Srinivasan, and Tim McCarthy generously shared the results of their research. Particularly helpful were Tim McCarthy's details of the Indian missile programs and their history. I had the pleasure of spending a highly productive week in February 1992 with Steven Cohen, Itty Abraham, and other researchers at the Arms Control, Disarmament, and International Security (ACDIS) program at the University of Illinois and Urbana-Champaign, where I also presented an earlier version of the chapter at an ACDIS seminar. At the invitation of Thomas Hughes, I presented some of this material in a seminar at the University of Pennsylvania's Department of History and Sociology of Science. I appreciate the thoughtful questions from and discussion with faculty and students during that visit.

Much of the research for Chapter 4 was conducted during a trip to Israel in the summer of 1992, generously funded by the Institute for the Study of World Politics. My first field research experience was made far easier by the help I received from Oded Brosh, Avner Cohen, Seymour Hersh, Myron Lecar, Ted Postol, George Rathjens, Jack Ruina, and many others who helped me in planning the trip and establishing initial contacts. Of the many Israelis who were kind enough to meet with me, too many must remain anonymous. Their anonymity is unfortunate, not only because I cannot thank them by name, but because they have been deprived of recognition for their impressive dedication and accomplishments in the service of their country. Those whom I can name include Emanuel Adler, Yaron Ezrahi, Shai Feldman, Alon Gany, Eli Levita, Martin Navias, Reuven Pedatzur, Arnan Seginer, Amnon Selah, Gerry Steinberg, and Y. M. Timnat. My thanks to David Guston for the chapter's subtitle.

Mike Elleman, Bob Dietz, and Ted Postol helped out with some of the more detailed aspects of missile technology. Responsbility for the remaining technical errors is entirely mine. Unless otherwise noted, translations are by the author. My thanks to Aryeh Cohen for assistance with Hebrew texts.

Without the Havurat Shalom community, this dissertation would never have been finished. More important, it would have been much harder for me to remain sane, happy, or well-fed for the duration.

I owe (somewhat sheepish) thanks to all of my housemates over the last six years: Heidi, Dave, Michael, Rebecca, and Shoshanna, for putting up with so many late nights at the office and so many dirty dishes in the sink, and for creating a place I was happy to call home. I look back fondly on our time together; each would have fonder memories had this thesis never been written, but at least they're all still talking to me.

My sister (and mentor, colleague, and friend) extended constant help, humor, and encouragement on so many levels. She should have gotten here first.

My parents first raised me and then waited patiently through years of dissertation-induced incoherence, hoping to get their son back. Thanks, mom and dad--you did a good job.

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CHAPTER ONE

Exploding the Black Box:
The Historical Sociology of Missile Proliferation

I Introduction: Setting the Problem

This thesis is a study of why and how some countries develop the technologies to produce ballistic missiles. I tell that story for three countries--Brazil, India, and Israel. In each case, I try to look to at whatever seems important to the story, from fiberglass motor cases and solid propellant binders to organizational rivalries and the broadest philosophical debates of a society.

In the past few years, missile proliferation has gained new prominence in the debate on global security issues. With the end of the Cold War, politicians, security analysts and the media have all devoted more attention to the military programs of developing countries, especially weapons of mass destruction and their associated delivery systems. As a result, the myriad tables of who has what missiles are now the stuff of *The Economist* and U.S. congressional hearings.[1] At the same time, more detailed academic studies have begun to appear.[2]

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[1] Representative of the popular press coverage is "Third World Missiles: Look What I Found in My Backyard," *Economist*, 27 May 1989, pp. 44-45. Congressional hearings from the 101st Congress alone include: U.S. Congress. House. Committee on Foreign Affairs. *Proliferation and Arms Control.* 101st Cong. 2nd sess., 1990; U.S. Congress. Senate. Committee on Armed Services. Subcommittee on Defense Industry and Technology. *Ballistic and Cruise Missile Proliferation in the Third World.* 101st Cong., 1st sess., 1989; U.S. Congress. Senate. Committee on Foreign Relations. *National Security Implications of Missile Proliferation.* 101st Cong., 1st sess., 1989; U.S. Congress. House. Committee on Foreign Affairs. *Missile Proliferation: The Need for Controls (Missile Technology Control Regime).* 101st Cong., 1st sess., 1989; U.S. Congress. Senate. Committee on Governmental Affairs. *Nuclear and Missile Proliferation.* 101st Cong., 1st sess., 1989.

[2] Already the number of surveys, with anywhere from a few pages to a chapter devoted to individual programs, is large enough to discourage listing them all. The most prominent include: Robert Shuey, et al., *Missile Proliferation: Survey of Emerging Missile Forces*, Congressional Research Service, 9 February 1989; W. Seth Carus, *Ballistic Missile in Modern Conflict* (New York: Praeger, 1991); Janne Nolan, *Trappings of Power: Ballistic Missiles in the Third World* (Washington, D.C.: Brookings, 1991); and *Assessing Ballistic Missile Proliferation and Its Control*, A Report of the Stanford University Center for International Security and Arms Control (CISAC), November 1991. Some of the best focused studies of individual programs include: Thomas McNaugher, "Ballistic

The new focus on missile proliferation leaves room for policy innovation--and even more room for policy failure. It is all too easy to take old paradigms and try to force proliferation policy to conform to them. By adhering to a security-centered analysis, U.S. enforcement of the Missile Technology Control Regime (MTCR) has already been counterproductive in the cases of Brazil and India.[3] This thesis demonstrates that missiles (much like nuclear weapons) lie at the intersection of numerous broad forces: security concerns, economic and technological development, the evolution of scientific communities and technological systems, North-South conflicts, the legitimacy and prestige of regimes, and so on.

The confluence of forces that renders older, security-centered notions inapplicable also makes the subject an interesting one to study. The method used for reaching across so many issue areas and so many levels of analysis is the history and sociology of technology. Much of Chapter 1 explains this postmodern and deconstructionist methodology, with as little jargon as possible. While unfamiliar to many in the security studies field, the approach has great potential for understanding the politics of developing ballistic missile technology, as well as nuclear weapons and military technology more broadly.

Missile and Chemical Weapons: The Legacy of the Iran-Iraq War," *International Security* 15, no. 2 (Fall 1990): 5-34; some of the cases in William Potter and Harlan Jencks, eds., *International Missile Trade and Capabilities* (forthcoming), esp. Timothy McCarthy, "Emergent Missile Power: The Case of India"; and Scott Tollefson, "Brazilian Arms Transfers, Ballistic Missile, and Foreign Policy: The Search for Autonomy," Ph.D. diss., Johns Hopkins University, 1991.

[3]For an overview of the MTCR, see Frederick Hollinger, "The Missile Technology Control Regime: A Major New Arms Control Achievement," in U.S. Arms Control and Disarmament Agency, *World Military Expenditures and Arms Transfers, 1987*, Daniel Gallik, ed. (Washington, D.C.: U.S. Government Printing Office, 1988), 25-27.

The thesis examines the missile development programs in three of the most prominent cases of ballistic missile proliferation--Brazil, India, and Israel. In the Brazilian case (Chapter 2), I examine the propulsion systems for the core missile and space applications, looking particularly at the Sonda series of sounding rockets and at the Brazilian satellite launch vehicle, the VLS. For India (Chapter 3), the two major surface-to-surface missile programs, the Prithvi and the Agni, are seen through the prism of a comparison with the space program, though the missiles are deconstructed in more detail than the space launch vehicles. Finally, the Israeli case (Chapter 4) takes on the whole national system for producing military technologies, using examples from tactical and strategic missile programs of all kinds.

Case Selection:

The choice of Brazil, India, and Israel matches a number of criteria. First, each country has a relatively advanced indigenous missile development program, so that there is an LTS to study. This methodology would not be well illuminated by studying programs in a country such as Indonesia, which has conducted a small number of indigenous sounding rocket tests. The theory would cover cases such as Iraq, which made simple modifications to large numbers of foreign supplied missiles, but we would need to look at a different set of interactions than those studied in the three cases presented here. At the same time, the missile programs studied are young enough, small enough, or controversial enough to still be of significant policy interest. Studying Soviet or French missiles might make for good history, but this thesis attempts to move the constructivist approach beyond good history and towards current policy.

Second, these three cases span the spectrum of security environments. In Brazil's benign case, the last major war was over a century ago (Brazil did send a small expeditionary force to Europe in World War II). While the internal security situation has at times been more troublesome for the military, the period under study (the mid-1970s through the early 1990s) was relatively calm.[4] India confronts a more difficult set of security challenges, namely adversarial relationships with its neighbors, China and Pakistan. Yet India's only armed combat with China was a border skirmish (which resulted in an ignominious Indian rout) over thirty years ago. India's three wars with Pakistan may have cemented a hostile posture, but no battles have been fought since Pakistan's dismemberment over twenty years ago, and India's conventional superiority remains unquestioned.[5] Finally, Israel confronts one of the most severe security environments in the world. A series of heavily armed, often hostile states surrounds Israel, extending in some directions for a thousand miles. Outnumbered in every quantitative dimension, Israel has fought wars in each decade of her existence, often with her survival as a nation hanging in the balance.[6]

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[4]For a description of the internal security situation during this period, see Thomas Skidmore, *The Politics of Military Rule in Brazil, 1964-85* (New York: Oxford University Press, 1988).

[5]On Indian security, see Raju Thomas, *Indian Security Policy* (Princeton: Princeton University Press, 1986); and Stephen Cohen, ed., *The Security of South Asia: American and Asian Perspectives* (Urbana, Ill.: University of Illinois Press, 1987).

[6]Israeli experience through the early 1980s is ably related by Chaim Herzog in *The Arab-Israeli Wars: War and Peace in the Middle East from the War of Independence to Lebanon* (London: Arms and Armour, 1984). For more current perspectives, see Bernard Reich and Gershon Kieval, eds., *Israeli National Security Policy: Political Actors and Perspectives* (Westport, Conn.: Greenwood Press, 1988); and Shai Feldman, ed., *Technology and Strategy: Future Trends* (Boulder, Colo.: Westview Press and the Jaffee Center for Strategic Studies, 1989).

Security threats constitute the most important variable in most international relations theories. If any conclusions hold across all three of these cases, then they have a strong presumption for holding in many more cases. In particular, the field of security studies has a strong tradition of distinguishing between external and internal causes or motivations for national security issues, such as developing ballistic missiles. If the Brazilian case supports the hypothesis that internal factors are more important, then it will merely constitute an existence proof--that internal factors can produce such programs under the right circumstances, such as a benign security environment. At the other end of the spectrum, the Israeli case could serve as a crucial case for the same hypothesis. If internal factors dominate or have a strong impact on Israeli missile programs, even under such externally imposed security stress, then any analysis of such programs must give internal factors a prominent place. The more expected conclusion is that external factors gradually assume more importance as the security environment becomes more severe, with a mixture of internal and external factors always shaping a program's evolution--but I believe that my research highlights the importance of internal factors in that mixture more strongly than studies in the past.[7]

These same three cases also span a range of technological capabilities found in the broader societies. Parts of the Israeli technological infrastructure are comparable to anything found in the most advanced Western or Northern countries, yet Israel's small size and young age leave gaps in countless areas. Only through

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[7]For example, the Stanford study's "demand evaluation" emphasizes the primarily externally driven motivations of military effectiveness (perceived if not actual), stature and prestige (sometimes including the domestic audience), and economic imperatives (primarily export sales). Summarized in CISAC, "Assessing Ballistic Missile Proliferation," 78-81.

constant open access to foreign technology--from specialty parts to computer software to advanced materials--can Israel hope to construct complete sophisticated systems of any kind.[8] While the Indian research establishment can boast Nobel prize winners and some pockets of excellence, Indian technologists face constant frustration when attempting to put together working systems.[9] Finally, Brazil has been able to absorb technologies developed elsewhere, but has more difficulty carrying out indigenous innovations, much less developing advanced systems on their own.[10]

An interesting side benefit of these three particular cases is that they also span a spectrum of democratic norms. For the period under study, Brazil was under a military or military-appointed government, yet retained a relatively free press.[11] India is a parliamentary democracy, yet features a strong central planning orientation and nearly one-party rule.[12] Israel is a tumultuously open

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[8]See the generally optimistic study by Arie Lavie and Robert Lawrence Kuhn, *Industrial Research & Development in Israel* (New York: Praeger, 1988).

[9]See (and note the generous use of the future tense in) A. Rahman, M. A. Qureshi, and V. K. Gupta, "India," Part I in *Science and Technology in India, Pakistan, Bangladesh and Sri Lanka*, Abdur Rahman, ed., Longman Guide to World Science and Technology (London: Longman, 1990).

[10]See Peter Evans, *Dependent Development: The Alliance of Multinational, State and Local Capital in Brazil* (Princeton: Princeton University Press, 1979); Joao Carlos Ferraz, Howard Rush, and Ian Miles, *Development, Technology, and Flexibility: Brazil Faces the Industrial Divide* (London: Routledge, 1992); and Hubert Schmitz and Jose Cassiolato, eds., *Hi-Tech for Industrial Development: Lessons from the Brazilian Experience in Electronics and Automation* (London: Routledge, 1992).

[11]Skidmore describes the cyclical and rarely brutal attempts to reign in the press through the various military governments in Brazil. Skidmore, *The Politics of Military Rule*.

[12]Richard Sisson and Ramashray Roy, eds., *Diversity and Dominance in Indian Politics* (Newbury Park, Calif.: Sage, 1990).

democracy, though it imposes strong military censorship on the press.[13] This alignment gives us the opportunity to examine the influence of a variety of democratic institutions on the evolution of large military systems.

Sources and Methods:

For the Brazilian and Indian programs, information is readily available in the open literature, especially information dealing with less militarily-oriented aspects such as space launch vehicles. I have made heavy use of original sources. Many of the relevant organizations publish annual reports which permit some substantive material to leak through their generalities. Other government reports or speeches by officials have provided valuable background information. Both Brazil and India have a relatively free press, though Israeli journalists face heavier censorship. Accounts from their domestic media feature detailed descriptions of many relevant events and programs. Particularly revelatory accounts frequently involve organizational or personal rivalries that spill over into the public eye. I have relied mostly on those newspaper articles and radio and TV broadcasts printed by the Foreign Broadcast Information Service (FBIS) and the Joint Publication Research Service (JPRS). Since both publications issue annual indices, I have been able to complete comprehensive subject searches for the relevant period (approximately 1985 to 1990), as well as locate information on significant earlier events.

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[13]On civil-military relations, see Yoram Peri, *Between Battles and Ballots: Israeli Military in Politics* (Cambridge: Cambridge University Press, 1983). On censorship, one of the few sources in English is Itzhak Galnoor, "Israel," in Galnoor, ed., *Government Secrecy in Democracies* (New York: New York University Press, 1977), 176-200.

I have drawn heavily on the largely untapped resource of scientific and technical reports on particular aspects of the missile and space programs. These reports offer otherwise unavailable details on missile and related subsystems, and offer a general picture of the capabilities of the research establishment. These reports also provide valuable clues about research priorities, organizational affiliations, and project histories. Many of the citations for conferences, papers, and research articles were obtained from comprehensive subject searches on the CD-ROM version of Aerospace Database, which combines the paper indices for the International Aerospace Abstracts and NASA's Scientific and Technical Aerospace Reports.[14]

It would of course have been better to travel to each of these three countries, visit research and production facilities, and conduct large numbers of interviews. Unfortunately funding, contacts, and language skills were not sufficient to visit Brazil or India. I was able to conduct some valuable "meta-interviews," that is, talking with other researchers in the United States who have conducted their own interviews of people involved in these programs.

For Israel, the primary sources listed here were utilized, but offered much less information than they did for Brazil and India. Instead, a grant from the Institute for the Study of World Politics enabled me to travel to Israel and conduct dozens of interviews with researchers, industrialists, academics, and others. While the same level of detail as the other cases was not achieved, it was possible

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[14]All these databases are managed by the American Institute for Aeronautics and Astronautics in New York. For an interesting discussion of the potential that the technical literature has for historical research, see Mark Levinson, "Gleanings from Oft-Neglected Sources: Institutional History from Technical Documents--the Case of the NACA," *Technology & Culture* 28, no. 2 (April 1987): 314-23.

to gain a broader understanding of the overall system, as presented in the case chapter.

Particularly in the Israeli case, I obtained some information under conditions of strict anonymity. While a strong academic tradition frowns on unattributed information, I beg the reader's indulgence, as the cases would be much the poorer were I to exclude all such material. Although I realize that unsourced data cannot be checked independently, I hope the overall arguments are credible enough to maintain the reader's faith. For those interested in more information, please contact the author.[15]

Note that these cases draw only occasionally on the statements of political or military leaders. I have chosen to focus on lower-level interactions, far removed from the strategic abstractions that frequently constitute such statements. Nor do I analyze party politics or offer broad organizational histories. As explained below, I believe that examining technical artifacts captures the same information as examining more traditionally "political" data. These cases do draw on the usual sources in order to paint a picture of bureaucratic rivalries and political philosophies, but only enough to confirm that the technical artifacts effectively mirror that picture. The focus of the current study is on the artifacts.

A lack of data ultimately limits these analyses. None is a definitive history, even of the narrow missile programs in question. Nor is any a comprehensive

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[15]See the discussion on "studying a 'secret' technology" in Donald MacKenzie, *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance* (Cambridge: MIT Press, 1990), 12-14; and William Burrows, "A Study of Space Reconnaissance: Methodology for Researching a Classified System" in Martin Collins and Sylvia Fries, eds., *A Spacefaring Nation: Perspectives on American Space History and Policy* (Washington, D.C.: Smithsonian Institution Press, 1991), 225-40. For a more extensive discussion as well as an example of the feasibility of collecting information on classified systems, see William Burrows, *Deep Black: Space Espionage and National Security* (New York: Random House, 1986).

cultural analysis, though all incorporate elements of one. For Brazil and India, these analyses do represent a better missile history than anyone has published before; for Israel, the analysis contributes previously unpublished information on Israeli missile programs, and also aspires to be the first synthetic approach to the entire military R&D system. Most important, each should be a strong demonstration of the merits of applying the history and sociology of technology to important political and security issues.

II Security Studies

On one level, this is a very straightforward thesis. It belongs to that venerable class of case studies of weapons development, simply asking, "Why do we have the missiles we do?", or more specifically, why do Brazil, India and Israel have the missiles they do?[16] The thesis is also part of the growing policy debate on the causes and evolution of third world ballistic missile systems.[17] No one has cov-

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[16]The classics include Michael Armacost, *The Politics of Weapons Innovation: The Thor-Jupiter Controversy* (New York: Columbia University Press, 1969); Harvey Sapolsky, *The Polaris System Development: Bureaucratic and Programmatic Success in Government* (Cambridge: Harvard University Press, 1972); Edmund Beard, *Developing the ICBM: A Study in Bureaucratic Politics* (New York: Columbia University Press, 1976); and Ted Greenwood, *Making the MIRV: A Study in Defense Decision Making* (Cambridge, Ma.: Ballinger, 1975).

[17]See in addition to the works cited in notes 1 and 2, Martin Navias, *Going Ballistic: The Build-up of Missiles in the Middle East* (London: Brassey's, 1992); Matthias Dembinski, "Ballistic Missile Proliferation and the New World Order: A Critical Survey of the Literature," CSIA Discussion Paper #92-7, Center for Science and International Affairs, Harvard University, 1992; John Harvey, "Regional Ballistic Missiles and Advanced Strike Aircraft: Comparing Military Effectiveness," *International Security* 17, no. 2 (Fall 1992): 41-83; Steven Fetter, "Ballistic Missiles and Weapons of Mass Destrucution: What is the Threat? What Should Be Done? *International Security* 16, no. 1 (Summer 1991): 5-42; Lora Lumpe, Lisbeth Gronlund, and David Wright, "Third World Missiles Fall Short: The Threat from Third World Missiles has been Grossly Exaggerated," *Bulletin of the Atomic Scientists* 48, no. 2 (March 1992): 30-37; Azriel Lorber, "Tactical Missiles: Anyone Can Play; Short-Range Missiles--in Third World Hands--Pose a Serious Threat to Regional Security," *Bulletin of the*

ered these cases before in very much depth, especially from the technical side.[18] So just on the basis of the data that I have collected, the thesis already makes a contribution to the literature.

On this level, I also address some of the familiar security studies questions. Do these missile systems exist in their current forms because of external security factors or because of internal political or social forces?[19] The balance between internal and external forces is a key security studies question, indeed its Great Divide. As Evangelista describes it:

> One of the most common ways to characterize explanations of international relations is to divide them into two categories, depending on

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Atomic Scientists 48, no. 2 (March 1992): 38-40; Aaron Karp, "Ballistic Missile Proliferation," in *SIPRI Yearbook 1991: World Armaments and Disarmament* (New York: Oxford University Press, 1991), 317-43; Uzi Rubin, "How Much Does Missile Proliferation Matter?" *Orbis* 35, no. 1 (Winter 1991): 29-39; Janne Nolan and Albert Wheelon, "Ballistic Missiles in the Third World," in *New Threats: Responding to the Proliferation of Nuclear, Chemical and Delivery Capabilities in the Third World* (Lanhan Md.: Aspen Strategy Group and University Press of America, 1990), 89-127; Thomas Mahnken and Timothy Hoyt, "The Spread of Missile Technology to the Third World," *Comparative Strategy* 9, no. 3 (July-September 1990): 245-63; and James Hackett, "The Ballistic Missile Epidemic," *Global Affairs* 5, no. 1 (Winter 1990): 38-57.

[18]See the literature reviews given in each of the case chapters.

[19]Realists tend believe that "those seeking to understand and deal with potential threats to the security of their states...[should] interpret the action of...[other] states...on the premise that they are seeking rationally to increase their power." Waltz's third image sees states arming in response to the essential anarchic nature of the international system: "Because any state may at any time use force, all states must constantly be ready either to counter force with force or to pay the cost of weakness. The requirements of state action are, in this view, imposed by the circumstances in which all states exist." Kenneth Waltz, *Man, the State and War: A Theoretical Analysis* (New York: Columbia University Press, 1959), 160. Waltz, Hans Morgenthau, and other realists draw on Hobbesian traditions in political thought, believing that "out of civil states, there is always war of every one against every one...For WAR, consisteth not in battle only, or the act of fighting...but in the known disposition [prepations] thereto." Thomas Hobbes, *Leviathan* (New York: Collier, 1962 [1651]), 100.

> whether they emphasize internal or external determinants of state behavior. Explanations that emphasize external factors are variously known as realist, systemic, balance-of-power, and rational actor. Those that stress internal forces fall under the rubrics of bureaucratic politics and organization theory.[20]

My explicit bias is that the external factors are frequently an implausible explanation for even the basic existence of missile programs, much less their actual shape.[21]

In the Brazilian case, we will see that large, advanced missile programs bore no resemblance to Brazil's benign external security environment. For India, a long history of interest and accomplishment in missile research was coupled with an inability to build successful missiles. Yet in the 1980s, without any substantial shift for the worse in India's external security environment, the same sort of missile development programs, especially short-range and tactical missiles, received sufficient support to succeed. Finally, Israel's missile inventories are no mystery, being a clear response to a consistent external security threat. Yet Israel has purchased some foreign-produced missiles, both tactical and strategic, and has developed or produced others indigenously. Can externally-based arguments account for the existence of indigenous Israeli missile programs?

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[20] Matthew Evangelista, *Innovation and the Arms Race: How the United States and the Soviet Union Develop New Military Technologies* (Ithaca, N.Y.: Cornell University Press, 1988), 6; and the works cited therein, especially Bruce Russett, "International Interactions and Processes: The Internal vs. External Debate Revisited," in Ada Finifter, ed., *Political Science: The State of the Discipline* (Washington, D.C.: American Political Science Association 1983), 541-68. I share Evangelista's critique that "both types of explanation have failed to capture important features" of the development of military technologies, though our approaches differ substantially.

[21] In this brief discussion, I tend to use a conflated and caricatured portrait of the dominant schools of IR theory that Evangelista lists. My apologies to those who are seeking nuances.

More refined versions of the external versus internal debate first recognize that both matter, and then set out to differentiate areas where one matters more than the other. These versions constitute much of the debate over the causes and patterns of the development of military technology, especially for strategic systems. The literature has evolved some standard compromises to incorporate both sets of factors.[22]

One interpretation holds that we observe a stronger external influence the more severe the security environment. Only a truly compelling threat can break through the otherwise normal internal processes, or as Barry Posen concludes, "In times of relative international calm, organizational dynamics are allowed to flourish. But in times of threat, the actions of both statesmen and, to a lesser extent, soldiers will tend to override these dynamics."[23] Another approach is that we see a stronger external influence for general policy questions. Thus while the security environment may determine the existence of missile programs, it will not determine their shape.[24] In a somewhat circular argument, the more central an issue is to core security concerns, the stronger the external influence. Strategic systems, according to this argument, would be shaped more by external factors

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[22]For a nicely balanced integration of the two that nonetheless grants precedence to internal factors, see the first chapter of Jack Snyder, *The Ideology of the Offensive: Military Decision Making and the Disasters of 1914* (Ithaca, N.Y.: Cornell University Press, 1984), 15-40.

[23]Barry Posen, *The Sources of Military Doctrine: France, Britain, and Germany Between the World Wars* (Ithaca, N.Y.: Cornell University Press, 1984), 40.

[24]Waltz, for example, argues that "a theory at one level of generality cannot answer questions about matters at a different level of generality," so that balance of power theory should not be expected to explain "why state X made a certain move last Tuesday." Kenneth Waltz, *Theory of International Politics* (Reading, Mass.: Addison-Wesley, 1979), 121.

than tactical weapons.[25] Finally, some theories picture states as attempting to respond to external factors, but the limits of perception and rationality interfere.[26] These compromise positions in the debate can also reinforce each other. Thus one could believe that even the details of U.S. or Soviet ICBMs would have been externally determined because they are strategic systems in a high threat environment.[27]

Choosing missiles as an object for study may favor explanations based on external factors, at least according to the versions of traditional IR theories just described. Ballistic missiles are high-profile strategic systems which require a large investment and which often involve core security interests of the state. On the other hand, precisely because missiles are all those things, they may receive the same kind of special treatment that nuclear weapons have often received.

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[25]Bernard Brodie argues against this approach in his discussion of the subjectivity of vital interests and expansibile conceptions of security. Brodie, *War and Politics* (New York: Macmillan, 1973), 341-74.

[26]Robert Jervis, *Perception and Misperception in International Politics* (Princeton: Princeton University Press, 1976); many authors have applied the research articles reprinted in Daniel Kahnemahn, Paul Slovic, and Amos Tversky, *Judgment Under Uncertainty: Heuristics and Biases* (New York: Cambridge University Press, 1982), to security studies issues; finally, there is a body of literature on crisis decision making, such as Richard Ned Lebow, *Between Peace and War: The Nature of International Crisis* (Baltimore: Johns Hopkins University Press, 1981).

[27]For example, Colin Gray argues that President Carter's Multiple Protective Shelters deployment mode for the MX missile is a necessary response to increasing Soviet ICBM accuracies. Colin Gray, *The MX ICBM and National Security* (New York: Praeger, 1981), 35-37. Gray himself makes suspect the link between MX deployments and the external security environment. Gray continued to support the MX missile in a newly proposed and admittedly vulnerable basing mode, arguing in favor of the launch under attack options that he had previously excoriated as "an accident-prone tactic of dubious technical feasibility that is virtually devoid of operational strategic merit." Compare Gray, *MX ICBM*, 86; and Gray, "ICBMs and Deterrence: The Controversy Over Prompt Launch," *Journal of Strategic Studies*, 10, no. 3 (September 1987): 285-309.

We will also see that they can be organizationally detached from the security structures of the rest of the state.[28]

This thesis does not tackle these various interpretations of realism head on. The ideal research design for investigating the balance between external and internal motivations would generate hypotheses from each perspective. When those hypotheses conflict, then the battle is joined. The perspective whose predictions hold when examining a set of cases would thus emerge victorious. I have not been able to find cases that I could boil down to such a mechanistic level, and yet are still interesting enough to be worth examining. Nor do I believe the attempt would be worth the effort, since "definitive" demonstrations of a theory's superiority rarely are.[29]

Instead, in eschewing such reductionist approaches, the primary theoretical contribution of this study is to present a strong methodology for probing the internal motivations for the development of military technology. I use the history and sociology of technology simply to tell the story of how missile systems came to be in Brazil, India, and Israel. I view external, security-centered explanations as prima faciae unlikely, and therefore look first to other kinds of explanations.

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[28]For the case of India and nuclear weapons, for example, see Itty Abraham, "India's 'Strategic Enclave': Civilian Scientists and Military Technologies," *Armed Forces & Society* 18, no. 2 (Winter 1992): 231-52.

[29]See the discussion of the difficulties of falsification in Imre Lakatos, *Philosophical Papers*, John Worrall and Gregory Currie, eds. Vol. 1, *The Methodology of Scientific Research Programmes*, (New York: Cambridge University Press, 1978), 8-101, esp. 16-17, 26-27, 30. My apologies to J. David Singer, who justifiably carps that "if by some remote chance, we begin to gather scientific momentum, and there is a real danger the cumulativeness and codification might get out of hand, [we] allude to Kuhn and call for a new paradigm." Singer, "Cumulativeness in the Social Sciences: Some Counter-Prescriptions," ch. 13 in Singer, *Models, Methods, and Progress in World Politics: A Peace Research Odyssey* (Boulder, Colo.: Westview Press, 1990), 151-56, 156.

If I find some that are adequate, I do not look much harder for more explanations. The reader can then judge the result: if the cases make sense intuitively, on the basis of the explanations presented here, then security threats are not necessary to account for the evolution of ballistic missile technology in these cases.[30] The realist explanation does lurk in the background throughout these analyses, but primarily as a foil rather than a full-blown competitor.

This study does compete with the realist perspective in another sense. Paradigm shifts tend not to occur unless and until a strong replacement is available, regardless of the weaknesses of the hegemonic paradigm.[31] By constructing a consistently successful explanation of these cases, I offer a viable alternative to those who already have doubts about neorealist theories. The direct competition may be less important than the competence and attractiveness of the replacement. The thesis therefore concentrates more on developing the capabilities of the new methodology.

Another important task for any security studies analysis is to aid in policy formulation. What lessons does this thesis provide for improving future U.S. nonproliferation policy?

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[30]The biggest problem with such an approach, besides requiring the reader to read the case material, is that outcomes can be overdetermined. If both security and other kinds of factors would have been enough, independently, to spur the development of missile technology, then this approach does not help us. As pointed out in the case studies, at least some aspects of these cases do seem to directly contradict security-based explanations, so that my proposed theories offer some of the "excess empirical content" required for the acceptance of a new, competing theory. See Lakatos, "Changes in the Problem of Inductive Logic," ch. 8 in *Philosophical Papers*. Vol. 2, *Mathematics, Science and Epistemology*, 128-200, esp. 170-81.

[31]"Once it has achieved the status of paradigm, a scientific theory is declared invalid only if an alternate candidate is available to take its place." Thomas Kuhn, *The Structure of Scientific Revolutions*, 2nd ed. (Chicago: University of Chicago Press, 1970), 77.

With the end of the Cold War, researchers in securities studies have needed to reorient our theories and our priorities. The danger in rapid retooling is that practitioners are tempted to look for those problems to which their current expertise is most applicable. The result, in my opinion, is a plethora of analyses that follow the natural predilection to see third world proliferation through Cold War lenses.[32] These analyses place inappropriate emphasis on missiles, bipolar security systems, spiral dynamics, and security threats.[33] Even those who question the current emphasis on the missile threat tend to focus on technical analyses

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[32]The terms "third world," "developing countries," "advanced industrialized nations," and so on, are all hopelessly imprecise. Fortunately, I mean nothing precise by them. For a discussion of the terminological issues, see the entire first chapter of Yezid Sayigh, "Confronting the 1990s: Security in the Developing Countries," *Adelphi Papers #251*, International Institute for Strategic Studies (Summer 1990): 8-15.

[33]Though proliferation is clearly an important issue, it can become a simple substitute for the suddenly evaporated Soviet threat. For a time, various members of Congress took great interest in "cracking down" on missile related exports. See for example, U.S. General Accounting Office, "U.S. Efforts to Control the Transfer of Nuclear-Capable Missile Technology," GAO/NSIAD-90-176, 1 June 1990. The CIA choose nonproliferation as the focus for one of the five new centers at CIA headquarters, created in the fall of 1991, "after proliferation emerged [sic] as a top intelligence threat." Paula Scalingi, "Intelligence Community Cooperation: The Arms Control Model," *International Journal of Intelligence and Counterintelligence* 5, no. 4 (Winter 1991-2): 401-10, 402-3.

Even SDI wants to got on board the missile proliferation steamroller, emphasizing the threat from third world ballistic missiles and performing a stunning pirouette--what used to be protection against a small number of Soviet missiles (the Global Protection against Accidental Launch) is now an umbrella against the missile-armed Saddam Hussein's of the world:

> "If there ever was a case for SDI, this is it....The continuing proliferation of missile development capabilities in Third World nations is very, very ominous. It should send a clear signal to Congress that SDI is necessary," [says Martha Cosgriff,] a military aerospace analyst in the Washington, D.C., area.

"Latin Trade in Missile Technology Means SDI is Needed, Analyst Says," *SDI Intelligence Report*, 24 April 1991, p. 65.

rebutting assertions that third world missiles pose a significant security risk to the United States.[34]

Current U.S. policies show the dangers of continuing the Cold War focus on capabilities and security threats. Policy analyses need to ask whether ballistic missile programs in the third world are a threat to the United States or anyone else, on the basis of their origins and motivations. Probing intentions not only helps to evaluate the magnitude of the threat, it also helps us to pursue more effective policies. If missile programs are not responses to security threats or spiral dynamics, then security-centered policies are simply inappropriate, and possibly counterproductive.

For example, both Brazil and India have been the target of U.S. policies explicitly designed to control missile proliferation. (The United States has no active policy for our third case, Israel, perhaps because Israel has been producing missiles for so many decades that it is difficult to include under the rubric of non-proliferation.) This thesis is not a study of how effective those policies have been. Instead, the analyses presented here provide the basis for making evaluations, such as those presented briefly in the concluding chapter.

III The History and Sociology of Technology

This thesis is also a thoroughly postmodern analysis of missile technology. Such an analysis is interesting in its own right, as part of the larger theoretical school of

[34]Fetter, "Ballistic Missiles and Weapons of Mass Destruction"; Harvey, "Regional Ballistic Missiles and Advanced Strike Aircraft"; and Lumpe, "Third World Missiles Fall Short."

the history and sociology of technology. I believe that it also interesting because of its implications for more traditional security analysis. Even in my cases' most straightforward storytelling sections, I have consistently followed a deconstructionist approach. The theory that I am describing may not be absolutely necessary for understanding the results, but it did infuse the conduct of all of my research. Though unfamiliar for most researchers in security studies, I believe that the approach has much to offer for that field. The rest of this introductory chapter describes the most recent research in the history and sociology of technology and how it can be applied to the study of the development of military technology.[35]

A fundamental principle of this approach is that separating the technical from the political gets in the way of telling better stories--about military technology or about anything else that happens in the world. Consider this marvelous soliloquy from a manager in an Israeli defense industry on the politics of developing technology, and observe how much it resonates with any other description of politics:

> There hasn't been the smallest problem--about a pin or a screw or a bolt--that has not been discussed with quite opposites. Somebody imagines--[but] it doesn't work in practical engineering--that all these things come out by clear mathematics. That's a myth, it's mythological. They argue about *everything*. They argue about the paint, they argue about the washer, and they argue about whether you fire the [missile] motor vertically or you fire them horizontally; whether you have a [missile] casing from kevlar or fiberglass, whether you take this steel or the other steel, whether you have a movable nozzle or other kinds of thrust vectoring. It's amazing! There are discussions going on endlessly about how you should do anything...

[35]Much of the section that follows will be published, in a different form, as part of "Exploding the Black Box: The Historical Sociology of Nuclear Proliferation," *Security Studies* 3, no. 1 (Fall 1993), forthcoming.

> Everything is always under question, they argue about it. And they argue about it with the same *fanaticism* like they argue about the [Israeli-occupied] territories or about anything else. Really. And they hate each other for it! They argue about PBAN or HTPB [missile propellant binders], they argue about everything. And everyone has his promoters, his own believers.[36]

Recent research in the history and sociology of technology offers new methods for better understanding the politics of missile proliferation by treating its technology more seriously. Current theories of proliferation do not address the lower level interactions that create, sustain, and mold the large technological systems that underlie any production of ballistic missiles. We are missing the tools needed to bridge the chasm between abstract strategic arguments and the formidable and multifaceted effort that make such weapons a reality.

The history and sociology of technology is an established methodology that elevates technology to the same status as bureaucracies, nationalism, or security threats--all of them, subjects worthy of detailed scrutiny. The approach often takes as its basic unit of study the "large technological system."[37] The develop-

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[36]The speaker must unfortunately remain anonymous, but he is a veteran of many decades of political battles over military R&D. He knows whereof he speaks.

[37]The concept is described succinctly in Thomas P. Hughes, "The Evolution of Large Technological Systems," in Wiebe Bijker, Thomas P. Hughes, and Trevor Pinch, eds., *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (Cambridge: MIT Press, 1987), 51-82; and at more length in Thomas Hughes, *Networks of Power: Electrification in Western Society, 1880-1930* (Baltimore: Johns Hopkins University Press, 1983). Some of the semi-annual conferences on large technological systems have been published: Bijker, Hughes, and Pinch, *The Social Construction of Technological Systems*; Renate Mayntz and Thomas P. Hughes, eds., *The Development of Large Technical Systems* (Boulder, Colo.: Westview, 1988); and Wiebe Bijker and John Law, eds., *Shaping Technology/Building Society: Studies in Sociotechnical Change* (Cambridge: MIT Press, 1992). *Large Technical Systems in Radical Reconfiguration*, the Fourth Meeting in the Conference Series on the Dynamics of Large Technical Systems, was held in Vadstena, Sweden, 7-11 August 1992. On definitional issues, Bernward Joerges, "Large Technical Systems: Concepts and Issues," in Mayntz, ed., *The Development of Large Technical Systems*, 9-36, and Iskender Gokalp, "On the Analysis of Large Technical Systems," *Science Technology & Human Values* 17, no. 1 (Winter 1992): 57-78.

ment, production, and maintenance of missiles involves just such a system. In the United States, for example, the missile system includes everything from pensions for assembly line workers in Thiokol's propellant plants in Utah to the Air Force's high-security communications links--components that may seem far removed from more obviously "missile" hardware, but which are nonetheless essential to the overall system. In other words, a country's development of ballistic missiles *is* the evolution of a large technological system.

Studying the historical sociology of missile proliferation promises to improve our understanding of the reasons and processes behind the development of ballistic missiles.[38] Compare this approach to more conventional wisdom, which might hold for example that missile proliferation in South Asia stems principally

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[38]The approach described in this article comes with many names, including the history and sociology of technology, the historical sociology of technology, and the social study of technology. The field is only called "sociology" of technology because of its extremely close relationship to the sociology of scientific knowledge, as described below. Much of the research to date has relied heavily on historical and narrative methods, deriving understanding from experience, not theory. See the discussion in Donald MacKenzie, *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance* (Cambridge, MIT Press, 1990), 6-12.

Some of the other common labels are large technological systems (LTS) theory, network theory, and the social construction of technology (SCOT). The term system or network does not refer to the reductionist systems of many social and physical scientists; rather, systems consist of *all* components interacting purposefully across networks over time toward the achievement of specified ends. Components in a system are often seen as systems themselves, and vice versa. LTS theory is described in the works cited in note 37. On network theory, see an early example in Michel Callon, "The State and Technical Innovation: A Case Study of the Electric Vehicle in France," *Research Policy* 9, no. 4 (October 1980): 358-76; and Michel Callon, John Law, and Arie Rip, eds., *Mapping the Dynamics of Science and Technology: Sociology of Science in the Real World* (Basingstoke: Macmillan, 1986). The social construction of technology, or "constructivist" school, is described in more detail below. If one if willing to drop the distinction between human and non-human actors, as argued below, then SCOT and network theory are essentially equivalent.

from Indian and Pakistani security concerns.[39] But merely examining those concerns, perhaps by analyzing statements of political and military leaders, leaves no room for understanding what my approach calls the "seamless web" of development philosophies, satellites, scientists, and even rural education programs that all support the development of indigenous missile technology in India.

I should caution that while the sociology of technology would add new tools to the existing literature, it cannot answer questions like, Which countries will acquire ballistic missile in the next ten years? Nor can one deduce universally applicable causes of proliferation from the theory's principles. Finally, this analysis focuses on indigenous systems, since complete weapons acquired from abroad involve a different relationship with large technological systems.

Why Does Technology Matter?

While the production of long-range missiles involves a large technological system, why should that be the focus of study? A traditional security theorist, when examining the growing production of U.S. nuclear weapons in the 1950s, might point to NSC-68 as a partial explanation.[40] But that approach glosses over the critical links leading from a young Paul Nitze's scribblings about the Soviet threat

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[39]Compare to Carnegie Endowment Task Force on Non-Proliferation and South Asian Security, *Nuclear Weapons and South Asian Security* (Washington, D.C.: Carnegie Endowment for International Peace, 1988), 25.

[40]For example, Samuel Wells, "Sounding the Tocsin: NSC 68 and the Soviet Threat," *International Security* 4, no. 2 (Fall 1979): 116-158. NSC-68 advocated "a further increase in the number and power of our atomic weapons." "United States Objectives and Programs for National Security," *NSC-68*, 14 April 1950, reprinted in Thomas Etzold and John Lewis Gaddis, eds., *Containment: Documents on American Policy and Strategy, 1945-1950* (New York: Columbia University Press, 1978), 385-442, 416.

to the resulting metaphoric swing of an Inuit laborer's pick axe in a Yukon uranium mine. Similarly, in examining missile proliferation, we need to remind ourselves that such links occur only as the end result of a tremendous focusing of diverse resources bound together in the form of a large technological system.

Imagine a group of people in a third world country advocating a missile capability. They would need to recruit an array of allies: the security elite, the military R&D establishment, commercial subcontractors, the press. Each one of these potential allies has its own perspectives, interests, and alternative solutions to its own problems--solutions that would not require missiles. The Air Force does not want missiles, it wants another squadron. Scientists want publishable research and better laboratories. Economists want to save money and to invest in development. Party leaders are too busy focusing on their power base and the upcoming election.

These diverse communities and interests will never monolithically decide to construct missiles, with the technical processes then obediently following in the wake of the political decision. Instead, complex systems start small and build painstakingly on existing resources. If successful, a growing LTS recruits both "social" and "technical" allies along the way.[41] Builders of a large technological system, especially in a third world country, face limits on all resources--money, political authority and consensus, laboratory quality reagents, access to imports. The process by which these scarce resources are recruited and fixed in a stable

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[41]"Social" here refers to political, economic, and cultural factors--i.e., that which is not "technical." The sociology of technology argues against maintaining such distinctions, and ideally this thesis would not use such terms at all. Similarly, the word "system" carries different meanings when applied to "weapons systems" versus "large technological systems." For readability, I continue to use terms that have common intuitive meanings. The reader is invited to add a liberal dose of ironic quotation marks.

network capable of producing the comparatively simple artifacts of "ballistic missiles"--all of this *is the process of missile proliferation.* It cannot be studied effectively without examining technology.

Why Does the Social Study of Technology Matter?

The history and sociology of technology's three most powerful insights for examining missile proliferation are the ideas that a system is composed of heterogeneous elements; that its evolution is contingent; and that its artifacts represent congealed culture. These three ideas, along with the rest of the methodology, give us concepts for a better understanding of missile proliferation and new tools for making better nonproliferation policy.

The approach lets us see the *heterogeneity* of a system, that is, how a missile LTS needs to recruit diverse allies, from electric utility executives to electrons to obedient moustache hairs, in order to survive and evolve (see below).[42] With complete political agreement and authority, a system would need fewer allies. Allies add not just specific capabilities needed to manufacture ballistic missiles; they sustain and support the growth of the whole system. The system must collect momentum and resources into a big coalition, or missiles will never be produced. Traditional analyses, on the other hand, often assume that the only relevant allies for missile systems are external security threats and foreign technical assistance. These elements clearly do matter. But we need to see all the other allies involved, and use them to find new policy openings.

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[42]Throughout this article, I refer to technologies and artifacts as actors or allies, personifying them with abandon. The theoretical justification is described below.

An historical approach also lets us see the *contingency* of missile programs, that is, how the system's evolution might have been different.[43] Understanding contingency gives us the optimism to believe that we can engineer other outcomes, and helps us to find ways to encourage those other outcomes. If missiles do not follow inevitably from security threats or technical capabilities, then policy makers can try to decipher what else might be leading to or inhibiting missile proliferation in a particular case. The concept of contingency reaches beneath the veneer of inevitability, telling us what explanations not to accept and where to look for better ones.

Social constructivist theories of technology view artifacts as *congealed culture*, that is, as physical manifestations that are condensed out of their particular cultural environment. By deconstructing the details of artifacts, we can see how they are shaped by and embody the social and political context of their original construction. But why should differences in the design details of long-range ballistic missiles or other missile systems matter? The details do not matter to those upon whom the missiles would fall. We need to go on to reconstruct the artifacts (hence the title of the thesis)--not stopping with the demonstration that technology can be viewed as congealed culture, but using that understanding to gain a view of a particular political culture in operation. The concept of congealed culture gives us the tools to look at a country's missile system and estimate the importance of various allies or differentiate among competing motivations by

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[43]In the political science literature, this approach to historical contingency is also called a "martingale process," where "the chance fluctuations of history change the baselines of the next step of the historical process...All events are forks" in history that cumulatively determine subsequent events. The concept is reviewed as part of James March and Johan Olsen, "The New Institutionalism: Organizational Factors in Political Life," *American Political Science Review* 78, no. 3 (September 1984): 734-49, 745.

decoding the artifacts themselves. In other words, the details do matter: policy makers can use this approach to try prevent the missiles from being constructed in the first place.

Theory: Pedigree and Principles

This section presents the development and basic principles of the history and sociology of technology and how it relates to current political science theories. Since this approach is unfamiliar to most researchers in security studies and often runs against currently accepted ideas, this section describes the literature in some detail.

The Theory's Pedigree:

Studies of technology used to consist of:

> earnestly detailed narratives of the development of machines, devices, and processes...[that] were positivistic and reductionist in character, virtually ignoring nontechnical and nonscientific factors...Technological development thus takes place in a hermetically sealed world of invention, engineering, and science until the fruit of thought and labor is loosed on the world to have its "social impact."[44]

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[44]Thomas Hughes, "From Deterministic Dynamos to Seamless-Web Systems," in Hedy Sladovich, ed., *Engineering as a Social Enterprise* (Washington, D.C.: National Academy of Engineering, 1991), 7-25, 7-9. This internalist, deterministic school reached its peak with the five volume *A History of Technology*, edited by Charles Singer (Oxford: Clarendon, 1954-1958). One of the first studies to break out of this mold, Lynn White's *Medieval Technology and Social Change* (Oxford: Clarendon, 1962), systematically integrates technical and non-technical components, though still viewing technology as deterministically "causing" social change. One of the first studies to look explicitly at environmental shaping of technical artifacts was Louis Hunter's *Steamboats on the Western Rivers: An Economic and Technological History* (Cambridge: Harvard University Press, 1949). Hunter's work was also one of first studies of technology transfer, pointing out how "Robert

Studies of larger systems viewed technology as an external force, with the only interesting social or political questions arising after the technology has already appeared.[45]

More recent studies of technology recognize that technology is shaped by its social, political, and economic context--that is, they see technology as being socially determined. These studies believe that human actors willfully determine a technology's creation, optimizing technological outcomes to fit their specific interests. Some identify the market as the independent variable which determines the evolution of technology; others point to class interests or gender as the most important force.[46]

Fulton, a steamboat inventor, made the mistake of assuming that technology could be transferred from one geographical region to another without substantial modification." Hughes, "Deterministic Dynamos," 15-16.

[45]In an otherwise admirable history, Edmund Beard refuses to peek inside any black boxes in his history of the early U.S. missile programs, *Developing the ICBM: A Study in Bureaucratic Politics* (New York: Columbia University Press, 1976). Similarly, the studies of the innovation school are mostly macrolevel economic or political studies that treat artifacts and technologies as black boxes. The school is discussed in Trevor Pinch and Wiebe Bijker, "The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other," in Bijker, Hughes, and Pinch, *The Social Construction of Technological Systems*, 17-50, 21-22; examples include Christopher Freeman, *The Economics of Industrial Innovation* (Cambridge: MIT Press, 1982); Joan Woodward, *Management and Technology* (London: H.M.S.O., 1958); and from a similar perspective, David Landes, *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present* (London: Cambridge University Press, 1969).

[46]The market is the determining force in the "strategic choice" model. See Jacob Schmookler, *Invention and Economic Growth* (Cambridge: Harvard University Press, 1966). For Marxist accounts, the most technologically sensitive accounts are David Noble's books, *America By Design: Science, Technology, and the Rise of Corporate Capitalism* (New York: Knopf, 1977) and *Forces of Production: A Social History of Industrial Automation* (New York: Knopf, 1984). More broadly, see Harry Braverman, *Labor and Monopoly Capital: The Degradation of Work in the Twentieth Century* (New York: Monthly Review, 1974). Mike Cooley, in *Architect or Bee? The Human Price of Technology* (London: Hogarth, 1987), argues that engineers suffer from a false

In the last ten years, numerous researchers have developed new approaches in the social study of technology that can bring together the social and the technical aspects of a missile LTS.[47] Their ideas follow largely from the sociology of scientific knowledge, drawing on research which deconstructs the actual content of science--not merely its practice--by examining histories of scientific discoveries or conducting ethnographic studies of laboratory research. These theories refuse to take "Nature" as the ultimate force which determines questions of fact or reality; they instead insist on asking *why* people accept certain facts or realities and not others.[48] In other words, this theory tells us that if we try to hold up a

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consciousness about the interests that their work serves. For meta-analyses of various Marxist theories of technological change, see Donald MacKenzie, "Marx and the Machine," *Technology and Culture* 25, no. 3 (July 1984): 473-502; and Bruce Bimber, "Karl Marx and the Three Faces of Technological Determinism," *Social Studies of Science* 20, no. 2 (May 1990): 333-51. Feminist analyses assert that gender-specific conceptions shape scientific and technological outcomes: see Evelyn Fox Keller, *Reflections on Gender and Science* (New Haven: Yale University Press, 1985); Sandra Harding, *Whose Science? Whose Knowledge? Thinking from Women's Lives* (Ithaca, N.Y.: Cornell University Press, 1991); and more generally, Emily Martin, *The Woman in the Body: a Cultural Analysis of Reproduction* (Boston: Beacon, 1987).

[47]By 1984 Trevor Pinch and Wiebe Bijker had published their seminal article, "The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other," *Social Studies of Science* 14, no. 3 (August 1984): 399-441. (For the discussion that followed, see Stewart Russell, "The Social Construction of Artefacts: A Response to Pinch and Bijker," *Social Studies of Science* 16, no. 2 (May 1986): 331-46; and Trevor Pinch and Wiebe Bijker, "Science, Relativism and the New Sociology of Technology: Reply to Russell," *Social Studies of Science* 16, no. 2 (May 1986): 347-59). That same year, a workshop at the University of Twente, The Netherlands, marked "the birthplace" of a new discipline. Wiebe Bijker, "Do Not Despair: There Is Life after Constructivism," *Science, Technology, & Human Values* 18, no. 1 (Winter 1993): 113-138, 114. Papers from that workshop were later included in Bijker, Hughes, and Pinch, *The Social Construction of Technological Systems*, which remains the best introduction to and overview of the field.

[48]Early theoretical treatments include David Bloor, *Knowledge and Social Imagery* (Boston: Routledge and Kegan Paul, 1976); Michael Mulkay, *Science and the Sociology of Knowledge* (London: George Allen and Unwin, 1979); Bruno Latour and Steve Woolgar, *Laboratory Life: The Social Construction of Scientific Fact* (Princeton, N.J.: Princeton University Press, 1979); and Karin Knorr Cetina, *The Manufacture of Knowledge: An Essay on the Constructivist and Contextual Nature of*

mirror to Nature, all we see is ourselves. The next section describes how these abstract ideas can help us to understand how technology is put together.

General Principles:

Technical artifacts, or even whole systems, appear unproblematic at first glance. We do not usually concern ourselves with the details of, for instance, a refrigerator's or automobiles' operation nor with the history of their development. When a technology works well, all that we can see is a "black box": a few inputs, such as electricity or gasoline, and the desired outputs, such as cold air or acceleration--or in the case of missiles, an explosion. A successfully black boxed technology asserts that everything besides those inputs and outputs can be safely ignored as mere detail.[49]

Science (Oxford: Pergamon, 1981). The best overall sample of the field is Andrew Pickering, ed., *Science as Practice and Culture* (Chicago: University of Chicago Press, 1992). Among the many excellent historical studies see Steven Shapin and Simon Schaffer, *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life* (Princeton, N.J.: Princeton University Press, 1985); and Lily Kay, *The Molecular Vision of Life: Caltech, the Rockefeller Foundation and the Rise of the New Biology* (New York: Oxford University Press, 1992). Ethnographic studies include Latour and Woolgar, *Laboratory Life*; and Andrew Pickering, *Constructing Quarks: A Sociological History of Particle Physics* (Chicago: Chicago University Press, 1984). For a view of how such analyses fit into the broader panorama of the sociology of science, see Harriet Zuckerman, "The Sociology of Science," in Neil Smelser, *Handbook of Sociology* (Newbury Park, Calif.: Sage Publications, 1988), 511-74.

[49]In other words, a black box is completely characterized by its inputs and outputs. The origin of the term is in operations research, where such an analytically tractable property is highly desirable. In the meantime, however, "no information is conveyed regarding the details of what is going on inside the black box." William Huggins, "System Dynamics," in Charles Flagle, William Huggins, and Robert Roy, *Operations Research and Systems Engineering* (Baltimore: Johns Hopkins University Press, 1960), 637-684, 638. See also R. D. Whitley, "Black Boxism and the Sociology of Science: A Discussion of the Major Developments in the Field," in P. Halmos, ed., *The Sociology of Science* (Keele: University of Keele Press, 1972), 62-92. To open the black box (or in this case, the ice box) of refrigerator design, see Ruth Cowan, "How the Refrigerator Got Its Hum," in Donald MacKenzie and Judith Wajcman, *The Social Shaping of Technology: How the Refrigerator Got Its Hum* (Philadelphia: Open University Press, 1985), 202-18.

When a technology does not work well, the black box opens, sometimes forcefully. When we take our car to a mechanic, she may first open the hood, then pull out the engine, and then remove the pistons, finally emerging to tell us how many thousands of dollars it will take to close the black box again.[50] Black boxes may burst open for reasons beyond narrow technical failures. MX missile basing modes or SDI technologies become the focus of heated political battles, and in the process the average newspaper reader begins to learn about nuclear fratricide or laser fluences. In the late 1980s, U.S. nuclear weapons production reactors that were successfully black boxed for decades suddenly needed to reveal their viscera, offering piping diagrams and x-rays to Congressional committees. In other words, opponents of a technology--whether dissatisfied consumers, arms control advocates, or business competitors--wage their battles by assembling the resources needed to open black boxes and consider the details of technology's construction.

Constructivist analyses of technology also insist on opening black boxes, to inspect, deconstruct, and challenge their contents. A fundamental principle of the social construction of technology (SCOT) is that:

> Our technologies mirror our societies. They reproduce and embody the complex interplay of professional, technical, economic, and political fac-

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[50]A storm in New York City recently opened a black box that had been sealed for decades. Flooding shut down most of the subway system in Manhattan, not because the tunnels themselves were flooded, but because of the flooding of the only two generators capable of supplying the twenty-five cycle alternating current that the signal network requires. When that network was first installed in the 1920s, competing and mutually incompatible sixty cycle and twenty-five cycle electricity still battled for dominance. Then for decades, the "reliance...on a rare and archaic type of electrical current" was a technical detail of the signal system. Last December that last remnant of past wars delayed thousands of subway riders. James Dao, "Aging Generators Cited In Subway Disruption," *New York Times*, 13 December 1992, p. 55.

tors. In saying this, we are not trying to lodge a complaint....Rather, we are saying that *all* technologies are shaped by and mirror the complex trade-offs that make up our societies....The idea of a "pure" technology is nonsense.[51]

SCOT does not claim that technology is purely a product of its human environment, or that the human environment is purely a product of technology. This perspective rejects the dichotomy of society and technology. Instead, when looking at technological systems, all we can see are "networks of varying degrees of durability linking together both human and non-human actors....it is too weak a position even to see technology and politics as interacting: there is no categorical distinction to be made between the two."[52]

The theory spins a "seamless web" of technical, political, cultural, and economic components, without needing to distinguish human from non-human actors or individuals from organizations.[53] In place of these traditional

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[51]Wiebe Bijker and John Law, "General Introduction," in Bijker and Law, *Shaping Technology/Building Society*, 1-14, 3.

[52]Donald MacKenzie, *Inventing Accuracy*, 410-11, 412-13. Since one of the axioms of the theory is the lack of boundaries between the social and the technical, the term "social" construction is problematic. Although early constructivists did privilege the social over other factors, this tendency has faded. For example, the 1986 edition of Bruno Latour's and Steve Woolgar's classic *Laboratory Life: The Social Construction of Scientific Fact* dropped the "Social" from its title. While problematic, the tag "SCOT" captures much of the essence of the theory and is one of the few easily pronounceable acronyms in the literature, so I make frequent use of it.

[53]Thomas P. Hughes, "The Seamless Web: Technology, Science, Etcetera, Etcetera," *Social Studies of Science* 16, 2 (May 1986): 281-92. See also one of the first strong statements of this principle in Callon, "The State and Technical Innovation: A Case Study of the Electric Vehicle in France." As John Law describes it:

> It makes sense to treat natural and social adversaries in terms of the same analytical vocabulary....[one seeks only] to follow the fortunes of the network in question and consider its problems, the obduracy of the elements involved in those problems, and the response of the network as it seeks to solve them....Those elements that are human or social do not necessarily differ in kind from those that are natural or technological. Thus the point is not, as in sociology, to emphasize that a particular type of element, the social, is fundamental to the structure of the network; rather it is to *discover* the pattern of forces

categories, we see system-builders who corral diverse allies and resources as components for the evolving networks of which they are a part.[54] Because the builders of large technological systems do not abide by traditional distinctions such as technology versus society, we call them "heterogeneous engineers"--for example, Thomas Edison, whose notebooks show that he "so thoroughly mixed matters commonly labeled 'economic', 'technical' and 'scientific' that his thoughts composed a seamless web."[55]

Charles Stark Draper was a heterogeneous engineer par excellence. Hailed (or reviled) as the inventor of ballistic missile inertial guidance systems, Draper did more than patent gyroscope and accelerometer designs. He enrolled Navy and Air Force engineers who had studied in his laboratory into a "guidance mafia" that helped assure continued support for his research. He "flew across the country [to an early conference on guidance technology]...in an aircraft navigated by a prototype inertial system, ensuring for himself the conference limelight and cutting the ground from under the feet of anyone disposed to argue the impossibility of inertial navigation." He convinced the janitors in his laboratory to record any time a broom knocked against a gyroscope's test stand. He admonished his assembly workers about the "danger inherent in facial hair and holidays--debris from moustaches and sunburnt skin could play havoc with deli-

as these are revealed in the collisions that occur between different types of elements, some social and some otherwise.

From "Technology and Heterogeneous Engineering: The Case of Portuguese Expansion," in Bijker, Hughes, and Pinch, *The Social Construction of Technological Systems*, 111-34, 114.

[54]John Law, "Technology and Heterogeneous Engineering," 111-34.

[55]Hughes, "The Seamless Web," 285.

cate instruments."[56] As MacKenzie concludes, "Changing people's perceptions and gathering resources...[were] at least as important a part of the process [of inventing accurate ballistic missiles] as writing equations and drawing blueprints."[57] These tasks are not extracurricular activities, an unimportant side show to the main work of increasing gyroscope accuracies. Without them, gyroscope accuracies would never increase.

The growth of a large technological system is not ordained; it must be promoted. Thomas Hughes captures a system's ebb and flow with his battlefield metaphor of the "reverse salient"--that portion of the battlefront which stubbornly resists a broad advance. In the inevitable resistance that an evolving technological system encounters, "a reverse salient appears...when a component of the system does not march along harmoniously with other components...As a result of the reverse salient, growth of the entire enterprise is hampered, or thwarted."[58] Reverse salients are not an objective feature of an LTS. In promoting the continued growth of the system, different actors in a network will identify and attack different reverse salients. Over time, goals and contexts also shift, so that new reverse salients appear despite technical "success." Furthermore, "there is a natural tendency to identify...the reverse salient as that particular obstacle to progress

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[56]Donald MacKenzie, "Missile Accuracy: A Case Study in the Social Processes of Technological Change," in Bijker, Hughes, and Pinch, *The Social Construction of Technological Systems*, 195-222, 206-7.

[57]MacKenzie, *Inventing Accuracy*, 384.

[58]Hughes, *Networks of Power*, 79-80.

that you can remove."[59] For example, it is possible to characterize decades of growth of South Africa's nuclear system as a series of successful attacks on an orderly progression of reverse salients identified by the uranium mining industry.[60]

We may use the analogy of a chess game, in which a player's strategy is a product of both their own moves and their opponent's, constrained by the existing structure of the game (the idea of a "player," an eight-by-eight board, particular pieces, etc.) In an LTS, however, actors also modify the rules or change the shape of the pieces. Thus, the fluidity of the battlefield is one of best available metaphors for capturing how "actors (people, organizations [and technical artifacts]) are both shaped by, but yet help to shape, the context in or with which they are recursively implicated."[61]

A final principle in the history and sociology of technology is that there is no one best way to reach a given technological goal. The evolution of an LTS or of individual artifacts is not "a naturally unfolding process of technological development; at all points it should be seen rather as product of contingency. The result is that it twists and turns as social and technical circumstances change."[62] In

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59MacKenzie, "Missile Accuracy," 198; for a more general discussion, see Hughes, *Networks of Power*, 79-105. Note the similarity to garbage-can processes, though in a systems analysis at least some actors have a vision of an overall system whose growth they are trying to promote (often over the visions of other actors). The system itself also channels or limits available choices.

60See the case study on South Africa in Flank, "Exploding the Black Box," forthcoming.

61Bijker and Law, "General Introduction," 10.

62Bijker and Law, "Do Technologies Have Trajectories? Introduction," in Bijker and Law, *Shaping Technology/Building Society*, 17-19, 17. A natural reaction to this unforgiving indeterminacy is to demand recourse to a factual foundation that can sustain some technologies as simply better than others. But the claim that technological knowledge is contingent is:

> not a question of debunking, of exposing the causes of false or inadequate knowledge....There are always grounds for challenging any knowledge claim. But not all knowledge is challenged, nor is all challenge successful or even credible. Why some knowledge

other words, no matter how far inside the black box we descend, technology retains its shifting, constructed character.

Relationship to Other Theories:

Traditional international relations theories underlie most analyses of missile proliferation. In Waltzian terms, the sociology of technology combines elements of the first, second, and third images, weaving together the ambitions of individual system-builders, the interactions of relevant organizations within a state bureaucracy, and the symbolic role of ballistic missiles in the international system. We should expect any theory that views technological systems as part of a seamless web to cross these levels of analysis shamelessly. Nonetheless, SCOT's emphasis on technical details, bottom-up processes, and networks necessarily focuses the analyst's attention on second image processes, and in particular on the interactions that feature so prominently in theories of bureaucratic politics.

Bureaucratic politics and the social construction of technology share many features. Both highlight the messy, combative nature of large-scale decisions. Both maintain neutrality on which interests are the most powerful, preferring

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> claims are challenged and some are not, and why some challenges succeed and some fail, thus become interesting empirical questions....[Contingency is] an ineradicable aspect of all technological knowledge.

MacKenzie, *Inventing Accuracy*, 10-11; see also his "The Problem with 'The Facts': Nuclear Weapons Policy and the Social Negotiation of Data," in Roger Davidson and Phil White, eds., *Information and Government* (Edinburgh: Edinburgh University Press, 1988), 232-51; and "From Kwajalein to Armageddon? Testing and the Social Construction of Missile Accuracy," in David Gooding, Trevor Pinch, and Simon Schaffer, eds., *The Uses of Experiment: Studies of Experiment in the Natural Sciences* (Cambridge: Cambridge University Press, 1989), 409-35.

instead to offer methods for examining the relevant processes.[63] By including technology within the scope of the analysis, the sociology of technology is more consistent with the bureaucratic politics paradigm than the practice of bureaucratic politics studies has been.[64] While viewing everything else as the product of organizational contests, alliances, and interacting world views, bureaucratic politics has previously taken technology as exogenous and unproblematic. SCOT extends the reach of the analysis--with some important differences.

First, constructivist analyses of technology grant technology the symmetric status of an actor. In other words, technology can influence decisions, expand or restrict options, and alter other actors' conceptions just as much as people or organizations.[65] Second, such analyses often include a textual and interpretive

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[63]Some versions of bureaucratic politics explicitly tie interests to bureaucratic positions--"where you stand depends on where you sit." Graham Allison, *Essence of Decision: Explaining the Cuban Missile Crisis* (Boston: Little, Brown, 1971), 176. Analyses based on this version of bureaucratic politics have been heavily criticized for their theories and predictions. See David Welch, "The Organizational Process and Bureaucratic Politics Paradigms: Retrospect and Prospect," *International Security* 17, no. 2 (Fall 1992): 112-46, esp. 120-21, 128-34; and Jonathan Bendor and Thomas H. Hammond, "Rethinking Allison's Models," *American Political Science Review* 86, no. 2 (June 1992): 301-22, esp. 314-18.

[64]Thus, although Beard in *Developing the ICBM* permits himself to examine every personality conflict, organizational routine, and political machination, he steadfastly refuses to consider, for example, how choosing a particular propulsion system may force the kinds of bureaucratic results that he is interested in. Beard is by no means exceptional; rather, the lacuna is particularly noticeable only because the rest of his analysis is of the highest quality.

[65]See the debate in Pickering, *Science as Practice and Culture*: Harry Collins and Steven Yearley, "Epistemological Chicken," 301-326, esp. 309-322; Michel Callon and Bruno Latour, "Don't Throw the Baby Out with the Bath School! A Reply to Collins and Yearly," 343-368; and Collins and Yearley, "Journey Into Space," 369-389. For those who are squeamish about treating technology as actor, recall that self-described realists have no qualms about treating the "state"--itself an obdurate product of its social and political context--as an actor. See Paul Chilton, "Metaphors and Models of International Relations," ch. 9 in Chilton, *Orwellian Language and the Media* (London: Pluto Press, 1988), 93-106; or better, Paul Chilton and George Lakeoff, "Foreign Policy By Metaphor," Berkeley, Calif., 1989, photocopy. For parallel discussions in political theory about the conceptual status of

bent, that is, rejecting reductionist explanations and depending instead on insights gains from analogy, comparison and contrast, and other traditional modes of thought and understanding. One part of this approach is questioning the construction of meaning--for concepts, for actors, and for artifacts. For example, a good LTS analysis of Star Wars would study not only interservice rivalries, but also how ballistic missile defense came to signify for some the ultimate triumph of technology over the superpower rivalry.[66]

Like history, much of the practice of the sociology of technology consists of telling stories. I mean nothing derogatory by this description--storytelling is one of the oldest and still one of the most effective forms of communication.[67] As

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autonomous technology and the autonomous state, see Langdon Winner, *Autonomous Technology: Technics-Out-of-Control as a Theme in Political Thought* (Cambridge: MIT Press, 1977); and Stephen Krasner, "Regimes and the Limits of Realism: Regimes as Autonomous Variables," in Stephen Krasner, ed., *International Regimes* (Ithaca, N.Y.: Cornell University Press, 1983), 355-368.

[66]For examples of such interpretive analyses, see H. Bruce Franklin, *War Stars: The Superweapon and the American Imagination* (New York: Oxford University Press, 1988), esp. 3-6 and 199-203; and an analysis of SDI through political cartoons, Edward Linenthal's *Symbolic Defense: The Cultural Significance of the Strategic Defense Initiative* (Urbana, Ill.: University of Illinois Press, 1989). Similarly, SCOT retains the sociology of science's emphasis on language and inscription. In the sociology of science literature, see Latour and Woolgar, *Laboratory Life*; and G. Nigel Gilbert and Michael Mulkay, *Opening Pandora's Box: A Sociological Analysis of Scientists' Discourse* (Cambridge: Cambridge University Press, 1984). The practice of the sociology of technology is interpretive rather than nomological or analytical. See "Problems in the Logic of Historical Inquiry," ch. 15 in Ernest Nagel, *The Structure of Science: Problems in the Logic of Scientific Explanation* (New York: HarCourt, Brace & Word, 1961), 547-606.

[67]For an excellent integration of theory with the history of history, see John Staudenmaier, *Technology's Storytellers: Reweaving the Human Fabric* (Cambridge: MIT Press, 1985). See also R. A. Buchanan, "Theory and Narrative in the History of Technology," *Technology and Culture* 32, no. 3 (July 1991): 365-76; and E. Oches, et al., "Storytelling as a Theory-Building Activity," *Discourse Processes* 15, no. 1 (January - March 1992): 37-72. A good example in this class is Stephen Jay Greenblatt, *Marvelous Possessions: The Wonder of the New World* (Chicago: University of Chicago Press, 1991).

Donald MacKenzie observes, "These considerations [about sociological approaches] need not always be spelled out formally. Indeed, they simply describe the practice of good, modern history of technology."[68]

The thick description of a sociological approach leaves room for an historian's appreciation of the key role that odd contingencies can play in the evolution of a large, heterogeneous system, as we will see in each of our cases.[69] Authors who may not be familiar with SCOT, but who pay careful attention to technology, can thus still provide valuable histories consonant with a SCOT perspective.[70]

Methodology: Examples and Guideposts

The approach that this thesis uses is best understood through example. No one has yet provided compelling, comprehensive SCOT analyses of missile proliferation, but a few brief examples from other technologies of interest to security studies should provide a taste of the range and vigor of SCOT's growing literature. These analyses also demonstrate how the sociology of technology spans

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[68]MacKenzie, *Inventing Accuracy*, 9.

[69]On thick description, see Clifford Geertz, "Thick Description: Toward an Interpretive Theory of Culture," ch. 1 in *The Interpretation of Cultures: Selected Essays* (New York: Basic Books, 1973), 3-30.

[70]See, for example, George Valley, "How the SAGE Development Began," *Annals of the History of Computing* 7, no. 3 (July 1985): 196-226. This excellent participant's account describes, among other stories, how trying to develop air defense technologies came to involve developing both Lincoln Laboratory and digital computers.

levels of analysis, from the collision of entire systems down to seemingly insignificant technical details.[71]

Part of Thomas Hughes's classic *Networks of Power* tracks the fate of systems confronting a newly ascendant LTS. London's political boundaries in the late nineteenth century did not match the boundaries of the emerging electric power system. This tension between the two systems, one existing and the other emerging, led to adaptations in both. Many methodologies could not encompass such different systems, but in Hughes's telling, we see them engaging each other on the very same battlefield. For a time, the political system dominated, and electrification unfolded far more slowly than in Hughes's other cases, Berlin and Chicago. Eventually the emerging power system won (in part thanks to a new ally, the First

[71]Some of the best works in this proliferating field that may be of interest to those studying missile or military systems include, on electric power networks, David Nye, *Electrifying America: Social Meanings of a New Technology* (Cambridge: MIT Press, 1990); on military technologies, Edward Constant, *The Origins of the Turbojet Revolution* (Baltimore: Johns Hopkins University Press, 1980); Merrit Roe Smith, ed., *Military Enterprise and Technological Change: Perspectives on the American Experience* (Cambridge: MIT Press, 1985), particularly Alex Roland, "Technology and War: A Bibliographic Essay," 347-79; and Everett Mendelsohn, Merritt Roe Smith, and Peter Weingart, *Science, Technology and the Military*, 2 vols. (Dordrecht: Kluwer Academic Publishers, 1988); on space technology, Robert Smith, "Selling the Space Telescope: The Interpenetration of Science, Technology, and Politics," along with many of the other essays in Martin Collins and Sylvia Fries, eds., *A Spacefaring Nation: Perspectives on American Space History and Policy* (Washington, D.C.: Smithsonian Institution Press, 1991), 29-62; and Pamela Mack, *Viewing the Earth: The Social Construction of the Landsat Satellite System* (Cambridge: MIT Press, 1990); and on nuclear weapons, Matthew Evangelista, *Innovation and the Arms Race: How the United States and the Soviet Union Develop New Military Technologies* (Ithaca, N.Y.: Cornell University Press, 1988); Hugh Gusteron, "Testing Times: A Nuclear Weapons Laboratory at the End of the Cold War," Ph.D. diss., Stanford University, 1991; and Sybil Francis, "Creative Destruction: Inside the Nuclear Weapons Design Laboratories," Ph.D. diss., MIT, 1993, forthcoming.

World War), as London's smaller political jurisdictions had their power reduced or even obliterated.[72]

Other studies highlight the role of particular communities within a single broader system. The most thorough application of SCOT to military technology to date is Donald MacKenzie's study, *Inventing Accuracy*. MacKenzie, among many other themes, describes the key role of scientific and engineering organizations (a role which is also prominent in our analysis of the Indian missile systems). He quotes David Noble that "technical people strive continuously to anticipate and meet the criteria of those in power simply so that they may be able to practice their calling."[73] While admonishing Noble that technical people also actively shape the criteria of those in power, he describes the sway of the distinct goals and norms that help define technical communities such as Draper's inertial guidance laboratory. We will see in Chapter 2 how the Brazilian missile engineers working under Jayme Boscov also display this drive to "practice their calling": building and perfecting the systems to which they have devoted their lives; searching out and securing sponsors and allies to stabilize their institutions and products; training generations of students in their school of design and technical practice.[74] For both Boscov and Draper, their artifacts show a pattern of

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[72]See Thomas Hughes, "London: The Primacy of Politics," ch. 9 in *Networks of Power*, 227-61. Hughes contrasts the outcome in London with similar confrontations in Berlin which instead "culminated in negotiated coordination and cooperation rather than in stalemate" (p.261).

[73]Noble, *Forces of Production*, 43.

[74]Many of the first professors at the Brazilian Air Force's technical institute, the ITA, were trained at MIT when both "Doc" Draper and the philosophy of "design" engineering reigned. Boscov himself was in the first generation of ITA students, graduating in 1959. "Obstacles to VLS Development Reviewed," *Folha de Sao Paulo*, 14 July 1989, p. G-3, in FBIS-LAT-89-156, 15 August 1989, pp. 28-31. My thanks to Antonio Botelho for discussions on the influence of "professional" thinking among engineers in Brazil and the Air Force technical establishment.

direct, evolutionary refinements to a core design. Even when technologically distinct and theoretically superior alternatives are proposed, their systems win out because decades of meticulous perfection have produced superior systems from seemingly inferior foundations.[75]

By concentrating on the successive generations of a single technology--SLBM guidance packages--MacKenzie and Graham Spinardi highlight the shifting alliances within an LTS. The Polaris missile had to be accurate enough to help prove the feasibility of the navy's brand new missile system, yet not so accurate as to challenge the air force's dominant counterforce role. Later, the Poseidon missile needed to be accurate enough to justify using the navy's own smaller warhead instead of the air force's higher yield Mark 17, but not so accurate as to spark Congressional opposition to counterforce weapons. With the Trident II, the navy's missile organization finally bowed to pressure from the Office of the Secretary of Defense and directly contested the counterforce monopoly of a weakened air force and its vulnerable MX missile.[76]

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[75]MacKenzie, *Inventing Accuracy*, 79-80.

[76]At the same time Draper and his Instrumentation Laboratory, which built each of these systems, faced competition from other guidance technologies. Draper's systems sometimes had to be less expensive than electrostatically suspended gyros or more accurate than ring laser gyros; at other times, they tried to avoid compromising their black box status, shunning any dependence on the Kearfott company's stellar sights, on the stars themselves, or even on the missile body--Draper did not produce any strapdown systems, long after computational power was readily available. Graham Spinardi, "Why the U.S. Navy Went for Hard-Target Counterforce in Trident II (And Why It Didn't Get There Sooner)," *International Security* 15, no. 2 (Fall 1990): 147-90; Donald MacKenzie and Graham Spinardi, "The Shaping of Nuclear Weapon System Technology: US Fleet Ballistic Missile Guidance and Navigation: I: From Polaris to Poseidon," *Social Studies of Science* 18, no. 3 (August 1988): 419-63; and "II: 'Going for Broke'--The Path to Trident II," *Social Studies of Science* 18, no. 4 (November 1988): 581-624.

SCOT analyses can simultaneously dissect and integrate a single artifact within a system. John Law has described the evolution of a British strike and reconnaissance aircraft, the TSR-2, as the reification of multiple alliances. Why did the Air Staff's requirements specify a large, cheap, tactical multirole aircraft, to be produced jointly by a number of British aerospace firms? Because of the different interpretations of what the TSR-2 needed to be: the Royal Air Force of course wanted an aircraft; the Ministry of Defence was happy with an aircraft as long as it was not a strategic bomber (which had just been ruled out in a contentious 1957 White Paper); the treasury would accept an aircraft, as long as it was cheap, and as long as it was only one aircraft (that is, it should perform all the missions that the RAF needed); the aviation ministry needed to combine the dozen or so existing airframe manufacturers, and so insisted on an aircraft produced by a large industrial consortium; and the Royal Navy wanted the RAF to purchase a *small* tactical strike aircraft--the navy's own Buccaneer.[77]

The alliance nature of the aircraft design persists farther inside the black box, where the design forged a concatenation of the consortium members' experiences.[78] Thus Vickers's short take-off and landing (STOL) expertise and English

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[77]See John Law and Michel Callon, "The Life and Death of an Aircraft: A Network Analysis of Technical Change," in Bijker and Law, *Constructing Technology/Building Society*, 21-52; John Law, "The Olympus 320 Engine - A Case-Study in Design, Development, and Organizational Control, *Technology and Culture* 33, no. 3 (July 1992): 409-40; and John Law, "The Anatomy of a Socio-Technical Struggle: The Design of the TSR2," in Brian Elliott, *Technology and Social Process* (Edinburgh: Edinburgh University Press, 1988).

[78]Tracy Kidder reports a similar insight when he describes a computer engineer's reaction upon first seeing the insides of a competitor's computer: "Looking into the VAX, West had imagined he saw a diagram of DEC's corporate organization. He felt that VAX was too complicated...there was too much protocol involved...[It] embodied flaws in DEC's corporate organization [and] cautious, bureaucratic style." In *The Soul of a New Machine* (New York: Avon, 1982), 32.

Electric's supersonic experience, a pairing which "seemed irreconcilable" at the time, led to a successful design featuring exceptionally large flaps with forced high-pressure flow and extremely powerful engines.[79] Here, the design's "suc cess" refers to its ability to hold together these diverse allies, rather than its ability to fly.

One of the strengths of all of these analyses is the ability to descend to detailed technical levels and emerge with insights into general aspects of the social or political foundations of the relevant systems. In contrast to many other types of theory, the social construction of technology does not assume that levels of analysis must stay separate. Rather, just as the general environment can influence local technological choices, so seemingly trivial details can be at the junction of important broader forces.

To demonstrate this point, we examine one technical detail from Chapter 3, the choice of fuel for the Indian short-range ballistic missile, the Prithvi. The Prithvi uses a self-igniting combination of red fuming nitric acid and xylidine.[80] Xylidine may seem like an odd choice--after some research in the 1950s, the

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[79]Cited in Law and Callon, "The Life and Death of an Aircraft," 29. After the Defense Ministry accepted the initial design, the need to include STOL advocates and technology in the alliance lessened, and the designers received permission to build an aircraft for half runways and rough strips rather than STOL (p.30).

[80]Hormuz P. Mama, "Progress on India's New Tactical Missiles," *International Defense Review* 23, no. 7 (July 1989): 963-64. More recently, the same correspondent expressed puzzlement at the "archaic," "primitive," and "antiquated" xylidine propellant when "India also has the technology for...much more powerful" propellants. Mama, "Improved Prithvi Missile Launched," *International Defense Review* 25, no. 8 (August 1992): 784.

United States never used xylidine, even in developmental systems.[81] Nor do any currently operational systems in the former Soviet Union use xylidine.[82] Furthermore, this propellant choice entails substantial costs in terms of toxicity and ease and speed of fueling, while its corrosiveness requires special attention in handling and in materials for tanks and pipes. Immediately we see a conflict between users and developers, in which the Army seems to have less voice in the construction of this technology.[83]

Xylidine has a significant history in India. An aborted missile project from the 1970s, the Devil, also used xylidine fuel. Probably to reduce the development effort needed for the Prithvi, the Indian development teams seem to have adopted the Devil's engine wholesale, not even performing the modifications that would be needed to use a different fuel.[84] Furthermore, the Devil program had itself made an alliance with the Soviet-made SA-2 anti-aircraft missile, which

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[81] A search of *Chemical Abstracts* revealed several dozen papers in the 1950s which discuss xylidine, such as Riley Miller, "Ignition Delays and Fluid Properties of Several Fuels and Nitric Acid Oxidants in Temperature Range from 70 to -105 F," *NACA Technical Note #3884* (1956). By the late 1960s, only non-U.S. papers mention xylidine as a propellant. For example, A. Rajendran, M. Ramanujam, "Some Developments of Lignite Based Chemicals," *Urja* 19, no. 6 (June 1986): 401-2, describes processes for manufacturing xylidine from the plentiful deposits of brown coal in India.

[82] According to Barton Wright, assisted by John Murphy, *Soviet Missiles*, vol. 1 of *World Weapon Database*, Randall Forsberg, ed., (Brookline, Mass.: Institute for Defense and Disarmament Studies, 1986).

[83] Several observers do assert that the armed services in India, organizationally detached from development organizations, act as mere customers who only see new systems at the end of their development process. Raju Thomas, *Indian Security Policy* (Princeton, N.J.: Princeton University Press, 1986), 119-34; Itty Abraham, "India's 'Strategic Enclave': Civilian Scientists and Military Technologies," *Armed Forces & Society* 18, no. 2 (Winter 1992): 231-52.

[84] Very little has been made public on the Devil program. For what hints do exist, see Chapter 3.

India was license-producing at the time, and which also used xylidine fuel.[85] Both the Prithvi and the Devil needed to strengthen whatever links they could in their respective networks, and therefore tied themselves to the relatively stronger facts of existing missiles, rocket engines, and fuels. So xylidine teaches us about the comparatively weak support for the Prithvi project.

The Prithvi's fuel also teaches just as many lessons by what it is not. Notice that while the Prithvi incorporated the foreign technology of the Soviet SA-2 missile, the Indian Space Research Organization's much more advanced rocket technology is nowhere to be seen.[86] The ISRO's new liquid fuels could only join the Prithvi's design by a substantial engine redesign--an effort that the Prithvi was not strong enough to carry out alone and an effort in which the space agency had no interest. Notice also that the Prithvi does not use any of its own organization's new fuels which were specifically developed to recruit new members into the missile alliance. Cashew nut shell liquids and turpentine-based propellants tried to

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[85]The best public description of the SA-2 is Steven J. Zaloga, *Soviet Air Defence Missiles: Design, Development and Tactics* (Coulsdon: Jane's Information Group, 1989), 36-76. To trace the pedigree further, the German designers of the SA-2 worked largely from their own Wasserfall and Schmetterling designs for Nazi Germany, which used related fuels including xylidine. Plentiful coal reserves and nonexistent domestic oil sources in Germany had helped promote the catalytic cracking technologies for producing these fuels, but only in combination with a series of organizational, economic and political decisions made by industrialists and government leaders during and after the First World War. For an understanding of the development of the hydrogenation processes through which these fuels are produced, and for an understanding of the historical processes through which these technologies are produced, see Thomas Hughes, "Technological Momentum in History: Hydrogenation in Germany 1898-1933," *Past & Present*, no. 44 (August 1969): 106-32.

[86]For example, S. R. Jain, Rama Rao, and K. N. Murthy, "Studies on the Synergistic Hypergolic Ignition of Hybrid Systems," *Combustion and Flame* 71, nos. 3-4 (March 1988): 233-43; or more generally, A. E. Muthunayagam, "Some Recent Developments in Liquid Propulsion Systems in ISRO," in *Proceedings of the 41st International Astronautical Congress* (6-12 October 1990), IAF Paper #90-241.

compete directly with xylidine, and would have tied important agricultural sectors to the Prithvi project.[87] But the links evidently could not be forged, and the ancien regime (xylidine) prevailed.[88]

I do not claim that which fuel the Prithvi uses has great political or strategic implications in itself. Xylidine probably has its greatest impact on the soldiers who have to hold their noses while loading the fuel tanks. Rather, we can use the Prithvi's fuel to *understand* important histories, motivations, and power structures. These examples demonstrate how the history and sociology of technology can open previously unavailable windows onto sociotechnical questions, especially by focusing on conflicts and alternatives in technological choices. The next section describes how such examinations should in general be conducted.

Guideposts:

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[87]From scientists at the Defence Ministry's Explosives Research and Development Laboratory, we learn that "hypergolic liquid propellants of specific interest in India are xylidine-triethylamine-red fuming nitric acid (RFNA), hydrazine-RFNA and [UDMH]-N2O4. Fuels like [these], though indigenous and energetic, are costly. In search of a low cost fuel, we found that 3-carene, a major constituent of Indian turpentine, when mixed with cardanol, a distillation product of cashew-nutshell liquid...exhibited synergistic hypergolic ignition with RFNA as oxidizer." S. P. Panda, et al., "On Performance Evaluation of a New Liquid Propellant," *Defence Science Journal* 36, no. 1, (January 1986): 1-8, 1. See also P. K. Dutta, G. C. Pant, B. B. Umap, "Hypergolic Rocket Fuels Based on Turpentine Oil and Cashewnut Shell Liquid," *Journal of Armament Studies* (Journal of the Institute of Armament Technology) 12, no. 2 (1976): 108-17. India's technical defense literature contains an interesting but insignificant minority of such examples of development-oriented technology.

[88]By contrast, polyol (an indigenously developed solid propellant binder based on castor oil, of which India is the world's second largest producer) won out over more conventional binders in sounding rocket and apogee kick motor applications. See V. N. Krishnamurthy and Solomon Thomas, "ISRO Polyol - The Versatile Binder for Composite Solid Propellants for Launch Vehicles and Missiles," *Defence Science Journal* 37, no. 1 (January 1987): 29-37.

The practice of SCOT consists of techniques for prying open the black box of technology and admonitions about what kinds of explanations *not* to accept. As Latour summarizes, "We study science *in action* and not ready made science or technology."[89] I present here a series of guideposts for evaluating "good" SCOT stories, distilled from some of the existing literature.

Avoid technical superiority or cost-effectiveness as an explanation. Instead, look for why or why not a system *becomes* superior or cost-effective. System-builders and other actors shape their environment in ways that affect the growth of the system. For instance, Hughes concludes that "entrepreneurs like Edison designed not only devices but societies within which these devices might be successfully located."[90] Despite the systems metaphor, a good constructivist analysis does not reify the boundary between "inside" and "outside" the system.

For example, South Africans faced energy decisions that they framed as a choice between coal-fired plants and nuclear power stations, with economic analyses playing prominent roles. SCOT directs our attention to the broader technological systems in which this choice was embedded, such as how the existing infrastructure of South Africa's gold and uranium industry lowered fuel and equipment costs.[91]

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[89]Latour, *Science in Action: How to Follow Scientists and Engineers Through Society*, 258. This chapter itself might be entitled, "The Sociology of Technology in Action: How to Follow Missile Proliferation Through Its Technology."

[90]Paraphrased in Bijker and Law, "General Introduction," 12.

[91]Mining costs have historically been absorbed solely by gold mining operations, with uranium as a byproduct. The industry debated changing its accounting in the late 1970s. See "What the New Emphasis on Uranium Means to South Africa," *Cola, Gold Base Miner, South Africa* 26, no. 8 (August 1978): 41,43, cited in Abstract no. 9756, *Energy Research Abstracts* 4, no. 5, 15 March 1979, p. 1037.

South African analyses calculated that transportation costs from coal mines to distant operating stations made nuclear power more cost-effective for some locations.[92] A constructivist story should not stop there. If the rail networks had co-evolved with coal power, then they might have included larger gauge rails with shallower turns, permitting larger rail cars and longer trains. If the system also excluded passenger trains, easing scheduling difficulties and shortening transit times, then perhaps the nuclear system would not have been superior.[93] Historians and sociologists of technology are not content with concurring that coal was more expensive than nuclear power. They insist on questioning how the system's evolution has made it so.[94]

Avoid money or other resources as an explanation. Instead, look for why or why not a system has access to those resources. The analyst should translate any

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[92]See, for example, Lawrence Shelton Garth, "Nuclear Weapons, Deterrence and Non-Proliferation: The Case of South Africa," Ph.D. diss., University of Witwatersrand, 1991, pp.249-58. Garth notes that by 1986, official figures reported that the average cost of nuclear power in South Africa was 5.2c/kWh, and for coal, 1.89c/kWh (p.256).

[93]Co-evolution, in the biological sense, "refers to the joint evolution of two (or more) taxa that have close ecological relationships but do not exchange genes, and in which reciprocal selective pressures operate to make the evolution of either taxon partially dependent upon the evolution of the other." Erich R. Pianka, *Evolutionary Ecology* (New York: Harper & Row, 1973), 175, cited in Constant, *The Origins of the Turbojet Revolution*, 14. On the concept of co-evolution in technological systems, see Constant, "On the Diversity and Co-evolution of Technological Multiples: Steam Turbines and Pelton Water Wheels," *Social Studies of Science* 8, no. 2 (May 1978): 183-210.

[94]Technical superiority is hard to distinguish from cost-effectiveness. Usually, the tasks of a technology claiming to be superior can be fulfilled by existing systems, but perhaps less elegantly or more expensively. On the concept of failed innovations, see H. J. Braun, "Symposium on Failed Innovations - Introduction," *Social Studies of Science* 22, no. 2 (May 1992): 213-30; and the rest of that special issue.

claim that a technology would have succeeded but "the money dried up," into an admission that the technology lacks the support of some crucial constituency. Sufficient resources reflect authority, consensus, or support.[95] When the Eagle computer prototype at Data General is constantly on the verge of success or failure, its health is mostly a function not of the achievements of the programmers and technicians, but of the group head, Tom West, in mustering resources and protecting the project from its adversaries. Yes, the project succeeded because they had enough people, money, access to testing facilities, and so on; but those resources represented how well West had done his job as group leader.[96]

As described in Chapter 2, the Brazilian launch vehicle (the VLS) progressed well in the 1980s under the direction of the Institute for Space Activities (IAE). By the turn of the decade, however, trouble loomed--the money was drying up, while "the prospects for 1991 look[ed] even worse...barely covering 15 percent of the money needed for the VLS."[97] Under such circumstances, test failures and

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[95]The extreme version of this position is that "reality" is simply that which is resistant to change. Bruno Latour takes such a principle as his starting point for his study, "Irreductions," in *The Pasteurization of France*, trans. John Law, 151-236. (Cambridge: Harvard University Press, 1988), 158-59.

[96]Kidder, *The Soul of a New Machine*. This excellent non-theoretical history of the development of a computer is entirely compatible with a constructivist perspective. See also, Latour, *Science in Action*, 150-57.

[97]According to Lt. Col. Tiago da Silva Ribeiro, the president of the IAE, the money that the space program received in March 1990 had been "totally spent by July." The agency was "negotiating a budget supplement of 150 million cruzeiros to continue the project. The IAE has so far received only the equivalent of one-fourth of the 1.5 billion cruzeiros that it requested for 1990." "Official Says U.S. Withholding Motors: Space Program Delayed," *Folha de Sao Paulo*, 24 August 1990, p. A5, in FBIS-TAC-90-026, 18 September 1990, p. 13A.

other technical difficulties would seem easy to explain.[98] But the lack of money reflected the system's broader difficulties. The launch vehicle had lost crucial allies. The Brazilian satellite-building organization had reneged on its commitment to launch its first satellites on the VLS, and was shopping for a foreign-supplied launch vehicle instead. The private company that mass produced IAE-designed rockets for military export was bankrupt and had halted production. A newly elected civilian government replaced the military-appointed government that had supported launch vehicle development. The network of allies that supported the VLS program was falling apart and the physical artifact was falling apart along with it. The loss of resources upon which the project could call is only an intermediate variable in this story, and not a very interesting one at that.[99]

Avoid truth or reality as an explanation. Instead, look for why actors are willing to accept something as the truth. This admonition does not deny the existence of reality; it only reminds us that the determination of truth is the (unavoidably social) process of convincing ourselves and others. The social and political nature of truth reveals itself most in the midst of controversies, when powerful actors have the resources and incentives to pry open the black box of technology. Thus, antinuclear advocates do not accept that a utility's calculation of failure

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[98] For a report of some of the test failures, see "Obstacles to VLS Development Reviewed," *Folha de Sao Paulo*, 14 July 1989, p. G-3, in FBIS-LAT-89-156, 15 August 1989, pp. 28-31.

[99] The full story is recounted in Chapter 2. Resource availability can still be important when comparing technological systems across societies, such as India and Germany. Even there, the analyst should keep in mind the political and historically contingent nature of those differences, such as the political and economic conflicts of North-South relations.

probabilities for a nuclear reactor reflects reality. Whether contested or not, truth claims in complex societies are often mediated by social position.[100]

Consider a case where a proliferator has not conducted any known nuclear tests, yet has built up a nuclear arsenal. An analyst looking at this situation may conclude that the leaders either know it works anyway or have conducted testing in secret. A constructivist analysis of the same case would instead ask if those leaders care whether their weapons work, or how different actors define a "working" nuclear weapon. If the scientists doing the nonnuclear testing are the ones making decisions (as may be the case in India), they may decide that a weapon really works if those nonnuclear tests match their calculations. Perhaps the lack of testing is a strong indicator that no relevant actors are challenging nuclear weapons policy, that no one is trying to open the black box of whether or not the weapons will work (as may be the case in Israel).[101] By acknowledging that truth

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[100]As Donald MacKenzie observes:

> The apparently simple question "which is the most accurate gyroscope?" cannot be answered in a way that compels consensus, if a skeptic is determined and resourceful enough...Testing inevitably involves "the construction of a background against which to measure success."...Nowhere in this complex process of modeling and testing do unchallengeable, elementary, "atomic" facts exist. This does not mean that accuracy is a mere fiction, an "invention" in the pejorative sense, for this absence of "atomic" fact is characteristic of all scientific knowledge. It does mean, however, that the more deeply one looks inside the black box, the more one realizes that "the technical" is no clear-cut and simple world of facts insulated from politics.

MacKenzie, "The Construction of Technical Facts," ch. 7 in *Inventing Accuracy*, 341, 372-73, 381. On testing, see also Edward Constant, "Scientific Theory and Technological Testability: Science, Dynamometers, and Water Turbines in the Nineteenth Century," *Technology and Culture* 24, no. 2 (April 1983): 183-98; and Trevor Pinch, "Testing - One, Two, Three...Testing!" *Science, Technology, & Human Values* 18, no. 1 (Winter 1993): 25-41. On truth claims more broadly, see Jurgen Habermas, *Communication and the Evolution of Society*, trans. Thomas McCarthy (Boston: Beacon Press, 1979).

[101]Consider MacKenzie's concept of an "uncertainty trough," correlating uncertainty with one's distance from the site of knowledge production. Donald MacKenzie, Wolfgang Rudig, and Graham Spinardi, "Social Research on Technology and the Policy Agenda: An Example from the Strategic Arms Race," in Elliott, *Technology and Social Process*, 152-80.

is a social artifact, a constructivist can extend the inquiry farther than a traditional analysis would.

Look for how alliances form, and how they shape the system. Individual actors or monolithic organizations rarely have the power to create large technological systems. Instead, an LTS evolves by combining organizations, interests, existing artifacts and other heterogeneous elements. This process is especially visible when technologies take on multiple or even conflicting roles and interpretations. Thus rocket technology is frequently an alliance that includes both space and missile components, while nuclear technology can build an alliance between power generation and nuclear weapons.

We see the necessity for alliance-building in the Indian space organization's relationship with external organizations, such as the end-users of satellite technology (telecommunications, weather, television). The space program proudly proclaimed that their INSAT 1A satellite was the first geostationary satellite in the world combining "the triple functions of telecommunication, direct TV broadcasting and weather watching."[102] Yes, previous satellites had not featured this combination, but not because it is technically difficult. Rather, the Indian space program needed to load the satellite with such a variety of capabilities to build a strong enough alliance to make the project succeed.

Look for how the links in a network are strengthened, and how they stabilize the system. Large technological systems succeed (or artifacts reach "closure") because the networks in which they are embedded become more obdurate.

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[102]Radhakrishna Rao, "India in Space," *Space World* (March 1983): 16-18, 17.

When Robert Fulton won a government-sponsored monopoly to move his steamboats from the Hudson River to the Mississippi, he was soon defeated by another system that linked its alternative steamboat design more strongly to the river's environment. Less efficient but lighter high-pressure engines combined plentiful firewood on the shore with a shallower draft that could pass over the Mississippi's plentiful sandbars and deltas. The river's famous muddy waters got along better with a noncondensing compressor. Local crafts skills could better maintain the simpler engines.[103]

Stability may prove elusive even for systems that do form many alliances. Brazil's Jayme Boscov has linked his one paradigmatic form of rocket technology to atmospheric research, long-range artillery, space launch vehicles, and ballistic missiles, with organizational sponsors including the Brazilian military, the science and technology ministry, private Brazilian companies, and the U.S. Air Force Geophysical Laboratory.[104] These supporters have permitted Boscov's organization to develop and refine its core rocket designs to a point where no other missile technology in Brazil can hope to compete. Yet because these alliances have proved tentative or ephemeral, his organization's ultimate technological triumph, the Brazilian satellite launch vehicle, has itself never fully stabilized, and may well never be launched.

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[103]Hunter, *Steamboats on the Western Rivers*, 4-27, 61-180.

[104]Boscov's series of Sonda rockets share the same basic conception, many components, and often whole stages. See the summary of Sonda development given in A. C. F. Pedrosa, T. S. Ribeiro, and Jayme Boscov, "The Brazilian Space Program: Actual State of the Art," in *Proceedings of the Ninth ESA/PAC Symposium on European Rocket and Balloon Programmes and Related Research* (1990), Paper ESA SP-291, pp.213-18.

Strengthening links in a network is often equivalent to extending a laboratory system to a broader environment.[105] For example, the Polaris A1 missile "was really a prototype which had 'been designed to be flight tested by engineers...it demanded, but you couldn't give it, tender loving care.'" In other words, the artifact was not yet stable outside of a very particular environment which engineers could, in their person, enforce. Human and non-human allies gradually stabilized the missile. Missile engineers reproduced themselves by training navy personnel; subsequent versions of the Polaris extended and enforced the laboratory environment with new systems for insulating and protecting the missile.[106]

Look for patterns in the web, and how they apply across systems. The fabric may not have the familiar seams of technology, politics, society, and economics. In their place, the history and sociology of technology must search out generalizations to move us beyond the minutiae of each system's evolution. As Bijker and Law put it, "Only when the self-evident and unambiguous character of such ensembles has been deconstructed does the quest for the origins of their obduracy become relevant."[107] At this point the social construction of technology can finally begin to offer what traditional social scientists would recognize as

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[105]This process is a major focus of Bruno Latour's history, "War and Peace of Microbes," in *Pasteurization of France*, trans. Alan Sheridan, 1-150.

[106]MacKenzie and Spinardi, "The Shaping of Nuclear Weapon System Technology: From Polaris to Poseidon," 439.

[107]John Law and Wiebe Bijker, "Postscript: Technology, Stability and Social Theory," in Bijker and Law, *Shaping Technology/Building Society*, 290-308, 291.

results--for example, the ideas that the difficult task of assembling ballistic missiles requires constructing large and stable networks, that the list of the allies that promote that construction extends beyond security threats and foreign assistance, and that without these allies, existing large technological systems disintegrate. Identifying such patterns suffers from all the plagues of generalization found in any other social science, and it is only now becoming the focus of SCOT research. This thesis attempts, tentatively, to paint such patterns for missile proliferation.

IV Beyond Construction

A good theory should be parsimonious--it should use few variables in explaining many phenomena. By analogy, the approach presented here uses few methods in explaining the complex stories that follow. With this methodology in hand, we are now ready to examine detailed cases on Brazilian, Indian, and Israeli missile technologies. The patient, detailed research that good history and good analysis require should help move us beyond this chapter's abstract discussions toward a more compelling demonstration of the method's utility.

The cases should also help us to move beyond deconstruction to the aim of this thesis, *reconstructing* rockets. I intend two different meanings by "reconstruction." First, like an archeologist, I want these cases to reconstruct the artifacts that I examine, to figure out how all of the pieces fit together. Traditional stories, bound by disciplinary categories, would ordinarily leave these stories broken into the shards of politics, technology, economics, and so on.

Second, reconstructing rockets is a purposive, positive undertaking, in contrast to the almost nihilistic dismantling of deconstruction. Instead of being left with scraps of the story in a chaotic pile on the cutting room floor, I want to put them back together in a new way, in the form of a story that can be *used* for something, namely, for actively changing the world. When I reconstruct rockets, I reassemble their histories in order to help us disassemble the rockets themselves.

CHAPTER TWO

What Goes Up Must Come Down?

Convergence and Divergence in the Brazilian Missile and Space Program, 1980-90

I. Introduction

Since the 1960s, Brazil's military establishment has been researching, building and occasionally test firing solid-fuel rockets. By the mid-1980s, active programs included three sounding rocket designs, two separate medium-range ballistic missiles and a powerful satellite launch vehicle, while preliminary work was conducted for 1,000 km range missiles. What accounts for the existence of these programs, and what are the motivations that have driven the particular technical choices that have been made?

If one tries to look at the various Brazilian programs as being militarily-inspired, they appear to be quite mysterious. Short-range rockets have been produced by the thousands since 1981, yet none were purchased by the Brazilian Army.[1] Medium- and long-range ballistic missiles are designed, with no adversaries to provide targets. Sophisticated rockets are constructed and launched, without any plans for mass production. Advanced, high quality solid propellant technology is combined with an almost nonexistent guidance capability. If missiles in Brazil are a military program, they appear to lack any compelling military justification or rationality.

At one level, this chapter makes the negative claim that a drive for military capability cannot account for the Brazilian missile program. Since the early 1970s, the Brazilian security environment, both internal and external, has been among the more benign in the world. We will see that Brazilian threat percep-

[1] In 1990, Brazil finally purchased a few Astros rockets, but only with heavy subsidies from their manufacturer, Avibras. Robert Godoy, "Army Receives First Battery of Astros II," *O Estado de Sao Paulo*, 7 March 1990, p. 11, in FBIS-LAT-90-074, 17 April 1990, p. 25.

tions are nowhere to be found in either the technical details or the rhetoric of justification for any of these programs. As one of the main figures in the research effort, an Air Force colonel, said, "After all, whom will we attack?"[2] A traditional security analysis, looking at threats, rivals, security dilemmas and military capability, is clearly insufficient to explain this case.

For a U.S. audience, the traditional approach's inadequacy is not an idly academic question. Some parts of current U.S. policy toward Brazil seem to be predicated on the belief that these missile programs are military in origin, threaten U.S. security interests, and should be responded to in appropriate fashion. Understanding the politics of Brazilian military technology is the necessary first step if the United States is to avoid counterproductive policies.[3] Instead, U.S. policy makers can search for ways to satisfy or redirect the drives that currently manifest themselves in the form of ballistic missiles.

This chapter will attempt to reconstruct the motivations driving the Brazilian missile program by deconstructing the technology being produced. Following the methods of the history and sociology of technology, I conclude that the program is a result of a temporary convergence of a diverse set of personal, organizational, and ideological interests--an historically contingent convergence whose time has mostly past. This style of analysis assumes that artifacts are the product of the

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[2]The director of the IAE (the Space Activities Institute), Col. Antonio Carlos Pedrosa, said "Ours is an essentially civilian program. If the VLS [Satellite Launch Vehicle] was intended for military purposes, it would have to be manufactured in numbers, hundreds of them. We will manufacture no more than a few units. After all, whom will we attack? Our South American neighbors? This does not make sense." *Jornal do Brasil*, 6 November 1988, in FBIS-LAT-88-217, 9 November 1988, p. 12.

[3]See Scott Tollefson, "Brazil, the United States, and the Missile Technology Control Regime," ch. 11 in "Brazilian Arms Transfers, Ballistic Missiles, and Foreign Policy: The Search for Autonomy," Ph.D. diss., Johns Hopkins University, 1991, pp. 382-518.

social and political context in which they were constructed. In other words, I treat technology as congealed culture. Thus, to understand the complex interactions that we are calling the Brazilian missile program, we look in detail at the system that constructed it and at the artifacts that this system left behind.

One matter of terminology--I refer to a "Brazilian missile program." It is not, but nor is it a space program, nor is it a high-atmospheric research sounding rocket program. Since a concern about missiles is why the whole issue has achieved prominence in the United States, it will remain a missile program for the remainder of this chapter.

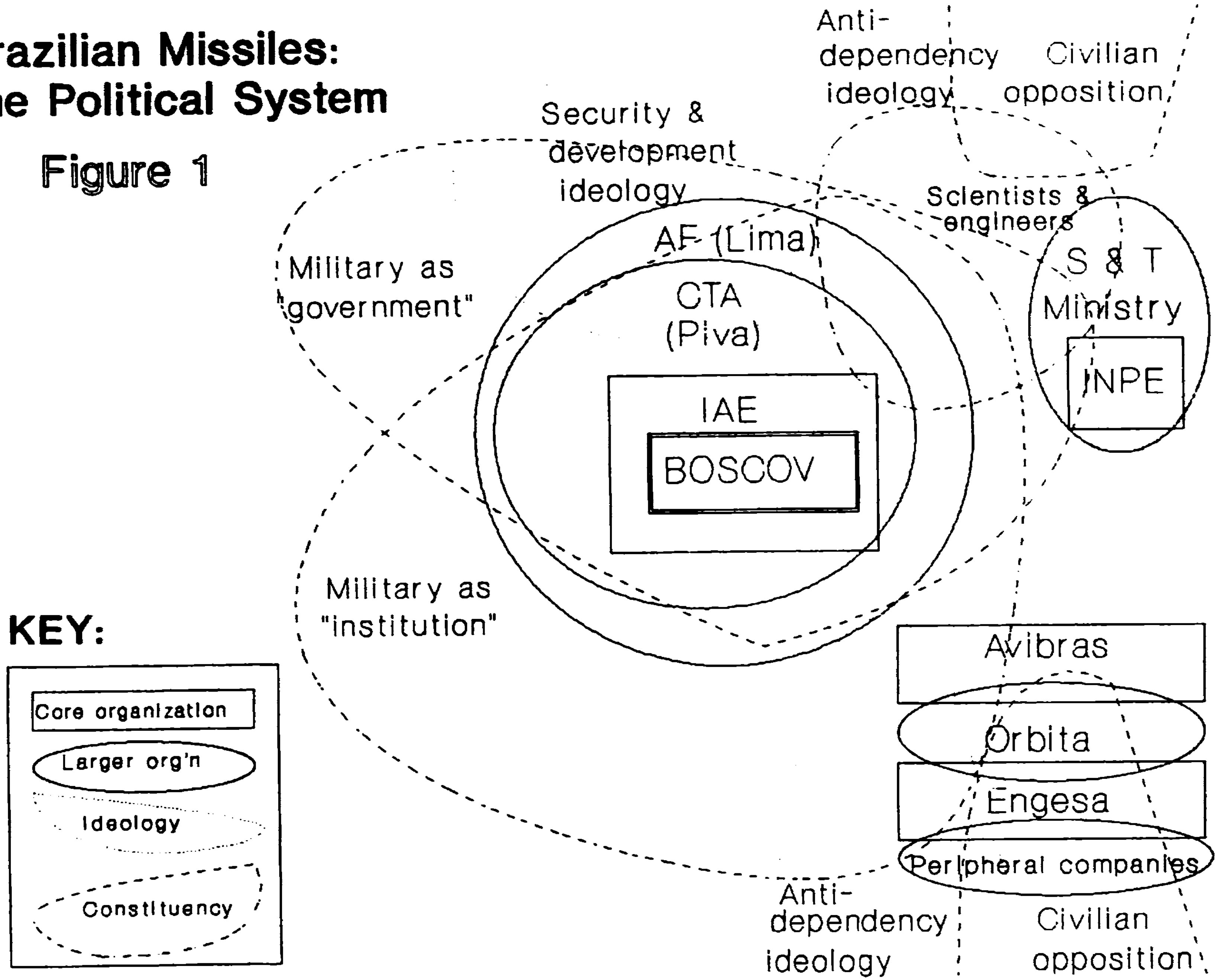
II. The Brazilian Missile System: Motivations and Actors

Figure 1 is an attempt to represent the system or network in which the Brazilian missile program is embedded. Although this figure violates almost every one of Professor Tufte's rules about visual presentation, it does communicate the complex and heterogeneous nature of the actors and forces driving the program.[4] I will discuss briefly the motivations of each of these actors, where an actor can be an individual, a tightly knit organization, a loosely bound organization, a constituency, or an ideology. As discussed in the first chapter, I will be including technology as one of the categories of actor as well.

[4]Edward Tufte, *Envisioning Information* (Cheshire, Conn.: Graphics Press, 1990). The overlapping sectors in the figure depict the separation or lack thereof of organizations, ideologies, and constituencies. For example, the military as "government" overlaps with the Science and Technology Ministry, while the military as "institution" does not. Sources for all figures are given in the List of Figures, pp. 8-9.

Brazilian Missiles: The Political System

Figure 1



Core Research Organizations

At the center of the Brazilian program, as with so many other technological systems, is a system-builder or heterogeneous engineer--an innovator and entrepreneur who has a central vision of what he or she wants to construct, and who combines technical, organizational, managerial, and political skills and components in a seamless web in order to construct the system. Fifty-nine year old Engineer Jayme Boscov, at the IAE (Space Activities Institute), has been designing, promoting, building, and launching Brazilian rockets since the 1960s. His history, his accomplishments, and most of all his technological style remind me of no one so much as Charles Stark Draper of MIT's Instrumentation Laboratory (now renamed the Draper Laboratory).[5]

For both Boscov and Draper, their primary drive was simply to be able to "practice their calling"--to build and perfect the systems that became their lives. They train generations of students in "their" school of design and technical practice.[6] As we will see in detail for Boscov, their systems are direct, evolutionary refinements of a core design. Even when technologically distinct and theoretically superior alternatives are proposed, their systems win out because decades of

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[5]Donald MacKenzie, *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance* (Cambridge: MIT Press, 1990)

[6]David Noble, *Forces of Production: A Social History of Industrial Automation* (New York: Knopf, 1984), 43. Many of the first professors at the Brazilian Air Force's technical institute, the ITA, were trained at MIT when both "Doc" Draper and the philosophy of design engineering reigned. Boscov himself was in the first generation of ITA (Institute of Aeronautics Technology) students, graduating in 1959. "Obstacles to VLS Development Reviewed," *Folha de Sao Paulo*, 14 July 1989, p. G-3, in FBIS-LAT-89-156, 15 August 1989, pp. 28-31.

meticulous perfection have produced superior systems out of seemingly inferior foundations.

Both Draper and Boscov demonstrate a willingness and a talent for recruiting diverse sponsors for their systems. Draper tried, often successfully, to have his system funded and used on civilian airplanes, submarines, space launch vehicles, and ballistic missiles. Boscov has embedded his rockets as sounding rockets for atmospheric research, long-range artillery, space launch vehicles, and ballistic missiles, with organizational sponsors including the Brazilian military, the Science and Technology ministry, private Brazilian companies, the U.S. Air Force Geophysical Laboratory, and one of Germany's Max Planck Institutes.[7] As Donald MacKenzie has observed in Draper's case, much of his success as a system-builder was in *creating a need* for the technology he wanted to construct.[8] Of course, even the most successful system-builder cannot create needs from a vacuum; we will see later how Boscov fits into the broader Brazilian context.

In one crucial way, Boscov and Draper are opposites. The rockets that Boscov develops demonstrate an almost complete lack of interest in accuracy. Dispersion plots for predicted versus actual impact points for Sonda III flights show

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[7]Most of these alliances will be explored in this paper. For the latter two sponsors, see R. E. Scarboro, E. F. McKenna, and R. E. Jacobs, "High-Altitude Recovery Programme (HARP)," *Proceedings of the 7th ESA Symposium on European Rocket & Balloon Programmes and Related Research*, Loen, Norway, 1986, ESA Report #SP-229, pp. 345-49; and G. Haerendel and A. Valenzuela, "Proposal for Support of an Ionospheric Modification Experiment at the Equator--'Coloured Bubbles,'" n.d., cited in Jayme Boscov and B. M. Furlan, "Sonda III Operational Brazilian Sounding Rocket," *Proceedings of the 6th ESA Symposium on European Rocket & Balloon Programmes*, 1985, ESA Report #SP-183, pp. 333-39, 334.

[8]Donald MacKenzie, "Missile Accuracy: A Case Study in the Social Processes of Technological Change," in Weibe Bijker, Thomas Hughes, and Trevor Pinch, eds., *The Social Construction of Technological Systems* (Cambridge: MIT Press, 1987), 195-222, 205.

accuracies between 50 and 150 *kilometers*, a factor of a thousand less accurate than U.S. or Soviet missiles with thirty times the range.[9] Detailed design choices demonstrate this disregard. With no thrust termination ports, burn times cannot be controlled precisely; with upper stages only spin stabilized, the direction of their thrust cannot be modified; and most important, without either inertial or radio guidance, Boscov's sounding rockets rely entirely on initial launch angle and subsequent attitude control. Boscov and his team have attacked numerous reverse salients with vigor and success (see Chapter 1); accuracy has clearly never been on their list. By implication, military utility has also not served as a primary motivation for this system builder.

The Brazilian program includes some other system builders that are less central. Hugo de Oliveira Piva, an Air Force general currently in the reserves, was the head of Boscov's home research organization, the CTA (Center for Aerospace Technology). Less focused and less successful than Boscov, Piva nonetheless headed the CTA in its confident heyday, undertaking projects in the aeronautics industry to develop air-to-air missiles, laser isotope separation for uranium, joint ventures with China, and of most interest for us, a satellite launch vehicle.[10] Piva may also have played a leading role in the Air Force's share of

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[9]Boscov and Furlan, "Sonda III." See Fig. 6, below.

[10]Arnoldo Cabral, "Science and Technology Policy: The Brazilian Experience in the Aeronautical Industry," *Science and Public Policy* 19, no. 1 (February 1992): 35-41; "Air Ministry, Orbita Study Piranha Missile Development," *O Estado de Sao Paulo*, 27 May 1988, p. 2, in JPRS-LAM-99-025, 11 July 1988, pp. 23-24; Roberto Godoy, "Sonda IV Command System May Serve Military Version," *O Estado de Sao Paulo*, 10 October 1987, p. 14, in JPRS-LAM-87-076, 7 December 1987, p. 5; "Brazilian-Chinese Agreement," *Tecnologia & Defesa*, no. 31 (March 1986): 24, in JPRS-TND-86-025, 17 November 1986, pp. 19-20.

the Brazilian nuclear program.[11] Since leaving the CTA, Piva continues to play a role through his engineering consulting firm, named with his own initials, HOP. The Brazilian aeronautics establishment has rejected the idea of designing and producing advanced indigenous missiles. Yet Piva and his 20 or so core missile engineers have surfaced in Brazil, Iraq and finally Iran, trying to find stable sponsors that would enable them to create technological systems that in Brazil are now considered "impossible" to produce in a developing country.[12] Piva's most valuable sponsor was another system-builder, General Moreira Lima, the long-time head of the Aeronautics Ministry (the institutional reflection of the Brazilian Air Force). Piva's favorite project, an air-to-air radar-guided missile, was at one point named with General Lima's initials (the MOL).[13]

Three research laboratories also take center stage in this story--the IAE (Space Activities Institute), which is part of the larger CTA, and the civilian INPE (Institute for Space Activities). For each of them we find, predictably enough, more organizational sorts of motivations--a desire for stable or higher budgets; for more or better trained personnel; and for exciting or prestigious projects. In addition, each agency has an identifiable "organizational essence," a mission which each views as uniquely its own, justifying the organization's existence in its own and others' eyes.

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[11] Piva was one of "the two most important figures" in the nuclear program that Science and Technology Minister Jose Goldemberg named in October 1990. Tollefson, "Brazilian Arms Transfers," 476.

[12] "Brazil Offers Missile Technology to Iran," *Defense Electronics* (May 1991): 12.

[13] "Engesa Firm to Build Medium-Range Missiles," *O Estado de Sao Paulo*, 16 December 1986, p. 2, in JPRS-LAM-86 FOUO [For Official Use Only] Annex, 19 December 1986, pp. D2-D3.

For the IAE, most of its activities center around Engineer Boscov's team, constructing bigger and more powerful rockets. The "made in Brazil" label is important to their mission. The very name, "Complete Brazilian Space Mission," demonstrates the importance of native technology.[14] Along with the rest of the CTA, they also emphasize the transfer of technology that they have developed to private Brazilian firms for routine production. For example, the Sao Paulo Bernardini Industrial Company is building the one-third scale version of the VLS under the general supervision of the IAE, with the overall effort involving some 200 Brazilian companies.[15]

The CTA is not only the central research organization for the Air Force, it is also at the center of an enormous high-technology industrial park about 90 km northeast of Sao Paulo, at Sao Jose dos Campos.[16] While the CTA is clearly

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[14]Within the MECB (the Brazilian Complete Space Mission), according to Colonel Pedro de Araujo Sousa, executive director of the GICLAN (Group to Establish the Alcantara Launching Center), the satellite launcher is 80% indigenous technology, and the satellites 90%. "Satellite Launch Delayed by Technology Controls," *Brasilia EBN*, 3 February 1988, in FBIS-LAT-88 FOUO Annex, date and page unknown.

[15]Roberto Lopez, "Space Vehicle Scheduled for Launch in November," *Folha*, 17 July 1988, p. A-30, in FBIS-LAT-88-138, 19 July 1988, pp. 34-35; and "Economic, Industrial Ramification of Space Launch, Program," *Veja*, 28 November 1984, pp. 72-76, in JPRS-LAM-84-141, 21 December 1984, pp. 104-9. I have not been able to gather enough information to determine if they have any particular attachment to, for example, computers, test facilities, or minitiarization. Those elements of a technological style which I have been able to identify seem mainly to be Boscov's. On the concept of "technological style," see Hughes, *Networks of Power*, 404-60.

[16]Sao Jose dos Campos is a 22 square kilometer campus, which includes the CTA and its associated institutes, the headquarters of the leading aeronautics firms, Engesa, Embraer and Avibras, and other metallurgical and electronics industries. The complex has provided employment for 50,000 members of the Metallurgical Workers' Trade Union, half of them involved in producing defense materiel. "Avibras Lays Off 4,000 Workers Since June," *O Globo*, 27 January 1989, p. 18, in FBIS-LAT-89-036, 24 February 1989, p. 60. It is also the site of an annual high-technology fair to encourage sales and joint ventures for Brazilian firms. "Economic, Industrial Ramification," *Veja*, 28 November 1984; and "IAE to Begin Sonda IV Tests; CTA Projects Discussed," *Jornal do Brasil*, 20 July 1981, p. 4 in JPRS-78863, Latin America Report no. 2360, September 1981, pp. 16-20. For the relationship of this enclave with the rest of Brazilian R&D and industry, see Itty Abraham, "Security,

responsive to Aeronautics Ministry concerns, its organizational essence is also tied to the development of the Brazilian arms industry and high-tech industry in general. Its accomplishments include developing both engines and fuel manufacturing techniques for Brazil's well-known alcohol fuels program; developing some new steel manufacturing technologies; and even transferring managerial "technologies" from industrialized countries.[17]

Affiliated with CTA is ITA, the Institute of Aeronautics Technology, which is one of the most important centers for technical education in the country. For example, some 60% of the 800 engineers at the state-owned aircraft manufacturer, Embraer, are ITA graduates.[18] According to the CTA's director, the

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Technology and Ideology: Strategic Enclaves in Brazil and India," Ph.D. diss., University of Illinois at Urbana-Champaign, 1992. For an excellent case study of the relationship between CTA and Embraer, see Patrice Franko-Jones, *The Brazilian Defense Industry* (Boulder, Colo.: Westview Press, 1992), 72-93, 108-18.

[17]Jayme Boscov boasts of transferring management techniques from Europe's Ariane project. Jayme Boscov, et al., "Sonda IV Brazilian Rocket: The Major Step for the Future National Satellite Launcher," AIAA Paper #86-2552 (New York: American Institute of Aeronautics and Astronautics, 1986). Boscov also writes that "among the National Space Program subproducts many important new technologies have been acquired by the Country, for instance all the significantivest improvements have already reached the steel and materials industry [sic]." Other publicity from CTA claims that special steel alloys from the space program are already saving $1 million of foreign exchange monthly. "IAE to Begin Sonda IV Tests," 16. The same article mentions a project for using vegetable oils in diesel engines and a joint project with Avibras for developing air traffic control radars. The CTA's best known project with a direct impact on Brazilians' lives was the alcohol engine. See Michael Barzelay, *The Politicized Market Economy: Alcohol in Brazil's Energy Strategy* (Berkeley: University of California Press, 1986), 139.

[18]Tollefson, "Brazilian Arms Transfers," 48, based on interviews; Raul de Gouvea Neto, "How Brazil Competes in the Global Defense Industry," *Latin America Research Review* 26, no. 3 (Summer 1991): 83-107, 93; and Franko-Jones, *Brazilian Defense Industry*, 72-73.

"main concern of the CTA is to transfer results of all research to private industry." The primary instrument for this task is the IFI (Industrial Coordination and Promotion Institute), another of the major components within the CTA.[19] Thus, expanding its own research base and ensuring technology absorption in Brazilian industry are key for the whole Center.

The INPE, housed in the civilian Ministry of Science and Technology, is concerned with building systems of its own--systems for which a satellite launcher would be a useful adjunct. The scientists, engineers, and technicians at INPE have successfully developed and put into use a series of satellite-based communications technologies, such as a transmitter for remotely collecting environmental data from distributed sites (the technology for which they subsequently transferred to a subsidiary of Engesa for mass production). They are also responsible for the receiving stations, ground support, and data processing for all satellite-based systems, including weather forecasting, telecommunications, and surveying.[20] The INPE's test facilities are a focus, so that the INPE could claim in 1987 that their new Laboratory of Integration and Tests was "the only

[19]"IAE to Begin Sonda IV Tests," 4.

[20]INPE lists utilization of natural resources as one of the justifications for a Brazilian space program. The institute has "already invested in facilities for reception, processing and distribution of data relayed by foreign-owned Earth observation and meteorological satellites," including GOES, the European Meteosat, and Landsat. The data are used for "geology, hail forecasting, environmental and pollution control, etc." INPE has also developed Data Collection Platforms (autonomous sensor and transmitter platforms which gather local data and relay via satellite) for use with the Tiros-N/NOAA (National Oceanic and Atmospheric Administration) and GOES (Geostationary Operational Environmental Satellite) satellites. "The prototype platforms have been tested and the technology will now be transferred to Engespaco," a subsidiary of Engesa. With 1000 platforms planned, the contract could be worth $2.5 million. Pierre Condom, "Brazil Aims for Self-Sufficiency in Space," *Interavia Aerospace Review* 41, no. 1 (1 January 1986): 99ff.

laboratory of this type in the Southern Hemisphere and Latin America."[21] Thus, in addition to their system-building activities, INPE's self-vision stresses the capability and sophistication of their equipment, both in orbit and on the ground.

Private Companies

In Brazil's mixed economy three privately owned companies, Avibras, Engesa and Orbita, have a prominent role in the missile programs. Avibras, originally founded as an aircraft manufacturer in the early 1960s, received the contracts to develop and produce the earliest sounding rocket designed by the IAE. The contract for this rocket. the first in the Sonda series, included extensive technology transfer from the IAE to Avibras. The company (and its first and only president, Joao Verdi) has built its fortune around a militarized version of the Sonda III, known as the Astros II. Similar to the U.S. Multiple Launch Rocket System, the unguided Astros rockets use a reverse engineered Swiss-designed radar tracking system to choose their launch angle with relatively good accuracy.[22] Avibras sold

[21]As described by the former head of INPE, in Marco Antonio Raupp and Paulo Tromboni de Souza Nascimento, "The Development of Space Activities in Brazil," *Tecnologia* 18, no. 4 (July 1987), pp. 24-25 of the U.S. Embassy translation. See also Clifford Graham, "The Brazilian Space Programme--An Overview," *Space Policy* 7, no. 1 (February 1991): 72-76. Other sources describing the Brazilian satellites include Aydano Barreto Carleial, "A Contagem Regressiva do Satelite Nacional," *Tecnologia* 18, no. 4 (July 1987): 50-55; and Carmen Dela, "Satelite Nacional Proximo da Conclusao," *Espacial* (May/June 1988).

[22]In 1979, when Astros-II "entered the final phase," the Swiss company Contraves cooperated with Avibras on the Fieldguard system, which compensated for unguided flight by using high-precision aiming vectors. A test launch in the appropriate direction self-destructs halfway through its flight. A computer tracks and calibrates the trajectory, adding adjustments based on weather reports. Avibras claims that the Astros systems exported to Iraq had only "40 percent internal similarity with the original Swiss project as to components and equipment, although the design of the layout remained the same." Roberto Godoy, "Swiss Missile Technology Said Little Used," *O Estado de Sao Paulo*, 15 August 1990, p. 7 in FBIS-LAT-90-176, 11 September 1990, p. 42. But see also "Guidance Systems Reported Reexported to Iraq," *O Estado de Sao Paulo*, 15 August 1990, p. 7, in JPRS-TND-90-015-S, 14 September 1990, p. 1, where Contraves claims "that material was

as much as $1 billion worth of Astros between 1981 and 1987; overall, approximately 90% of the company's sales have been for export.[23]

Avibras has also seemed intent on producing a 300 km ballistic missile known as the SS-300, based on the same IAE-developed technology as the Astros II. A flurry of reports in the mid- to late-1980s described an 8 to 12 meter missile with a 1 meter diameter and a payload of as much as 1 ton. The purported guidance systems included everything from radio-inertial to terminal homing. Prototypes and ground tests had supposedly been successfully completed and the system could be operational within a few years--provided, of course, that funders (Brazilian or otherwise) could be found.[24]

These reports have faded. Since 1988, when Iraq stopped paying its bills, Avibras has been in severe financial trouble, dropping from 6,600 employees to as low as 350 (in early 1991, the remaining employees were "on leave"), and filing

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delivered to Brazil along with a Brazilian certificate of end use (not for reexport)." The company also "doubts the truth of rumors that Avibras is now producing the guidance system. 'It is a sophisticated piece of equipment.'"

[23]As noted above, the Brazilian Army only took its first delivery of Astros in 1990, which was heavily subsidized by Avibras. "'Several potential buyers require that the equipment offered for sale in any negotiation must be in use by the defense forces of the supplying country,' explained Engineer Pedro Vial, the company's director of official relations." Godoy, "Army Receives First Battery of Astros II," 11. See also "Avibras Working to Order," *Defence* (December 1989): 934-35.

[24]"First SS-300 Missile Test in August 1987; New Arms Firm," *O Globo*, 30 November 1986, p. 15, in JPRS-LAM-87-005, 20 January 1987, p. 24; "Avibras Developed Tactical Ballistic Missiles," *O Estado de Sao Paulo*, 28 November 1986, p. 5, in JPRS-LAM-86 FOUO Annex, 16 December 1986, p. D3; "Technical Features of New Missile Viewed," *O Estado de Sao Paulo*, 12 May 1987, p. 6, in JPRS-LAM-87 FOUO Annex, 15 May 1987, p. D3; and "Brazilian Defense: Full Speed Ahead," *Defense & Foreign Affairs* (March 1987): 33-35. Additional sources are given in Robert Shuey, et al., *Missile Proliferation: Survey of Emerging Missile Forces*, Congressional Research Service, 9 February 1989.

for protection from its $200 million debt.[25] The company does have other product lines, such as parabolic receiving antennas, but is not in any sense diversified in either products or markets.[26]

Engesa is similar in many ways to Avibras. The company's only president, Jose Luis Whitaker Ribeiro, is a system-builder in his own right. Engesa has specialized in producing armored vehicles, with much of its original technology also transferred from military research agencies such as CTA or the Army's CTEX.[27] With employment as high as 11,000 and annual export sales in the hundreds of millions of dollars in the 1980s, Engesa was the lead company in a maze of subsidiaries engaged in a continuing flurry of possible deals and joint ventures which mostly proved to be ephemeral.[28] The company, with virtually no employees and

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[25]At the same time, $100 million worth of Astros were "stored in the firm's warehouses for over three years." With rumors of new Iraqi purchases after the invasion of Kuwait, "several dismissed workers were hastily called back to conduct an inspection of the missiles." "Paper Reports Iraq Trying To Purchase Arms," *Folha do Sao Paulo*, 8 September 1990, p. A-12, in FBIS-LAT-90-176, 11 September 1990, p. 35. Francisco Pereira, "Avibras Begins Paying Debt," *O Estado de Sao Paulo*, 5 January 1991, Economic Section, 11, in FBIS-LAT-91-040, 28 February 1991, pp. 29-30. In a November 1991 interview, Scott Tollefson summed up Avibras' predicament by saying, "There is no company."

[26]Roberto Godoy, "Multiple Rocket Launcher, Tank, Minesweeper To Be Produced: Multiple Rocket Launcher," *O Estado de Sao Paulo*, 4 February 1983, p. 5, in JPRS-83112, Latin America Report no. 2656, 22 March 1983, pp. 41-44, 43, is the first mention I have found of Avibras sales that include telecommunications equipment such as parabolic antennas. "Budget Cuts, Changing World Market Depress Brazil Arms Industry," *Defense News*, 4 December 1989, p. 42, notes that Avibras is trying to diversify into optic fibers and transport material.

[27]See the excellent analysis of Engesa's technological style in Clifford Graham, "Technology and Third World Defense Manufacturing: The Brazilian Firm Engesa," *Defense Analysis* 6, no. 4 (December 1990): 367-83.

[28]The organization is described in Franko-Jones, *Brazilian Defense Industry*, 21-25; Graham, "Brazilian Firm Engesa"; and de Gouvea Neto, "How Brazil Competes", 97-98, 103-4.

$150 million in debt, is now being dismembered and sold off to various buyers, including British Aerospace and the state-owned arms manufacturer, Imbel.[29] For a few years during the 1980s, one of the phantasms that Engesa pursued was the production of 150, 300, 600, and/or 1000 km range ballistic missiles for any number of clients, especially Libya. It is unclear how much work was ever performed on such systems. Flight tests were mentioned as being five years in the future. It also seems likely that the technology was to be directly appropriated from Boscov's Sonda project at the IAE.[30]

Engesa also played a role through its 40% share in a new venture formed in January 1987, the Orbita company. With another 40% in the hands of the state-owned aircraft manufacturer, Embraer, Orbita was intended at one point or another to build and operate the new Alcantara launch center, and to develop and produce the MOL air-to-air missile (developed by CTA and named after the Aeronautics Minister) and the LEO antitank missile (developed by CTEX, the Army Technical Center, and named after the Army Minister, Leonidas Pires

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[29]Franko-Jones, *Brazilian Defense Industry*, 203-4; and May 1992 interview with Scott Tollefson.

[30]One report describes how "the Libyan military mission that is currently visiting Brazil in mainly interested in the development of a whole 'family' of the MB/EE series of ballistic missiles to carry conventional warheads weighing up to 1 ton distances of 100, 600, and 1,000km...MB/EE-600 and MB/EE-1000 missiles will be developed on the basis of knowledge acquired in the manufacture of the experimental scientific rockets Sonda II and Sonda IV." "Libyan Military Mission Discussing Arms Deal," *O Globo*, 21 January 1988, p. 21, in FBIS-LAT-88-015, 25 January 1988, pp. 22-23; and "Offers Missile Development Aid," *O Estado de Sao Paulo*, 22 January 1988, p. 2, in FBIS-LAT-88-015, 25 January 1988, pp. 22-23. See also "Libya Offers to Finance Brazilian Missile Project," *Jane's Defence Weekly* (6 February 1988): 201, which describes an offer of $400 million per year for five years for the MB/EE-150 (reportedly a 12-meter long, 100 to 150 km range missile with a 500 kg payload); and "Libya Said Financing Missile Construction," *Rio de Janerio Rede Globo Television*, 3 February 1988, in FBIS-LAT-88-023, 4 February 1988, p. 32.

Goncalves).[31] Most important for our story, Orbita was to take a leading role in the VLS project, the Brazilian designed and Brazilian produced satellite launcher. With a President (Vito de Grassi) directly from the vice-president's slot at Engesa, and with Gen. Hugo Piva (former director of CTA) as vice-president, the formation of Orbita was announced with great fanfare.[32] In the end, however, the venture "has never been able to move out of the wooden sheds, visible from the highway and so neatly painted blue, that have housed its administrative headquarters since its founding."[33]

The Broader Political Landscape and the Military Government

These actors--system-builders, government organizations, private companies--all have their own reasons for participating in Brazilian missile programs. But their interests and capabilities took the forms that they did only because of their broader environment. We will see that the military-led governments in Brazil

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[31] See for example "Engesa to Build Missiles," *O Estado de Sao Paulo*. Responsibility for these projects was passed back and forth among various players, including Orbita, Avibras, Embraer, and Engemissil (an Engesa subsidiary). "Arms Company to Continue Producing Armaments," *Folha de Sao Paulo*, 2 September 1991, p. A-4, in FBIS-LAT-91-173, 6 September 1991, p. 42; and "Embraer Wants to Privatize Missile Project," *O Estado de Sao Paulo*, 24 August 1991, Economic Section, 5, in FBIS-LAT-91-168, 29 August 1991, p. 32.

[32] Franko-Jones, *Brazilian Defense Industry*, 26-27; Roberto Lopez, "Orbita and Space Launch: Brazil: Aeronautics Ministry Reviews Space Research Plan," *Folha de Sao Paulo* 27 July 1990, p. A5 in JPRS-TND-90-014, 23 August 1990, p. 25B; Eustaquio de Freitas, "Tactical Missile Development Reported," *O Globo*, 3 January 1988, p. 7, in FBIS-LAT-88-002, 5 January 1988, pp. 21-22; and R. M. Ogorkiewicz, "Orbita--A New Brazilian Missile Company," *International Defense Review* (April 1988): 448.

[33] Roberto Lopes, "Avibras Director Forecasts Recovery in Two Years," *Folha de Sao Paulo*, 6 April 1990, p. F4, in FBIS-LAT-90-091, 10 May 1990, pp. 55-56.

combined with existing philosophies about development, technology, and the role of the state to create a temporary opening for missile programs. In the language of political science's garbage-can theories, these larger currents created problems that missile programs could claim to solve.[34]

From the 1964 coup until the installation of a civilian President in 1985, the military controlled the government in Brazil. However, the military was not and is not a monolithic organization; nor has it been immune to the kinds of political pressures that we usually associate with democracies. In this analysis, I borrow Alfred Stepan's distinction between the military as government and the military as institution.[35] The military as government manages daily business and takes responsibility for the polity as a whole, often including civilians in positions of responsibility. The military as institution is the assemblage of organizations, personnel, resources, and sense of place in society that guarantees the continued existence and health of the military.

Up until the mid-1980s, the military as government was primarily concerned with maintaining its own regime, at least until an orderly transition to civilian government could be arranged. Among the strategies for accomplishing this task

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[34]Garbage-can models of organizational choice assume that "problems, solutions, decision makers and choice opportunities are independent, exogenous streams flowing through a system." Some versions posit that their conjunctions are determined by arrival times within the system, but our analysis here leaves much more room for strategic manipulation of such linkages. See the brief review in James March and Johan Olsen, "The New Institutionalism: Organizational Factors in Political Life," *American Political Science Review* 78, no. 3 (September 1984): 734-749, 746; and the original expositions in Michael Cohen, James March, and Johan Olsen, "A Garbage Can Model of Organizational Choice," *Administrative Science Quarterly* 17, no. 1 (March 1972): 1-25; and Michael Cohen and James March, *Leadership and Ambiguity*, (New York: McGraw Hill, 1974).

[35]Alfred Stepan, *Rethinking Military Politics: Brazil and the Southern Cone* (Princeton: Princeton University Press, 1988).

were repressing and/or buying off opponents, and the often overlooked strategy of giving legitimacy to military rule by promoting a viable vision of what was best for the nation. Such a vision was provided by the philosophy of "development and security" developed at the Brazilian war college, the Escola Superior de Guerra (ESG) in the 1950s and 1960s. The doctrine emphasizes how security depends on: controlling internal threats; effectively promoting economic development; and overcoming "political and economic threats to Brazil's emergence as a major actor in international affairs."[36] Thus, a philosophy that promoted military technology as a means of economic development not only helped to fulfill strategies for maintaining the regime, but also fit comfortably into both the military's and the broader polity's pre-existing philosophies.[37]

One form or another of an antidependency ideology has long been popular among both the civilian opposition and the scientific and technical community.

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[36]William Perry and Juan Carlos Weiss, "Brazil," in James Katz, *Implications of 3rd World Military Industrialization: Sowing the Serpents' Teeth* (Lexington, Mass.: Lexington Books, 1986), 103-18, 104-5. The foundations for this strategy were laid as far back as the First World War, when Brazil's major supplier, Germany, cut off all arms sales. By 1919, "Brazil's armed forces recognized the relationship between defense and the economy...[Leading generals were] 'aware of the links among international economic relationships, dependence, and national defense.'" Tollefson, "Brazilian Arms Transfers," 43, quoting Frank McCann, "The Formative Period of Twentieth-Century Brazilian Army Thought, 1900-1922," *Hispanic American Historical Review* 64, no. 4 (1984): 737-65, 761. See also the discussion of the philosophy and role of the ESG in Franko-Jones, *Brazilian Defense Industry*, 56-63, and the more general discussion of the military's development strategy in Wilfred Bacchus, *Mission in Mufti: Brazil's Military Regimes, 1964-1985* (Westport, Conn.: Greenwood Press, 1990), 83-104.

[37]Brazilian arms imports bear witness to the fact that indigenous arms production and the philosophy of development and security were not empty strategies. From 1971 to 1975, imports totaled $2 billion; during 1976-80, $2.5 billion; but from 1981 to 1985, only $0.18 billion. Michael Brzoska and Thomas Ohlson, *Arms Transfers to the Third World, 1971-1985* (New York: SIPRI and Oxford University Press, 1987), 340.

Government-sponsored development projects, protection of domestic technology, and absorption and appropriation of foreign technology--even when in connection with military projects--were welcomed by the military government's potential opponents, and helped to support its claims for legitimacy.[38] At the same time, generous support of scientific research was another means of co-opting what otherwise could have been a vocal opposition, the engineering and to a lesser extent the scientific community.[39]

Private companies, especially high-tech or defense-oriented ones, were generally supportive of the military government. That support was probably reinforced by the growth- and export-oriented development programs, especially in the defense sector, that were funded and guided by the state during this period. Their support for particular technological development programs does not seem to be tied to immediate profits. As a director of one metallurgical enterprise

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[38]See "Economic, Industrial Ramification," *Veja*. Consider also the broad support for aggressive computer technology development, described in Adler, *Power of Ideology*, 228-79; and Peter Evans, "Declining Hegemony and Assertive Industrialization: U.S.-Brazil Conflicts in the Computer Industry," *International Organization* 43, no. 2 (Spring 1989): 207-38.

[39]Jose Goldemberg, Luiz Pinguelli Rosa, the Brazilian Physics Society (SBF), and the Brazilian Society for the Advancement of Science (SBPC) did in fact play such an opposition role, as has occurred in other countries, from the Union of Concerned Scientists in the United States to Andrei Sakharov in the Soviet Union. See "Study Warns of Near Capability to Make Bomb," *Jornal da Tarde*, 3 July 1990, in FBIS-LAT-90-148, 1 August 1990, p. 33, on the role of scientists from the SBF. Engineers, on the other hand, split with scientists in the mid-1960s; after the coup, scientists were persecuted and underfunded, while engineers tried to take a leading role in development. Technically trained members of the military leadership in particular recognized the need to support the engineering profession. On scientific and engineering organizations and their relationship with the government, see Antonio Jose Junqueira Botelho, "The Professionalization of Brazilian Scientists, the Brazilian Society for the Progress of Science (SBPC), and the State, 1948-1960," *Social Studies of Science* 20, no. 3 (August 1990): 473-502.

noted, "No one made any money on these projects." Rather, as the director of another high-tech company noted, "the benefits will emerge gradually, as they did with the American program."[40] The Brazilian Studies and Projects Financing Agency (FINEP), a development agency, funded both major and minor defense R&D projects at dozens of Brazilian companies each year.[41] Some 200 companies in all are involved in the Brazilian missile and space programs, with 650 in the defense sector as a whole.[42]

Support for technical projects such as those undertaken by the CTA do help to build up the military as an institution, within certain bounds. Expanding the research base and constructing technologies and systems that could have military utility (such as missile and space technology) had been on the military's agenda for decades and were seen as a positive contribution. No one appeared to object that the research wasn't "military" enough, just as relatively few civilian critics complained that economic development pursued via military technology was inefficient or distorting.

According to Alfred Stepan, as the military as government used research programs and other means to promote its own legitimacy, it became less willing

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[40]This opinion comes from Eduardo Paula Santos, aged 47, an electronics engineer and director of Tecnasa, a Sao Paulo firm which serves the Aeronautics Ministry. He was commenting on the benefits of work on a "sheet steel that is only 3.2 millimeters thick and incredibly strong, for which the only known use is in the walls of the Sonda IV rocket, but it has arrived at a product of better than average quality [sic]." "Economic, Industrial Ramification," *Veja*, 105.

[41]A list of such products in de Gouvea Neto, "How Brazil Competes in the Global Defense Industry," 95, includes the Osorio tank, EMB-312 Tucano aircraft, a pilot microelectronics plant, a CAD/CAM system, and radio navigation.

[42]Other estimates range from 350 to 2000. Tollefson estimates that twenty-three companies have finished weapons as their primary product. Tollefson, "Brazilian Arms Transfers," 51.

to provide funding or manpower for the military as institution. Military spending and personnel levels per capita and per dollar of GDP became among the lowest in the world. Thus, paradoxically, large portions of the military became convinced that to survive as an institution they would need to give up control of the government. In Stepan's argument, this dynamic accounts for the military's voluntarily relinquishing power in the mid- and late-1980s.

Within the government, both military and civilian, another elite attempted to plan, coordinate, and promote economic activity and technological development. This diffuse planning elite, made up of economists, planners, military bureaucrats, and other professionals, came into its own in the late 1960s through developing the first Basic Plan for Scientific and Technological Development (I PBDCT), which described science and technology as the most dynamic element of Brazil's development. Its stated aims were to accelerate technology transfer and to strengthen the national capacity to innovate. By the time the third plan was issued in 1980, this approach ran out of steam, as people came to believe that planning was an impossible task in Brazil. Members of the planning elite were divided about whether to increase the role of state. For example, while promoting the Brazilian computer industry, the government decided against creating an equivalent of Embraer or Petrobras. The free market ideology, however, does not extend to antitrust laws, as the government often promotes and sustains monopolies and cartels.[43]

Control of the nation's productive sectors meshes with the military's desire to maintain control of the polity as a whole; similarly, a growth- and export-oriented policy, as opposed to laissez-faire or redistribution of wealth, would also promote

[43] Adler, *Power of Ideology*, 151-98.

both the planners' and the military's interests in control.[44] In fact, it is often difficult to distinguish between these two elites, which can be grouped under the label of "bureaucratic authoritarianism."[45]

The other significant elite for high-tech Brazilian programs is the scientists and engineers. The technical elite, while divided into scientists, engineers, and many smaller constituencies, tends to promote what some have called a "pragmatic antidependency" philosophy. They argue that dependency is a central issue for the nation to overcome, but remain willing to work with the military, with foreign multinational corporations, or with anyone else who could provide what they saw as the necessary support for achieving technological autonomy.[46] In general, these scientists tended to believe that technology was the best path to the future for Brazil, and that they were destined to lead the country down that path.

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[44]Benedict Clements and David McClain, "The Political Economy of Export Promotion in Brazil," in Lawrence Graham and Robert Wilson, eds., *The Political Economy of Brazil: Public Policies in an Era of Transition* (Austin: University of Texas Press, 1990), 62-93, 65, assert that the military government shied away from laissez-faire strategies in order to maintain more political control over the economy.

[45]David Collier, ed., *The New Authoritarianism in Latin America* (Princeton: Princeton University Press, 1979); and Guillermo O'Donnell, *Bureaucratic Authoritarianism: Argentina, 1966-1973, in Comparative Perspective*, James McGuide, trans. (Berkeley: University of California Press, 1988). The bureaucratic authoritarian state is sometimes viewed as a transition phase in development theory, one which is "necessary" to control political turmoil during development.

[46]Adler, *Power of Ideology*. Others analysts do not highlight antidependency ideology as being so common or important. In this view, the technical elite used antidependency as rhetorical justification for the primary motivation of wanting to practice their profession. From this perspective, the government was as much concerned with training, simply in order to increase the supply of technically trained people, as it was with development per se. My thanks to Antonio Botelho for pointing out this view.

III. Deconstructing Artifacts, Reconstructing Motivations

The Satellite Launch Vehicle (VLS)

As Figure 1 demonstrates, the heterogeneity of actors and their motivations for involvement in the Brazilian missile program make for a complex picture. Figure 2, I would assert, is essentially a reflection of Figure 1. The Figure shows the central artifact of the system, the VLS, in a hypothetical launching as it would have looked circa 1986.

Let us examine the various components, as shown in the schematics in Figure 3, viewing the artifacts as congealed culture, that is, as products of their social, political, and historical context.[47] We see that the VLS is a four stage rocket, with the first stage consisting of four strap-on boosters. The origin of each stage is clear: the third stage is a slightly modified version of the first stage of the Sonda IV sounding rocket, using a movable nozzle with a flex nozzle seal for thrust vector control. (In addition, the nozzle was extended to achieve a more efficient flight in vacuum, and the surface area of the internal bore was reduced for the same reason).[48] The second stage is almost identical, except that the propellant grain and the motor case have been extended by three meters (the grain was changed from 4000 mm to 7000 mm).[49] The four 1st stage strap-ons

[47]Most of the information in the following section is drawn from the technical articles cited. My thanks also to Ron Kerst, Mike Elleman, Scott Tollefson, and Ken Conca for additional information.

[48]Boscov, "Sonda IV Brazilian Rocket."

[49]Boscov, "Sonda IV Brazilian Rocket." However, a diagram in a later paper seems to indicate a 6.3m grain length. Toshiaki Yoshino, Jayme Boscov, and Wilson Shimote, "Main Propulsion System of the Brazilian Satellite Launch Vehicle VLS," *16th International Symposium on Space Technology and Science*, Sapporo, Japan, 22-27 May 1988 (Tokyo: Agne Publishing, 1988), 149-155.

Brazilian Missiles: The Artifacts

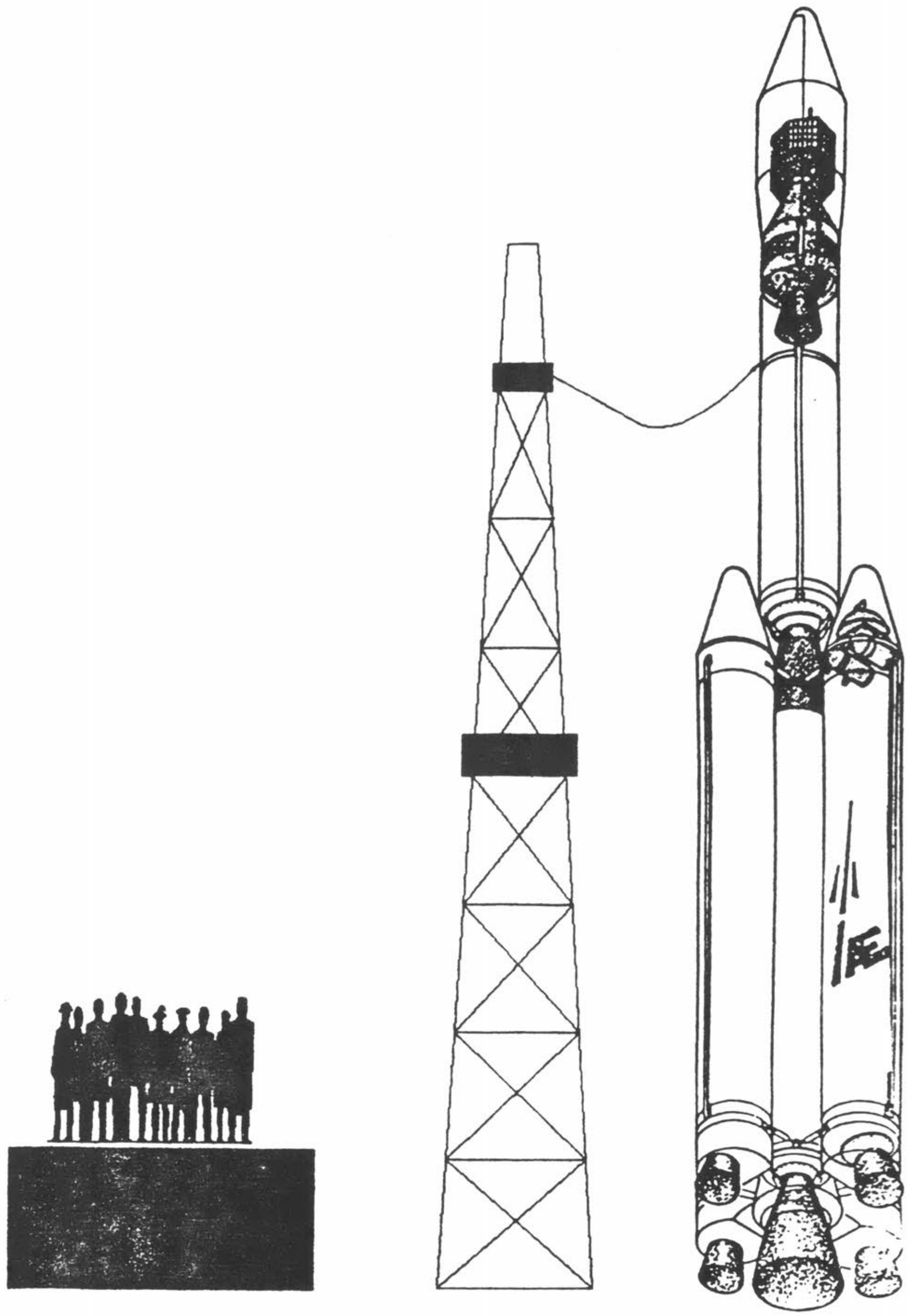
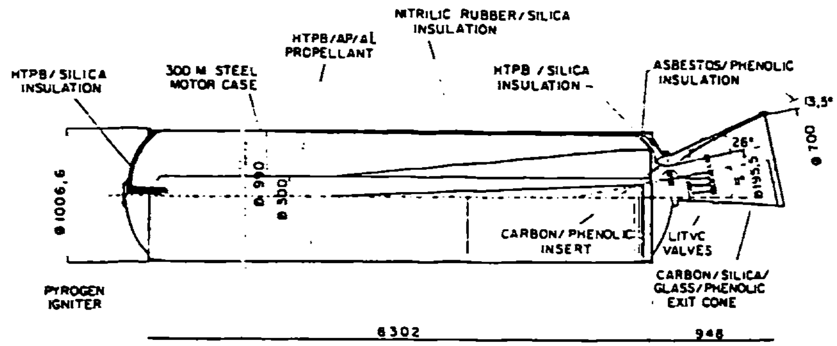
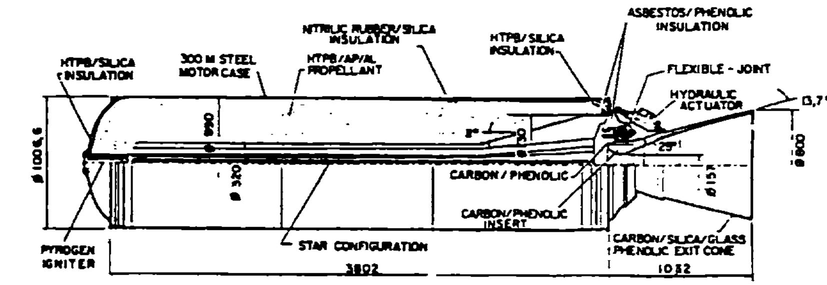


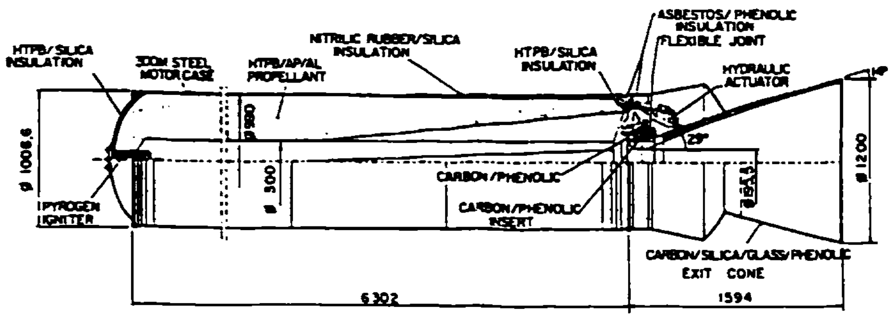
Figure 2



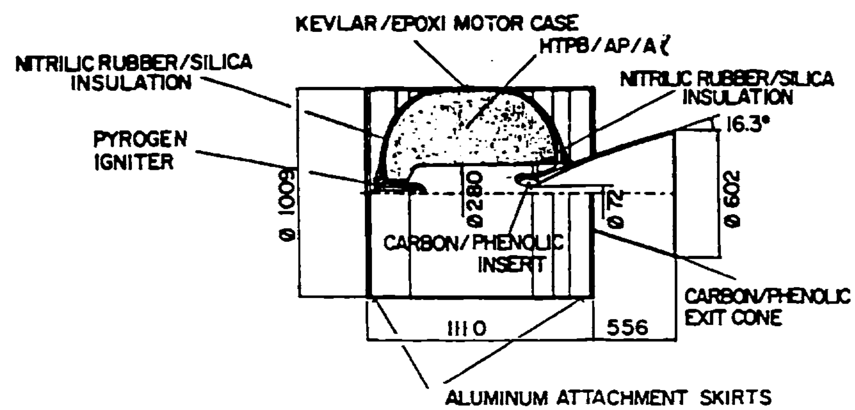
VLS First Stage Motor (S-43)



VLS Third Stage S-40TM Motor



VLS Second Stage S-43TM Motor



VLS Fourth Stage S-44 Motor

VLS Stages

Figure 3

are almost identical with the central 2nd stage, except their nozzles are fixed at an 11 degree inclination, with a liquid injection thrust vector control system taken directly from the first stage of the Sonda IV.[50] The fourth stage, on the other hand, is substantially different, with different dimensions, case material, and control system.[51]

What traces can be found in this configuration? First of all, it should be compared with the pattern of the evolution of the Sonda rockets (see Fig. 4). The Sonda I rocket was a small, experimental "learning ground" from the mid-1960s. The Sonda II, started in 1966, used lessons from the Sonda I to construct a much larger, single stage rocket. In 1969, the IAE began the design of the Sonda III, which used the Sonda II as a second stage, with the first stage sized appropriately. Similarly, the Sonda IV, whose design process began in 1974, used the first stage of the Sonda III as its own second stage, with the first stage again being sized appropriately. The Sonda program overall demonstrated a willingness and an ability to construct new technology for each step in the program, while using existing technology efficiently.[52]

A similar design philosophy for the VLS might have featured a new, powerful first stage. Presumably, its size would be optimized to take maximize advantage

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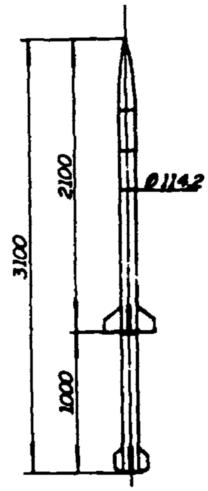
[50]Boscov, "Sonda IV Brazilian Rocket."

[51]Jayme Boscov and Wilson Katsumi Toyama, "Qualification Du Propulseur 4eme Etage due Lanceur Bresilien - VLS: Une Nouvelle Fusee Sonde," in *Proceedings of the Ninth ESA/PAC Symposium on European Rocket and Balloon Programmes and Related Research*, Lahnstein, Germany, 3-7 April 1989, ESA Report #SP-291 (June 1989), 209-12.

[52]A. C. F. Pedrosa, T. S. Ribeiro, and Jayme Boscov, "The Brazilian Space Program: Actual State of the Art," in *Ninth ESA/PAC Symposium on European Rocket and Balloon Programmes*, 213-18.



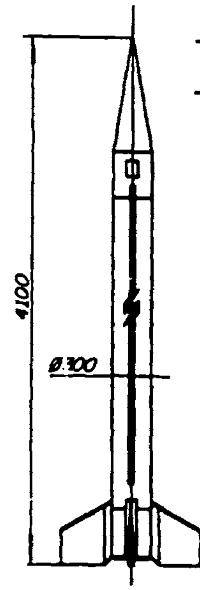
SONDA I

CHARACTERISTICS

Take-off mass (Kg) 59
Payload mass (Kg) 4,20
Maximum Velocity (m/s) 1380
Maximum acceleration (m/s^2) 250
Apogee Altitudes (Km) 65

1^{st} Stage
Motor mass (Kg) 27,5
Propellant mass (Kg) 12,7
Average thrust (N) 27000

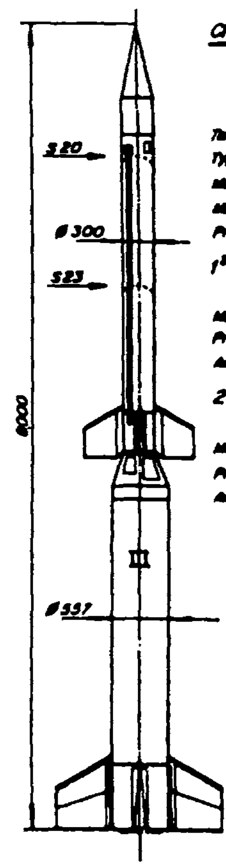
2^{nd} Stage
Motor mass (Kg) 27,3
Propellant mass (Kg) 13,2
Average thrust (N) 4240



SONDA II

CHARACTERISTICS

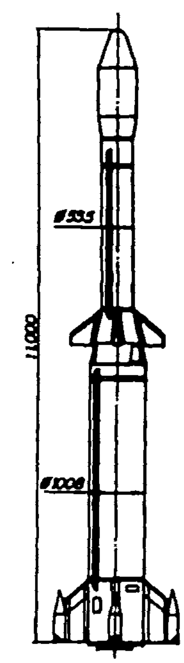
Take-off Mass (Kg) 360
Typical Payload Mass (Kg) 44
Maximum Velocity (m/s) 1600
Maximum Acceleration (m/s^2) 250
Propellant Mass (Kg) 229
Average Thrust (N) 3600



SONDA III

CHARACTERISTICS

	SIII	SIII-M1
Take-off Mass (Kg)	[illegible]	1527
Typical Payload Mass (Kg)	60	140
Maximum Velocity (m/s)	3170	2000
Maximum Acceleration (m/s^2)	305	100
Propellant Mass (Kg)	1083	977
1^{st} STAGE:		
Motor Mass (Kg)	1203	1205
Propellant Mass (Kg)	864	864
Average Thrust (N)	102000	102000
2^{nd} STAGE:		
Motor Mass (Kg)	[illegible]	182
Propellant Mass (Kg)	229	113
Average Thrust (N)	36000	18000



SONDA IV

CHARACTERISTICS

Take-off Mass (Kg) 7270
Typical Payload Mass (Kg) 500
Maximum Velocity (m/S) 3300
Maximum Acceleration (m/s^2) 110
Propellant Mass (Kg) 5250

The Sonda Rockets

Figure 4

of upper stages adapted from the existing Sonda rockets. Such designs existed (see Fig. 5), but were not accepted for the final configuration of the VLS. Instead, the current configuration is one that takes maximum advantage of technology available from the Sonda sounding rocket series, requiring the smallest amount of additional development work. Second, it is not optimized for its mission--by relying on the Sonda IV first stage so heavily, an inefficient design was the only choice.[53] As former IAE engineers and technicians complained to the press, this configuration is a "technical error" because it "requires a volume of steel three times larger than what would have been necessary had a single more powerful engine been used. In this case, more steel means more weight and the need for more fuel, as well as greater difficulty in the engineering design."[54] Our methodology reminds us, however, that technical errors are automatically suspect as explanations. Instead, we will see that Boscov and the IAE had to accept such a design because their support was not strong enough to develop the new technologies that a more efficient design would have needed.

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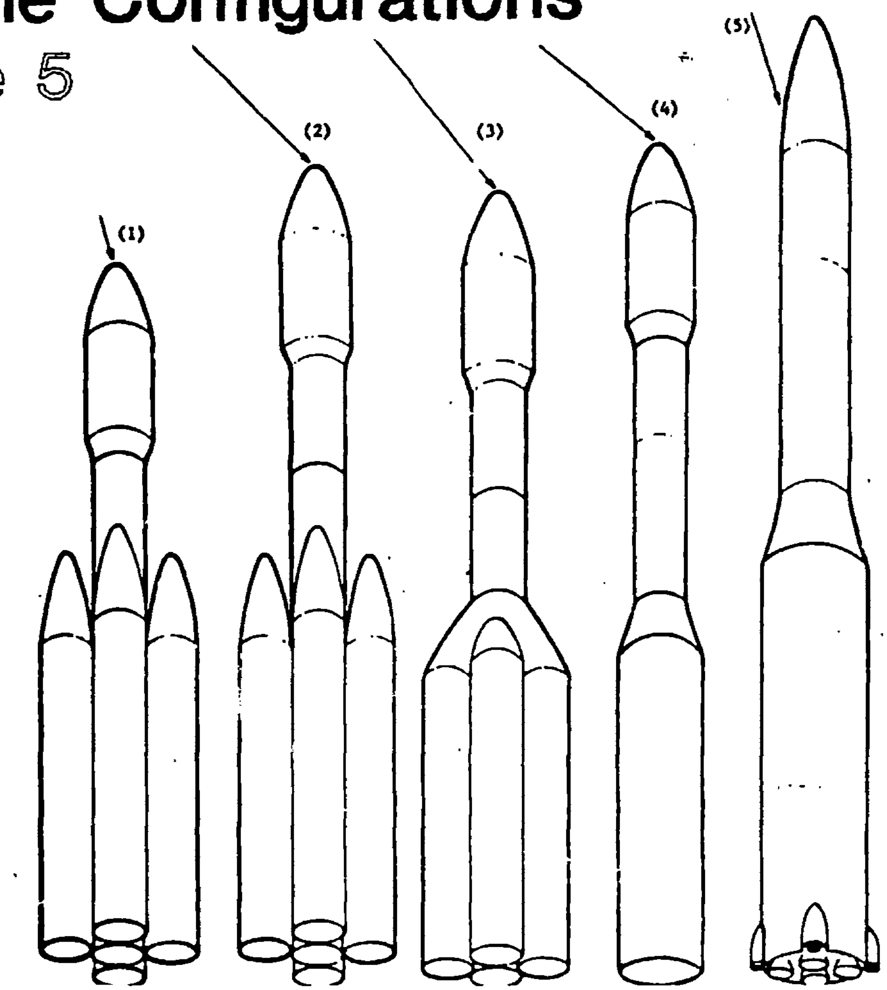
[53]Other reasons arguing for the chosen configuration include the limitation of existing foundries to manufacture motor cases over one meter in diameter (though our analysis also shows that the missile programs could be used effectively to overcome precisely those sorts of barriers in industrial capability for the good of overall technological development). Without increasing stage diameters, increasing the length of the rocket could make for too high a length-to-diameter (L/D) ratio (though we will see that in the Indian case, an L/D ratio as high as 23 was acceptable). Finally, existing testing facilities, such as wind tunnels, might not have been capable of accepting longer stages.

[54]"Obstacles to VLS Development Reviewed," *Folha de Sao Paulo*, 14 July 1989, p. G-3, in FBIS-LAT-89-156, 15 August 1989, pp. 28-31. This phenomenon is not limited to technology development in the third world, but is a typical feature of any contested program. For example, the U.S. space shuttle design originally featured a single, large liquid first stage without any strap-on motors. The eventual configuration with two solid fuel strap-ons raised overall program costs and failure probabilities, but also lowered front-end development costs enough to help win approval for the program.

Alternative Launch Vehicle Configurations

Figure 5



KEY:

1) ...initial configuration planned for the VLS, with five solid-fuel engines based on the first stage of the Sonda IV...later replaced by the following version.
2) Essentially the same...[with] a longer central stage plus another stage above it; configuration abandoned because testing it would have required large wind tunnels not available in Brazil.
3) Most recent and probably definitive form of the VLS, with four engines in the first stage and two additional stages...above it; a final decision...will be made by the end of this year [1985].
4) After the VLS...a larger-diameter solid-fuel engine...replacing the cluster of four engines used in the first stage of the VLS.
5) With the technology of liquid-fuel engines absorbed in China [sic]..., [using] as a second stage the same solid-fuel engine used in the first stage of the preceding model; ...these are merely basic plans of the CTA.

Another implication of this VLS configuration is that if anyone were to attempt to convert it into an operational missile, they would have serious if not insurmountable problems. With a large number of stages and the delicate connections for the four strap-on motors, the rocket could not be erected quickly and would be too fragile to be left in an erected state. Similarly, it could never be made into a mobile system. Reliability and quality control would be a major impediment to any military use. Not only does each of the seven rockets have to fire successfully, but the transition from four large strap-ons firing through second stage ignition requires symmetrical thrust termination and simultaneous stage separation. Subtle temperature differences from transport or from an insufficient prelaunch equilibration period makes such symmetry problematic under conditions of military launch. In sum, while the configuration of the VLS may be inefficient for launching satellites, it is simply unsuitable for military use.

Looking at the individual stages, we see solid fuel for each of them. Many of the engineers in the program speak longingly of liquid fuel, yet essentially no work has been done to create liquid rockets in Brazil. Why? First, as with Draper's single minded decades-long pursuit of the ultimate gyroscope accuracies with progressively more refined versions of the single-degree-of-freedom, floated integrating gyro,[55] Boscov has built up his paradigmatic solid-fuel system to such an extent that nothing else in the country can compete. Second, the difficult aspects of solid rockets lie in manufacturing, processing, and quality control technologies, while the challenge for liquid rockets is found in the analysis and computation needed to design the combustion chambers, as well as the complexity of the required valves and tubing. Given a choice between industrial processes or

[55]MacKenzie, *Inventing Accuracy*, 79-80.

computation, solid fuel is the winner in Brazil. Finally, solid propellant technology has more application and potential in the military arena than liquid fuels.

The history of the VLS program confirms this interpretation. In 1979, the nascent Brazilian program faced a clear choice between solid and liquid fuel technologies.[56] The Brazilian Complete Space Mission (MECB) was considering two main proposals for the satellite launch vehicle. France offered a joint venture to develop a rocket with a powerful liquid-fueled first stage and a Brazilian-made solid-fuel second stage, while the IAE proposed an entirely indigenous, multi-stage solid-fueled design.[57] According to a former director of INPE, Antonio Raupp, the liquid-fueled proposal was eventually rejected (by April 1980) on several grounds: the "technological unsuitability of liquid fuel for ballistic missiles"; uncertainties over the arrangements for technology transfer from the French for the liquid-fuel stage; reduced ability of Brazilian industry to participate in the unfamiliar liquid-fuel technology; and the high cost in foreign exchange that cooperation with the French would require. Approved at the Presidential level, the IAE medium-term plan called for launches starting in 1989 and a total cost of $790 million, with only 13% in foreign exchange.[58]

Beyond the choice of solid versus liquid fuel, the sources for the Brazilian fuel are revealing. In the 1970s, the military government undertook a major

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[56]The IAE only began design work on the VLS in 1978, of course seeking to incorporate its own solid fuel technology. Pedroso, "Actual State of the Art."

[57]The French design would have been taken from the 1st stage of the 1960s vintage Diamant launcher.

[58]Raupp and de Souza Nascimento, "The Development of Space Activities in Brazil," pp. 21-23 of the U.S. Embassy translation.

effort to build up Brazil's indigenous arms production capability.[59] But this effort was not limited to acquiring more technology or generating export markets. A philosophy of autonomy also motivated the government planners. We see the traces of a drive for autonomy in the sources of the VLS's fuel. All the major components (ammonium perchlorate, polybutadiene, and so on) are manufactured in Brazil, as a result of direct government planning. Processing technologies were for the most part developed at the CTA; an industrial partner was found, or sometimes created, and the technology transferred.[60] For example, the construction firm Andrade Gutierrez, which has other defense contracts as well, was selected to receive technology developed by the CTA to synthesize ammonium perchlorate. Specialists from the IAE's Chemical Division helped set

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[59]"The Brazilian military regime [undertook a] conscious effort to build up a more autonomous military-industrial complex...that focused explicitly on forging an arms industry...[and which featured] state holding companies working closely with the National Security Council, the Foreign Ministry, and the National Industrial Conference to mount a heavily subsidized, but internationally competitive, arms-export industry." Alfred Stepan, *Rethinking Military Politics: Brazil and the Southern Cone* (Princeton: Princeton University Press, 1988).

See also Clovis Brigagao, *O Mercado da Seguranca: Ensaios sobre Economia Politica da Defesa* (Rio de Janeiro: Editora Nova Fronteira, 1984), esp. pp. 15-68; Alexandre de S. C. Barros, "Brazil," in James Everett Katz, ed., *Arms Production in Development Countries: An Analysis of Decision Making* (Lexington, Mass.: Lexington Books, 1984), 73-87; Barros, "The Brazilian Military: Professional Socialization, Political Performance, and State Building", Ph.D. diss., University of Chicago, 1978; John Hoyt Williams, "Brazil: Giant of the Southern Cone," *National Defense* (November 1982): 16-20; and idem, "Brazil: A New Giant in the Arms Industry," *Atlantic Monthly* (August 1984): 24-27.

[60]"Before 1977...the CTA bought all the raw material needed to produce its rocket propellant from the United States and France. When the dollar price became too high, the agency discovered that Brazil did not have a single company capable of synthesizing the fuel. The solution was to assign production of each element of the whole to a different firm. Petroflex, a subsidiary of Petrobras, developed polybutadiene, a petroleum-based synthetic resin. Construtora Andrade Gutierrez was to mobilize its research department to produce ammonium perchlorate. Only a third element, powdered aluminum, was imported." "Economic, Industrial Ramification," *Veja*, 72-76.

up a plant with excess production in order to increase exports. Production began in 1985.[61]

The processes used for pouring the motors are quite advanced, even by U.S. standards. Their quality control seems high. For example, of 22 Sonda III flight tests whose results I know, only two have been failures, and these do not seem to be attributable to problems with the motors.[62] The same is true for the single failure out of four Sonda IV tests to date.[63] The company responsible for many of the operations is Avibras, which has come to produce the Sonda III by the thousands for its Astros system. Innovations reportedly include a continuous pour process that is only now being used in the United States, a process which enhances the quality and reproducibility of the casting. In the example of solid fuel, we see that the Brazilians are capable of constructing world class technology for their missile systems--if they so desire.

The engine cases also tell a story. They are made of a steel known as 300M, a high-strength, low-cost maraging steel, again developed by CTA and transferred to a private company that had been sought out for the purpose.[64] Some of the

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[61]Hugh de Oliveira Piva, "Brazil in the Space Age," unpublished paper, Institute for Space Activities (IAE), Sao Jose dos Campos, 69-73, n.d.; and "Have Perchlorate, Will Launch," *Economist*, 5 September 1987, p. 86.

[62]A Sonda III flight history is given in Boscov, "Sonda III Operational Brazilian Sounding Rocket." See also Condom, "Brazil Aims for Self-Sufficiency in Space."

[63]According to a U.S. Embassy cable from 30 November 1988, the October 1987 launch failed "when there was a malfunction in the electronic system which prevented the first stage from separating from the second."

[64]Jayme Boscov, et al., "Rocket Motor Cases in 300M Steel--A Pioneer Development Performed in the Brazilian Space Program," photocopy, n.d.

other components, such as valves and tanks for the LITVC, were also used as an engine for motivating the development of advanced SAE steels in Brazil.[65] Iron and steel industries are already a major component of Brazil's industrial and export base and a favored recipient for government development programs.[66] The new steels from the missile programs have already found applications such as manufacturing 747 landing gear for the Boeing Corporation.[67]

Contrast these steel engine cases with the IAE's intention to construct the fourth stage from a kevlar and epoxy resin composite, a radically different design. Apparently, a three stage version of the VLS was originally contemplated, but was ruled insufficient for the mission requirements.[68] A fourth stage with an extremely light case material would require the least change in the design of the rest of the VLS. The extra propulsion would enable the booster to place a given payload in the required orbit, while the advanced would impose the minimum weight penalty and the lowest structural loads.

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[65]For example, the motor cases for the Sonda II and III had used the standard SAE 4140 steel, which is "widely used in the Brazilian mechanical industries." Jayme Boscov, "Sounding Rocket Development Program," AIAA Paper #82-1745 (New York: American Institute for Aeronautics and Astronautics, 1982), 201-9. For the Sonda IV, the injectant tank for the LITVC uses SAE 304L stainless steel while bottles for high pressure nitrogen use SAE 4340 steel. Boscov, "Sonda IV Brazilian Rocket."

[66]For example, steel industries received over a billion dollars of government investment in the early 1970s alone. Bacchus, *Mission in Mufti*, 87.

[67]"Development of the Sonda rockets enabled CTA to create a fine-steel technology. The specialty steel called 300M, which was developed to enclose the Sonda rockets and whose technology was transferred to Metal Leve, has already won an international bid and is being used in making the Boeing 747 landing gear." "IAE to Begin Sonda IV Tests," 4.

[68]"After about two years of Preliminary Studies [the VLS] had its final configuration defined in March 1986....The three stages version which was studied in parallel was definitively canceled." Boscov, "Sonda IV Brazilian Rocket."

However, actually developing that material requires generating a substantial set of new capabilities.[69] The IAE would need to learn how to formulate the raw materials, synthesize the necessary filaments, determine winding patterns, and probably the most difficult task, perform the stress analyses that determine whether the structure will bear the required loads. Particularly when low inert weight is so important, the designers would be tempted to reduce safety margins to the minimum, requiring sophisticated analytic capabilities and dynamic testing techniques.[70] Finally, the four stage design was originally rejected because wind tunnel facilities in Brazil are not large enough to perform the necessary aerodynamic tests.[71]

It is possible that this design was intended to "work" only on paper--that is, the paper design would meet the paper requirements for the MECB mission. Though the fourth stage's construction would be extremely difficult, the development work on the artifacts that the IAE really cares about (the Sonda-derived stages) could proceed apace. Indeed, the fourth stage seems to have made little progress, with a realistic development plan only being formulated in 1989. That plan belatedly recognized the necessity of flight testing for such a radical innova-

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[69]When a smaller vessel with similar properties was needed for another component of the VLS (for the LITVC N2 tanks), it was purchased directly from a U.S. supplier.

[70]As a 1988 paper acknowledged, "the fourth stage motor represents the biggest development challenge in the VLS program. Its requirements of structural efficiency, total impulse dispersion, thrust misalignment and spin operating condition impose a severe qualification program." Yet the test series described does not yet include any flight testing. Yoshino, "Main Propulsion System of the Brazilian Satellite Launch Vehicle VLS."

[71]Hugo Piva, "CTA Director Discusses Space Accord With PRC," *Tecnologia & Defesa* no. 22 (April 1985): 21-24, in JPRS-LAM-85-068, 9 August 1985, pp. 98-103, 101.

tion, proposing a qualification test with a fourth stage placed on top of a single Sonda IV first stage.[72] To my knowledge, that test, originally scheduled for November 1991, has yet to take place. In sum, the anomaly of the fourth stage in the VLS configuration highlights the primary drivers for the rest of the design: Boscov's rockets combined with a philosophy promoting government programs that foster technological autonomy.

We can learn not only from the presence of particular technologies, but also from their absence. For example, neither the Sonda rockets nor the VLS appear to have any thrust termination ports. For a rocket which is either unguided, or only needs to achieve a high altitude, variations in total impulse or in thrust cutoff time are unimportant. However, without some mechanism for thrust termination, a missile could only be fired to its maximum range--a militarily useless arrangement. In addition, even at the appropriate range, imprecise thrust termination can be a major contributor to inaccuracy.

In late 1987 and early 1988, static tests on a modified Sonda II were conducted at the CTA's test facilities in Jacarei. These tests demonstrated both thrust termination ports and a flex nozzle seal.[73] The latter was incorporated in the VLS 2nd and 3rd stages, but the thrust termination ports are nowhere to be found in a detailed plan of the VLS's pyrotechnic systems dated mid-1988. The alternative solution, apparently adopted, was to have 2nd stage ignition occur before 1st stage burnout, and let the thrust vector control system compensate for

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[72]Boscov and Toyama, "Qualification du Propulseur 4eme Etage." This configuration of an S-44 (the VLS 4th stage) on top of an S-40 (the Sonda IV 1st stage) was dubbed the VS-40.

[73]The flex nozzle tests were performed on a Sonda II rocket. Roberto Lopes, "Controversial ICBM, Other Projects Viewed," *Folha de Sao Paulo*, 21 July 1988, p. A-24, in FBIS-LAT-88-142, 25 July 1988, p. 34.

any asymmetries in thrust tailoff for the strap-on boosters--a potentially troublesome design.[74] Yet thrust termination ports are easily within the IAE's current capabilities, especially for integral metal cases. The solution adopted seems to be saying that military utility and accuracy are not seen as essential for either the VLS or for future (possibly military) applications of the technology.

A lack of concern for accuracy or the ability to hit military targets may also be evident in the design of the thrust vector control systems. The LITVC on the first stage of the VLS (transferred directly from the Sonda IV) and the newer movable nozzle design on the second and third stages are limited to 2.5 and 3.0 degrees thrust angle, respectively.[75] These control systems are sufficient for attitude control during a satellite launch: vertical ascent with a gravity turn. More strenuous demands on the TVC systems are ameliorated by the conditions that might hold for a sounding rocket or space vehicle launch (or even a missile test). The launch could be postponed during turbulent atmospheric conditions. The bulk temperatures for each of the strap-ons, which are a prime determinant of propellant burn rates, can be carefully equilibrated so that the warmer strap-ons

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[74] "Each of the [strap-on motors] has an internally gas pressurized actuator, so that, a few seconds after the burnout of the first stage motors, pyrotechnic shaped charges are detonated to cut simultaneously all the physical links of the four motors to the 2nd stage. The internal gas pressure of the sleeves provides the required separation velocity to the empty motors." Pedrosa, "Actual State of the Art."

Asymmetric termination and separation seem like they could be severe problems. We noted above that the VLS reduced-scale test configuration (the R1) failed its only test as a result of stage separation problems. In addition, published acceleration data from Sonda III flights show long and spiky tailoffs. Boscov, "Sonda III Operational Bra 'lian Sounding Rocket." This problem is acknowledge by the designers: "The dispersion on the thrust tail-off of the four first stage motors may also demand careful motor parts construction and propellant processing because of the implications on boosters separation dynamic and vehicle control." Pedrosa, "Actual State of the Art."

[75] Boscov, "Sonda IV Brazilian Rocket"; and Pedrosa, "Actual State of the Art."

would not burn out earlier than the cooler ones. Most important, the VLS has large aerodynamically stabilizing fins--satellite launch vehicles do not have to worry about getting in the way of transport canisters, silo walls, or submarine tubes. For operational military launches on the other hand, none of these conditions hold, and a missile with such small TVC angles could encounter severe control problems.[76]

The guidance system is also conspicuous by its absence. The VLS guidance system is called the SIS, or "Inertial Solidarity System" (whatever that means). Although its capabilities, design choices, and status are unclear to me, some conclusions are still possible. Recall that the Avibras Astros system is totally unguided, though it uses an indigenized Swiss radar system to achieve impressive accuracies through simply controlling the angle of the launch ramp.[77] Similarly, most of the Sonda series has used simple attitude control for its missions. Sonda I and II were entirely unguided, relying only on the launch angle. The Sonda III still did not have a full TVC system, but added various sensors and instrumenta-

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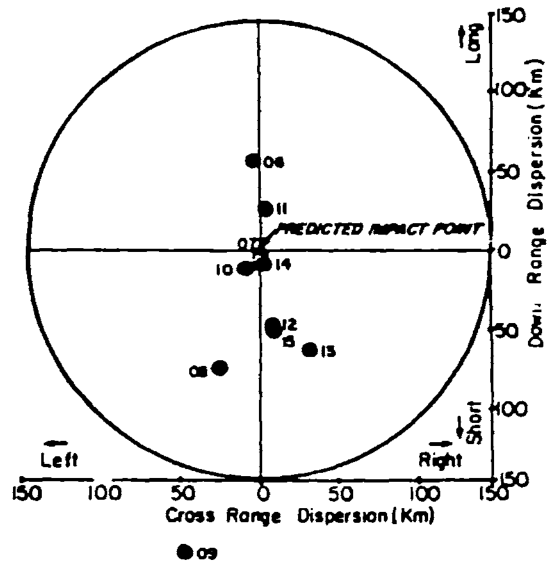
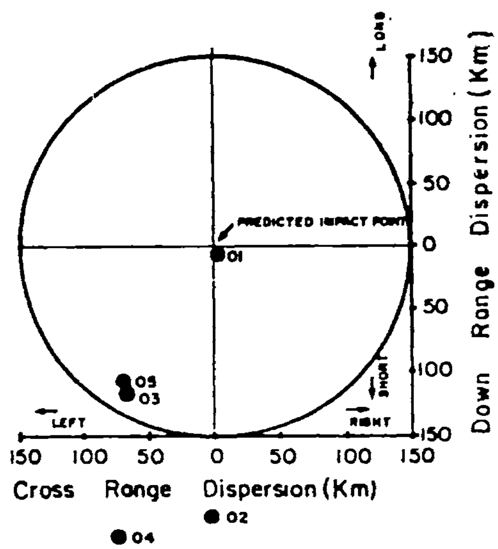
[76]As it is, the TVC system may have trouble coping with "porpoising" between second stage tailoff and third stage ignition. Also, during 1st stage separation, the frequency responses in the long, skinny core that remains could be problematic. "Aerodynamics of the Brazilian Satellite Launch Vehicle (VLS) During First Stage Separation," AIAA Paper #90-3098 (New York: American Institute for Aeronautics and Astronautics, 1990).

We might also note that the liquid injectant used in the first stage, Freon 113, is highly stable and therefore relatively easily to handle and insulate during flight; but it also has the lowest specific impulse of commonly used injectants. Boscov, "Sonda IV Brazilian Rocket."

[77]The Astros-II uses "aerodynamically stabilized unguided rockets...Without electronic guidance systems they are limited to the trajectory set by the Astros-II launching ramp." Roberto Godoy, "Role of Citizens in Iraqi Weapon Systems 'Hazy'" *O Estado de Sao Paulo*, 23 August 1990, p. 10, in JPRS-TND-90-015-S, 14 September 1990, p. 1.



Real Dispersion During Operational Flights



Real Dispersions During Qualification Flights

Sonda III Accuracy

Figure 6

tion for better trajectory calculation, and also included 3-axis attitude control for the payload.[78]

Nevertheless, when conducting tests for the U.S. Air Force Geophysical Laboratory, ground impact dispersion of 50 km was expected, and a 10 km bound on the apogee was deemed "very strict" (see Fig. 6).[79] Sonda IV featured full TVC for both stages, using LITVC for the first stage and a movable nozzle with a flex nozzle seal on the adapted Sonda III that constitutes the second stage, but still had no guidance system.[80]

For the VLS, the same technological style is in evidence. The control system continues to develop, with full 3-axis control (roll, pitch and yaw) using a combination of LITVC, movable nozzles, and spin-up motors. But the inertial guidance seems primitive, possibly reliant on foreign suppliers, and at any rate is not yet functional. When the United States refused to permit the export of the system that had been used to that point on the Sonda IV,[81] the government attempted to recruit Brazilian firms to fill the gap, particularly Avibras' SIS system that had been designed for use on their SS-300 and Barracuda antiship missiles.[82] But apparently these attempts were unsuccessful. Nor is radio or

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[78]Pedrosa, "Actual State of the Art."

[79]Boscov and Furlan, "Sonda III."

[80]Boscov, "Sonda IV Brazilian Rocket."

[81]The rockets had used the Space Vector A.C.S. Midas Analog Platform Model 20170-3. Boscov, "Sounding Rocket Development." On the U.S. refusal and its effects, see Tollefson, "Brazil, the United States, and the MTCR," 51-54.

[82]Joao Verdi (the Avibras President) says Avibras still uses imported gyros. Some foreign reports may be confused because SIS is also used as acronym for Secondary Injection System, which is the thrust vector control system. According to "Technical Features" *O Estado de Sao Paulo*, 12 May 1987, "The SIS was developed by Avibras, with its own technology...The SIS provides reference data and continually supplies the internal computer with information on the location of magnetic north with respect to the position in real time, and also calculates vertical and horizontal

command guidance used as a supplement. Furthermore, even if the SIS were to come to fruition, the orbit injection technique is one that the United States abandoned decades ago. Untested for the Brazilians, it relies on a combination of attitude control, spin stabilization, and the timing of fourth stage ignition, without any explicit guidance. The technique is only useful for attaining orbit, not for adjusting a ballistic trajectory. Again, the lack of a guidance system indicates to me the lack of strong allies for its construction, and the low importance given to military capabilities.

Finally, plans or technology for the mass production of the VLS, or even of components such as the individual motors, seem to be completely lacking. As we have already seen, technology transfer from research institutes, military or otherwise, is a common pattern in Brazil, and part of CTA's organizational essence. Furthermore, the motor production for the Sonda series through the Sonda III

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position. The combination of all this data allows for changes in the rotation of the axis. The processor, which is programmed as the missile is fired with the target location data, permanently keeps a reference point to guide the missile until the SS-300 drops thousands of antitank bombs, cluster bombs, fire bombs, antitank mines, bomblettes for destroying airstrips, and several combinations including small laser-guided missiles for attacking radar stations or armoured columns."

According to a U.S. Embassy cable, 30 November 1988, the Ministry of Aeronautics postponed a Sonda IV launch from 16 December to early February "due to difficulty in obtaining an inertial guidance system for the rocket...Traditionally, the Brazilians have purchased this hardware from the United States, but recent requests were denied. The Brazilians then tried to purchase the equipment in Europe, but due to the [MTCR], they were unsuccessful there as well. Current efforts are focussed on negotiations with the British firm Ferranti about repairing an old American guidance system know as the Space Vector. It is possible the MTCR will prevent agreement on this proposal as well. Another option is indigenous production. To that end, the Ministry of Aeronautics has been talking with Aeromot and Avibras, the latter being the only local company which already has experience in producing an inertial navigation system, while the former is currently producing electronic components for the AMX pursuit bomber."

was also transferred to industry. Each Sonda IV and the VLS, however, seem to be practically handcrafted.

In contrast to these "absent" technologies, telemetry, radar-tracking, and ground support are all quite well developed. Those functions, for the most part, are planned and performed by the INPE. That institute has successfully procured dedicated computers for various ground support operations, and has cooperated with foreign firms, especially MBB's DFLVR, to write appropriate software.[83] Similarly, the INPE is investigating inertial sensors for on-board satellite attitude determination.[84] Compare this effort to the lack of interest in either hardware or software for some of the IAE's guidance system activities.

A similar contrast is seen in the launch support equipment. The IAE boasts that the Sonda IV requires only a single attachment (the safety attachment ring) for launch support, requiring minimal site preparation or investment (see Fig. 7).[85] For a military system, this characteristic would be a plus. On the other hand, the launch site for the VLS, at Alcantara, is being developed from scratch

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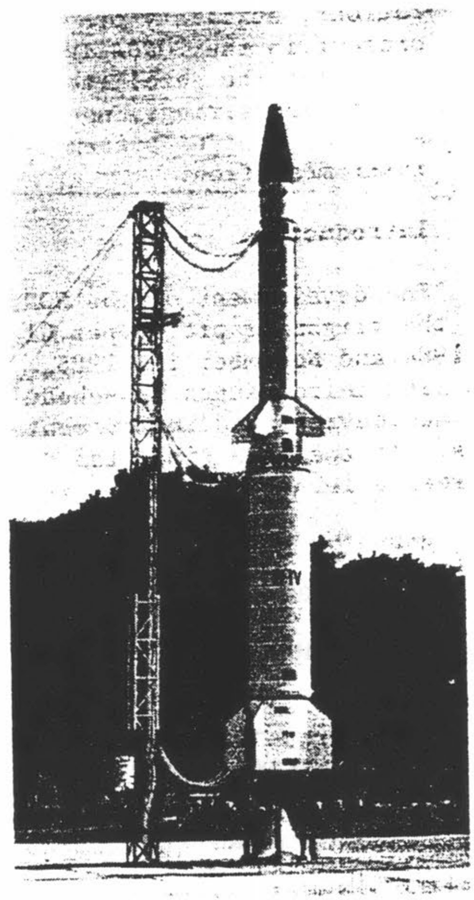
[83]For example, for the INPE's range safety system software, "a cooperation program with FRG's [Germany's] DFVLR is being carried out in the same condition that developed the software for the Sonda IV program." Boscov, "Sonda IV Brazilian Rocket."

[84]Valtair Antonio Ferraresi, "Utilization of Strapdown Inertial and Non-Inertial Sensors in Determination of Satellite Attitude by Kalman Filters," M.S. thesis, INPE, August 1987, NTIS Report #INPE-4313-TDL/280.

[85]The IAE boasts that launching can be conducted "in a very simple way, with no sophisticated devices being required....Only a safety attachment ring is used during the assembly, meaning that Sonda IV can be launched even from not so well prepared sites." Boscov, "Sonda IV Brazilian Rocket," 1418.



SONDA IV Prototype 01
Ready for Flight

Sonda IV Launch Support Equipment

Figure 7

in support of the VLS program, at a cost of $215 million dollars.[86] Note that it is the INPE that is responsible for much of the hardware being procured for the Alcantara project, in cooperation with the CTA.

Although Figure 2 notionally shows the VLS at the Alcantara launch site, in fact no tests of the VLS have yet occurred. More remarkably, none are planned--the first launch is to carry an operational payload. This schedule seems to be a sharp discontinuity with the testing philosophy displayed in the Sonda program. For both the Sonda III and the Sonda IV, five tests were scheduled as "developmental" or "prototype" tests. Within those tests, an orderly sequence of capabilities were added and exercised. For example, the first three tests of the Sonda IV saw a gradual reduction in the number of LITVC injection valves per quadrant from seven to five to three, while a different testing philosophy might have simply begun with three.[87] Even the one-third scale VLS model, the R1,

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[86] "Total investments in the Alcantara Center alone reach $215 million. The facility is being built by a joint venture of the Mendes Junior and Andrada Gutierrez construction firms, along with other subcontractors, which together employ over 2,500 people. Nearly 230 Air Force officers are assigned to Alcantara." "Satellite Launch Delayed by Technology Controls," *Brasilia EBN*, 3 February 1988, in FBIS-LAT-88 FOUO Annex, date and page unknown.

Alcantara itself would be a worthy subject for an LTS analysis, combining the space and missile programs described here with plans for offering launch services to advanced industrial powers such as Russia and France and with regional development programs in Brazil's notoriously poor northeastern states.

[87] After the first successful Sonda IV flight, eight valves were blocked off, lowering the number for the second flight to five per quadrant. After a successful second flight and additional study, the third flight used only three valves per quadrant. Boscov, "Sonda IV Brazilian Rocket." Similarly, while hoping to use 300M integrally cast motor cases, Boscov followed what he later called "some pessimistic results and recommendations from various international organizations" and followed a "step by step approach" that included parallel efforts for a case mostly made from 4340 SAE steel. Boscov, "Sounding Rocket Development"; and Boscov, "Rocket Motor Cases in 300M Steel."

was planned for only one flight test, which was destroyed by ground control on 16 December 1985 when one of the first stage motors failed to fire.[88] Nor does a published project schedule for the VLS demonstrate a strong emphasis on integration testing, static fires, or simulated launches.[89] Again, the absence of a strong test program indicates to me a lack of interest in whether the system "works" as a satellite launcher or as a missile. The few tests that occur may be more in the nature of "recruitment drives," as we will discuss below.

Finally, to emphasize the parallel nature of Figures 1 and 2, we see in the latter a viewing stand, with President Sarney, Aeronautics Minister Lima, and CTA Director Piva. An interesting future study might plot over time the Ministers who attend Sonda launchings. It seems reasonable, even expected, that a sounding rocket, often without even a scientific payload, could be launched without much notice from the higher echelons of government. But in Brazil, Presidents, chiefs of national intelligence, and ministers of commerce, industry, science and technology, or foreign trade, not to mention the Air Force, have all been in attendance, sometimes en masse. Their presence is, to me at least, just as much a part of the Brazilian missile system as the rockets themselves.

Reconstructing the System: How does it all fit together? And how does it not?

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[88]The rocket was teledestructed "after some of the rocket's turbine engines failed to fire." Clifford Graham, "The Brazilian Space Programme--An Overview," *Space Policy* 7, no. 1 (February 1991): 72-76, citing Ulisses Capozoli, "A Marcha do Programa Espacial," *Tecnologia* 19, no. 10 (October 1988). A second reduced-scale model was launched, apparently successfully, on 18 May 1989, with a "primary purpose...to test the separation system" of the four strap-on boosters. Joint Staff Information Service Center, "Launch of Reduced-Size Brazilian Launch Vehicle," from U.S. Embassy, Brazil to Secretary of State, Washington, D.C., 1 June 1989, p. 1.

[89]See the project schedule in Pedrosa, "Actual State of the Art."

We now combine the previous two sections--the motivations of the various actors and the deconstruction of the principal artifact of the system--to try to develop a complete "explanation" of the Brazilian missile program. The components described in both Figure 1 and Figure 2 need to bind together into a large technological system. The artifacts within that system need to form closed black boxes if the system is to be a success. Here, the "system" can be understood as either artifacts, such as the VLS, or the political system that makes constructing the artifacts feasible. As described in Chapter 1, I will follow the constructivist interpretation and not make much of a distinction between these two categories.

Although Boscov's team at the IAE is officially within a military organization, the people involved see themselves as technical people--scientists and engineers (note that "Engineer" is a title of honor in Brazil, as much as "General" or "Doctor"). As I described when comparing Boscov to Charles Stark Draper, their main goal is to keep building and designing new rockets. Clearly, if a missile program exists, or a program to build a satellite launcher, that program would help them achieve that goal. Boscov and the IAE will therefore recruit allies, such as the INPE or Avibras, to support their work, and to help fit their technology into other actors' goals.[90]

It is also important to realize that if their rockets *work*, then the technology itself becomes a valued ally. Every time a Sonda rocket takes off (without blowing up!), their technology, their designs, become more feasible, more concrete, more real. So when attempting to get Brazilian generals, or visiting Chinese rocket scientists, to support their work, their own technology serves as an ally in

[90]Again, this dynamic is the same as garbage-can theory would lead us to expect.

that effort.[91] In this sense, each test is implemented not so much for technology development, but as a recruitment drive for allies.

The IAE engineers are not the only group for whom the VLS can serve as a useful ally. The INPE has gradually acquired more and more expertise and capability in satellite design, construction, operations and ground support. They have contracted with foreign companies for everything from complete communications satellites to equipment for analyzing the chemical synthesis of hydrazine.[92] They have developed components, software, and earth stations, as well as now designing their own satellites. INPE has also taken responsibility for transferring some this technology to Brazilian industry for larger-scale production.[93] In many of these efforts, their task is made easier by the existence of the

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[91]The Chinese Central Space Agency and CTA signed an agreement covering "an exchange of fuel technology and guidance systems in the civilian and military sectors." Negotiations began in 1982, and it was signed by Piva at the end of 1983. The agreement was only possible because the Brazilians could use their solid rockets as allies: "Basically the Chinese are interested in Brazil's solid fuel technology, one of the best alternatives in existence for military use...On the other hand, the Chinese technology in microelectronics [for guidance systems] ranks among the most advanced in existence today...The two fields complement one another, and the scientists and military leaders in the two countries were not slow to understand this fact." "Brazilian-Chinese Agreement," *Tecnologia & Defesa*, no. 31 (March 1986): 24, in JPRS-TND-86-025, 17 November 1986, pp. 19-20. After concluding this agreement, the respect and interest of the Chinese, as well as their technology, could then serve as additional resources accruing in this "cycle of credibility." See the theoretical discussion in Bruno Latour and Steve Woolgar, "Cycles of Credit," ch. 5 in *Laboratory Life: The Social Construction of Scientific Facts* (Newbury Park, Calif.: Sage Publications, 1979), 187-233.

[92]Whitehouse, "Brazil Shows the Way." See also C. Bullock, "Brasilsat: A Good Investment that Justifies Its Cost," *Space Markets* No. 2 (Summer 1986), p112-14.

[93]INPE-developed data collection platforms were transferred to Engespaco. Condom, "Brazil Aims for Self-Sufficiency in Space." Similarly, INPE gave a $9 million contract for producing imaging instruments to Esca Engenharia Sistemas de Controle de Automacao of Sao Paulo. Carlos Lovizzaro, "INPE Lets Contracts for Satellites," *Gazeta Mercantil*, 27 June 1991, p. 13, in FBIS-LAT-91-146, 30 July 1991, pp. 36-37.

VLS program. The feasibility of a program to launch Brazilian-made satellites--physical, political, or conceptual feasibility--is enhanced by having a program to build a Brazilian-made satellite launcher. Again, with each success of the VLS program, INPE's program has a stronger ally on which to depend.

The alliance between IAE and INPE on rocket technology can be seen better as a marriage of convenience. In our description of the components of the VLS, the only portion where the traces of the INPE can be seen are in the satellite, of course, and in the ground support and launch site. The INPE could apply all of these components to different launchers with relative ease, and the VLS in turn is not strongly integrated with the INPE's facilities. Recall the fourth stage for the VLS, necessary for achieving the mission profile the INPE needs. For anyone with small children, the 4th stage seems like an answer to the Sesame Street song, "Which one of these things is not like the others?" The questionable feasibility, slow progress, and lack of a guidance system for the 4th stage all demonstrate the imperfect union between IAE and INPE. The somewhat mismatched diameters for the VLS and the payload also seem to demonstrate separate IAE and INPE concerns.[94] In other words, the MECB (the Complete Brazilian Space Mission), though "complete" in title, is cobbled together from different elements that are still self-sufficient, both politically and technically.

The temporary nature of the alliance between the IAE and the INPE, between the VLS and the satellites, is driven home by the events of the last few

[94]The diameter of the heatshield and shroud for the VLS follow from the Sonda IV, while the satellite dimensions for the INPE do not match particularly well--1200 versus 1000 mm. Some of the aerodynamic difficulties resulting from a "hammerhead" design are detailed in Joao Luis F. Azevedo, "Aeroelastic Analysis of Hammerhead Payloads" in *29th Structures, Structural Dynamics and Materials Conference,* , Williamsburg, Va., 18-20 April 1988, Technical Papers, Part 2 (Washington, DC, American Institute of Aeronautics and Astronautics, 1988), AIAA Paper #88-2307, pp. 770-80.

years. Having used the VLS and the MECB to help gain the necessary support, INPE moved firmly into the satellite building business. In Latourian terms, the technology became "ready made," closing the black box and reducing the system's vulnerability to challenges.[95] With this newly earned independence, the INPE began actively promoting a plan to launch its satellites on foreign-supplied launchers instead of the VLS.[96]

As one report noted, "In 1988, a simple suggestion to this effect would have provoked indignation in the Aeronautics Ministry." When the director of INPE at the time, Marco Antonio Raupp, first proposed such a plan in May 1988, "this irritated the Brigadiers. Paulo Camarinha, then chief of the Armed Forces Staff, charged Raupp with attempting to 'sabotage' the Brazilian space program [by leaking information about a Sonda IV test failure]. Raupp was dismissed at the beginning of 1989."[97]

The generals realized that a divorce between the IAE and the INPE would threaten the VLS. As we would expect, "opposition to the proposal came largely from the military members of the Ministry of Aeronautics who felt the entire MECB would be undermined by those unwilling to wait for the VLS's completion," then predicted for January 1992.[98] Soon, the VLS advocates realized that

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[95]Latour, *Science in Action*, 4.

[96]We see a similar dynamic when the U.S. Air Force abandoned NASA's Space Shuttle program after the Challenger accident, relying instead on procuring its own launchers. The air force was in a much better position than the INPE, having decades of successful satellite building experience.

[97]Roberto Lopez, "Brazil: Aeronautics Ministry Reviews Space Research Plan," *Folha de Sao Paulo*, 27 July 1990, p. A5, in JPRS-TND-90-014, 23 August 1990, p. 25B.

[98]Graham, "The Brazilian Space Programme."

a divorce would be hard to avoid given how loosely bound the system had become. Instead, they tried to find a foster parent for the VLS. "The government adopted a Solomonic attitude to meet both demands: It authorized an accord with the PRC, and assured the military that neither the Sonda-4 nor the VLS projects would be discontinued."[99]

When child support from China was not forthcoming, the military-dominated Brazilian space board (COBAE) agreed to participate in the INPE's search for a foreign launcher. (The search committee included the director of INPE but somehow omitted any representatives from IAE.[100]) The same development motivations that supported the MECB in the first place continued to play a role, but with wholly indigenous technology no longer taking first priority. Instead, "the VLS will...continue to be developed, but with another philosophy, which should open the project to partnerships between Brazilian industries and foreign enterprises." The role of the IFI (the in-house technology transfer organization for the CTA) was also broadened to include foreign industrial cooperation.[101] At the same time, provisions for technology transfer and development of the Alcantara launch site were important considerations in the bidding war that erupted among French, U.S., Soviet, and joint U.S.-Soviet proposals to provide launch vehicles for INPE's satellites.[102]

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[99]"Controversial ICBM, Other Projects Viewed," p. A-24.

[100]Lopez, "Aeronautics Ministry Reviews Space Research Plan."

[101]Graham, "The Brazilian Space Programme."

[102]"Growing Competition to Launch Rocket," *O Estado de Sao Paulo*, 1 May 1991, p. 1, in FBIS-LAT-91-094, 15 May 1991, pp. 30-31; "Government to Choose Foreign Satellite Launcher," *O Globo*, 28 February 1991, p. 23, in JPRS-TND-91-005, 28 March 1991, pp. 11-12; and Luiza Pastori, "Joint Ventures to Operate in Alcantara Studied," *Gazeta Mercantil*, 14 August 1991, p. 6, in FBIS-LAT-91-172, 5 September 1991, pp. 45-46.

Finally, the newly elected civilian government of President Collor and Science and Technology Minister Goldemberg awarded a launch contract to the U.S. Orbital Science Corporation, the providers of the Pegasus launch vehicle. A more expensive Soviet-led bid was rejected, even though it included far more technology transfer and launch facilities.[103] Though the MECB still exists on paper, for the moment at least, the victors appear to be INPE and the Orbital Science Corporation.

The timing of this controversy over foreign launchers is no coincidence. By looking at the overall technological system, we see the two factors that enabled the INPE to abandon the VLS. First, it was succeeding in black boxing its own technological systems, so that they became independent and portable. Second, as we discuss below, the changing needs of successive governments removed a key ally from the VLS.

Local actors such as Jayme Boscov have limited abilities to alter the course of entire regimes. However, for the first factor, Boscov's system-building instincts may have failed him. It might have been possible to use technology to bind the INPE satellites and the VLS together, making his own team an "obligatory point of passage," in Latour's phrase.[104] The design of the satellites and the VLS could have been made mutually dependent. Similarly, the IAE's Testing Division, which carries out numerous rocketry tests, won the responsibility merely "to ensure...the availability of the testing methods" for satellites.[105] The INPE, in

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[103]Roberto Lopes, "U.S. Company to Launch Brazilian Satellite," *Folha*, 11 July 1991, 3rd section p. 3, in FBIS-LAT-91-136, 16 July 1991, p. 23.

[104]Latour, *Science in Action*, 150.

[105]Piva, "Brazil in the Space Age."

the meantime, inaugurated an impressive testing facility for complete satellite checkout. In sum, instead of a tightly bound technological system, a temporary convergence of technical and political interests is now diverging.

We have seen that the VLS's network includes many corporate components as well, with the VLS serving as an ally for a number of Brazilian companies, peripheral and core, public and private. The existence of such a powerful rocket is a powerful argument that complex technological projects can be undertaken successfully within Brazilian industry. Similarly, the high domestic content of a functioning VLS supports efforts to indigenize other high-technology systems.[106] For peripheral companies, certain technologies get defined as "necessary" or important to national security, because the particular design of the VLS incorporates them. Presumably, some bargaining occurs between the design team and these outside corporations over which technologies they will incorporate.

But the CTA and INPE, even if firmly allied with private enterprise, cannot generate all the resources needed to run a missile program. They can recruit some private companies or foreign countries to provide support for their work, but for the most part they must depend on allocations from the Brazilian government. In fact, since the Collor administration was inaugurated and part of a new Congress elected, budgets have been slashed. While the program does

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[106]For example, the maraging steel, 300M, was developed by CTA and Electrometal Acos Finos S/A "with the necessary reliability for space application," "regardless of discouraging advices from some others countries space organization, that tried similar development program but without success [sic]." Boscov, "Rocket Motor Cases in 300M Steel."
The same arguments were used in United States, as the stock phrase, "If we can send a man to the moon..." testifies. See Richard Nelson, *The Moon and the Ghetto* (New York: Norton, 1977).

continue to limp along, it had received generous support during the early to mid-1980s. How did the broader sections of the Brazilian polity fit into this system?

We have seen that the military as government had numerous goals, such as a philosophy of "security and development" and a desire to maintain the legitimacy of its regime, and numerous constituencies to deal with, such as a civilian opposition, the Brazilian scientific and technical community, private and state-owned high-tech companies, and the military itself (as an institution). The details of the construction of the VLS demonstrate that the military was able to recruit that system as an ally in satisfying many of these goals and constituencies--but that those goals do not include acquiring a missile that would be effective in battle. The VLS is, all at the same time, an economic development program, a technology test bed, a military program, a research effort, a way to reduce Brazilian technological dependency, and a bold claim of Brazilian national autonomy.

We have also seen how these diverse aspects have traces in artifacts: the motor cases have served as a way to advance the Brazilian steel and materials capabilities; new processes have originated at CTA or INPE and been transferred to private companies as a result of the program; whole segments of military-industrial capability have been transplanted to Brazilian industry, such as solid fuel synthesis and processing; Avibras, in attempting to build its fortunes around derivatives of the missile program, has developed its solid fuel processing techniques to such an extent that liquid fuel rockets cannot compete in Brazil; others companies have been able to add niche markets to their product lines, such as the domestic replacement for the guidance package the United States stopped providing; even the presence of President Sarney in Figure 2 as a "component" of the system reflects the military's drive for legitimation.

To the extent that any generalization from this heterogeneous system is possible, it seems that the most powerful convergence of motivations for the military government was the drive for political legitimacy through technological autonomy. The Brazilian missile program generates significant new technology; it is limited enough so that government planning can try to ensure complete indigenization; and it is related to military technology. Therefore, the drive for autonomy in this area lies at the intersection of the opposition's desire for development, the engineers' desire for antidependency through technology, and the military's desire for security (and legitimacy) through development.

The System Falls Apart[107]

This complex, contingent convergence seems to have been temporary. Since about 1987, the Brazilian missile program has been in trouble. The MECB as a whole took a 55% cut in January 1989, enough for what Boscov called only a "vegetative existence";[108] in 1989, Alcantara was slated to receive $60 million and received $15 million instead;[109] the cooperative satellite program between

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[107]The metaphor "falls apart" carries the entailments of a gradual process that follows as much from neglect as any intent to dismantle. Contrast Brazil's experience with Argentinian policy on the Condor missile project. After a much more difficult transfer from military to civilian rule, the missile system was actively and physically destroyed, to the point of crushing some missile parts and manufacturing equipment. Interview with Felix Clementino Menicocci, Third Secretary in the Argentine Foreign Ministry, Directorate for International Security, Nuclear and Space Affairs, January 1992.

[108]"Obstacles to VLS Development Reviewed," *Folha de Sao Paulo*, 14 July 1989, p. G-3, in FBIS-LAT-89-156, 15 August 1989, p. 29.

[109]Joint Staff Information Service Center, "The Complete Brazilian Space Mission: The Launch Site," from U.S. Embassy, Brazil, to Secretary of State, Washington, D.C., 24 November 1989, p. 3.

INPE and the Chinese Academy for Space Technology was delayed for 15 months because the Brazilian government did not meet its funding commitment of a mere $6 million;[110] in fact, the Brazilian Air Force practically stopped flying its planes and the Army canceled all its parades in an effort to deal with the overall budget cuts. But our methodology reminds us that the budget cuts are not the cause of the program's difficulties; the budget cuts are part symptom and part result of the system falling apart.

A number of the system builders--Piva and Lima--are gone or incapacitated. Hugo Piva no longer directs CTA or Orbita, instead traipsing around the world in increasingly desperate attempts to find patrons for his systems, especially his beloved Piranha air-to-air missile. With the end of President Sarney's term, Aeronautics Minister Lima is also gone. The next President, Fernando Collor de Mello, was associated with a different set of philosophies and constituencies than Jose Sarney, Joao Figueiredo, or Ernesto Geisel, all of whom had been in regular attendance at Sonda launchings.

But even where people and interests remained constant, their configuration changed in ways such that the configuration of the VLS may no longer be stable. Thus, the INPE is now actively recruiting foreign space launch vehicles to serve as its next ally. A number of the core companies, especially Avibras, Orbita and Engesa, have lost enough of their own allies (especially Iraqi weapons purchases) that they are bankrupt or dismembered, no longer having use for whatever the VLS or IAE could provide. As the missile program falters, peripheral companies may come to see it as a less reliable ally; in addition, with the end of military

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110 "Resource Satellite To Be Built With PRC," *O Globo*, 21 December 1989, p. 30, in FBIS-LAT-89-247, 27 December 1989, pp. 43-44.

government and changing trade and economic policies, foreign technology has become more accessible and attractive to these companies.[111]

The end of military government has probably been the most significant factor in the changing fortunes of the Brazilian missile program.[112] One might think this change would be significant because the military wanted to fund military projects, while the new civilian government would not. But like most aspects of this story, the interactions are more complex. As Stepan argues, the military as institution was paradoxically one of the least supported constituencies of the military as government. With the change in regime, the military was finally able (with a certain sense of relief) to concentrate on matters of professional military concern--training, exercises, operational plans, force structure. Buying out scientists or the civilian opposition with technological development programs no longer mattered. Nor did technological autonomy need to be pursued as a source of legitimacy for a military regime. Many of the components in Figure 2, from President Sarney to the maraging steel of the motor cases, had become politically irrelevant. Their temporary political conjunction is now being loosened to such an extent that the physical system may not survive.

The current woes of the VLS do not mean that the program was a failure. Rather, we must understand that for many of the actors in this system, its actual

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[111]As another example of a bond that did not set well, the M300 maraging steel of which the VLS program was so proud appears not to have found widespread application in Brazil. That particular alloy has a high nickel content, leading to a strong but brittle material that has limited appeal outside of rockets. Thus the connections that the steel promised to provide from the launcher program to the rest of the economy seem to have been as brittle as the alloy itself.

[112]On the impact that the transition had on the military-industrial sector, see Ken Conca, "Technology, the Military and Democracy in Brazil," *Journal of Interamerican Studies and World Affairs* 34, no. 1 (Spring 1992): 141-77.

launching was never a requirement for "success". This artifact was constructed and recruited for all the diverse purposes already described, very few of them having to do with lifting a few hundred kilograms a few hundred kilometers above the earth. In this case, we can see, component by component, that the VLS has yet to be launched simply because it was not designed to be launched.

IV. Conclusions

The first conclusion that I draw from this research is that military capability cannot account for the Brazilian missile program. As we have catalogued the motivations of all of the various actors involved in the program, no particular military mission has come to the fore. Nor have I found a trace of the vague competition between Brazil and Argentina, which has not seen a military outlet since the War of the Triple Alliance ended in 1870 (a war in which Brazil and Argentina were formally allies). Similarly, as we have dissected the components of the systems being constructed, we have not seen many physical manifestations of a concern for battlefield utility. The artifacts examined were clearly optimized according to nonmilitary criteria. Nor did any external security threat seem to be a useful resource for anyone trying to drum up support for the program.

Instead, the motivations have been diverse, but have been essentially the usual suspects. Organizational interests, personal ambition, and broad social conflicts all play their part, only resulting in the construction of missiles because of the particular contingencies already discussed. This picture is, to an IR theorist, emphatically second image. Conditions within Brazil, and domestic politics in particular, have much more of a determining effect than interactions among states, or the structure of the international system.

Given Brazil's security environment, it may not be surprising that military capability is not the main motivation for its missile programs. It is in many ways a highly favorable case for anyone trying to demonstrate nonmilitary drivers for military programs. The remaining case chapters on India and Israel are necessary to complete the spectrum from benign to severely challenging external security environments and domestic threat perceptions. To this point, the Brazilian case has merely provided an existence proof that military capability is not always a primary motivation.

The second conclusion for this case is that the methods of the history and sociology of technology have opened up some vistas that might otherwise have remained clouded over. The heterogeneous system that we have described shows that Brazilian missiles would not have existed without certain allies, such as space applications and export markets. Previous analyses have already spotted these allies. But other allies also helped sustain IAE and Brazilian rockets for years, such as development philosophies or the needs of a particular military regime. By highlighting such a diverse assemblage, this analysis lets us see both additional pressure points for policy and the unimportance of security-based motivations (and therefore, the non-threatening nature of these programs).

This analysis also recognizes just how fragile this particular alliance is, and how the recent changes of government have affected it. If U.S. policy makers, for example, had shared this viewpoint, they might have found it less imperative to gain short-term resolutions. They might have realized that a "missile" in the U.S. context includes the ideas that missiles are aimed at somebody or that they explode. But the historical contingencies of an evolving technological system can produce entirely different sorts of missiles, which in the Brazilian case are not nearly so threatening.

Lastly, we have used the concept of congealed culture to decode many of the artifacts in the Brazilian missile programs. In terms of the old Cold War debates, this technique lets us infer intentions from capabilities. But while some analysts tried to posit Soviet intentions based on the destructive power of their missiles, we see in the Brazilian case that the technique works only through the kind of detailed deconstruction presented here. Note that I have not carried out the extensive interviews and put together the bureaucratic histories that would normally underpin the story of a missile program. Instead, this case presents just enough of the more traditional material to confirm what the core constructivist analysis tells us. The end result is to utilize a store of valuable--and oft-ignored--information about Brazilian motivations.

This case also demonstrates that the history and sociology of technology, in addition to providing interesting conclusions that differ from some traditional analyses, can also be a feasible approach. I was able to obtain enough information to carry out the analysis, even for a sensitive, controversial military technology from a foreign country which I did not visit and whose language I do not speak. With more resources and more time, I could have obtained more information to extend the analysis.

Finally, this constructivist analysis has helped us to understand what moves a country to undertake programs that at first glance appear to threaten U.S. interests. Foreign policy pressures, export controls, and trade regulations have all been instruments in the U.S. effort to bring Brazilian policy into line. As discussed in the concluding chapter, these efforts have in at least some cases resulted in outcomes that work against U.S. interests and that strengthen the original Brazilian motivations. But as I hope this chapter has demonstrated, those motivations turn out to be relatively benign, despite their manifestation in a technological form that appears less so. Armed with this analysis, we can instead move to ameliorate, redirect, or find other means of satisfying those concerns. Matching U.S. policy to real Brazilian needs and objectives seems a good place to start.

CHAPTER THREE

Indian Missile and Space Programs: Strategic Alliance vs. National Consensus

India is not a country which is going to be deflected from its course just because a few beady-eyed gentlemen in Washington and London have determined the 'acceptable' limits of our place in the world. The Agni is a signal that India is ready to assert its rightful role....This country has not developed an indigenous 2,500 km surface-to-surface missile by cowering before any foreign capital. Those days are over. The Agni is a symbol of self-confidence and belief in a national destiny. India has crossed another significant frontier on the way to rediscovering itself.

"Beyond Another Frontier," *The Telegraph*, 23 May 1989

I believe that several uses of outer space can be of immense benefit to developing nations wishing to advance economically and socially. Indeed without them, it is difficult to see how they can hold their own in a shrinking world...The question is not whether the developing countries can afford to utilize space science and technology, rather it is whether we can afford to ignore them.

U.R. Rao, *Space Technology: Its Relevance to the Development of the Nation*
IAEC Endowment Lecture, Bangalore University, 1976
Quoting Vikram Sarabhai, Chairman of the Atomic Energy Commission
from a speech as Scientific Chairman of the UN Conference on
Exploration and Peaceful Uses of Outer Space

I. Introduction

This chapter uses the sociology of technology to reconstruct the motivations driving the Indian space and missile programs by deconstructing the technology being produced. This analysis assumes that artifacts are the product of the social and political context in which they were constructed--in other words, it treats technology as congealed culture. Thus, to understand the complex interactions that we are calling the Indian missile program, we look in something of an archaeological fashion at the system that constructed it, and at the artifacts that this system left behind.

We saw in the Brazilian case that the missile and space programs were merely different faces of the same large technological system. By contrast, while there may be little technical difference between the Indian missile and space programs, they are politically quite distinct. The space program is supported by a stable, national consensus based on broad themes that are found throughout Indian politics. The missile program is less stable, an historically contingent alliance of particular interests, an alliance that could shift substantially in the future.

Purely as an analytic convenience, I break down the political dynamics of this story into three components: themes, actors, and artifacts. Broad political themes are what make these programs possible in the first place. They do not determine the form, timing, or capabilities of the systems, but create a framework for a garbage-can process--problems in search of solutions, and solutions in search of problems, forming historically contingent alliances.[1] Indian society contains a complex, pluralistic mix of broad ideas, theories and policies. Among the most popular or successful of these themes are: nation-building; self-reliance; development; technological autonomy; and international position. They are relatively stable resources, allies that can be mobilized; they can serve as legitimating motifs. They are also diverse, often inchoate. Politicians help give them meaning in the process of continually constructing and reconstructing them; the analyst tries to give them sharp edges or clear definitions.

As discussed in Chapter 1, I define the actors in this story to include people, organizations, technologies, and ideas. They are the less stable and more concrete components of the historical contingencies and alliances that shape the specific programs and outcomes that we observe.

Finally, artifacts such as the stages of a satellite launch vehicle are simultaneously a source and a reflection of the varied forces converging on missile and space programs. The artifacts can contribute strength to alliances and

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[1]See note 34 in Chapter 2.

can be concrete reflections of those alliances. Combining these themes, actors, and artifacts into a coherent story, this chapter tries to account for the shape of the Indian missile and space programs.

II. Themes: The Political Framework

Most of the themes discussed in this section relate could be considered as elements of an Indian national myth. The features of this myth include a strong, self-reliant Indian nation that has won the respect of the world through both its power and its restraint in using it, and has won the respect of its population through fair and secular government and economic development. This version of Indian nationalism is promoted by some, contested by others. The contestation can take forms as diverse as communal violence or voting against the Congress Party. Policies and programs which tap into and help sustain Indian nationalism can place greater claims on scarce resources, gain higher political prestige and visibility, and so on. For example, a policy's claims on legitimacy through promoting self-reliance can be contested by purchasing imported consumer goods or by unsuccessful indigenous technological innovation. Nation-building might be countered by regional favoritism or dissension. It is tempting to question when nationalist rhetoric is merely rhetoric. But a constructivist approach recognizes the real effects of any rhetoric. If a seemingly vacuous policy purports to promote nation-building, and thereby lessens the divisions of the society, how can the analyst challenge its reality? Therefore, in the analysis that follows, we look symmetrically at words, intentions, or deeds, while still leaving room for noticing when claims are contested.[2]

Now, the themes: Figure 1 is a rough schematic of the relevant themes in Indian politics, broken out according to the appropriate constituency. The figure attempts to represent some of the ways in which these themes mutually reinforce one another. Thus for example, a concern for India's international position can bolster India's quest for technological autonomy.[3]

Nation-building: One of the key themes for both the political elite and the mass public is "nation-building." Being new to Indian politics, I had always thought of India simply as, "India," an unproblematic identity. So I was surprised to see just how fractured Indian society is, along ethnic, religious, linguistic, regional, and state boundaries. Policies, ideas, and institutions that contribute to unifying this diversity are part of a "nation-building" endeavor that seems to play a key role in Indian political life.[4] So, for example, the Indian space program tries to identify

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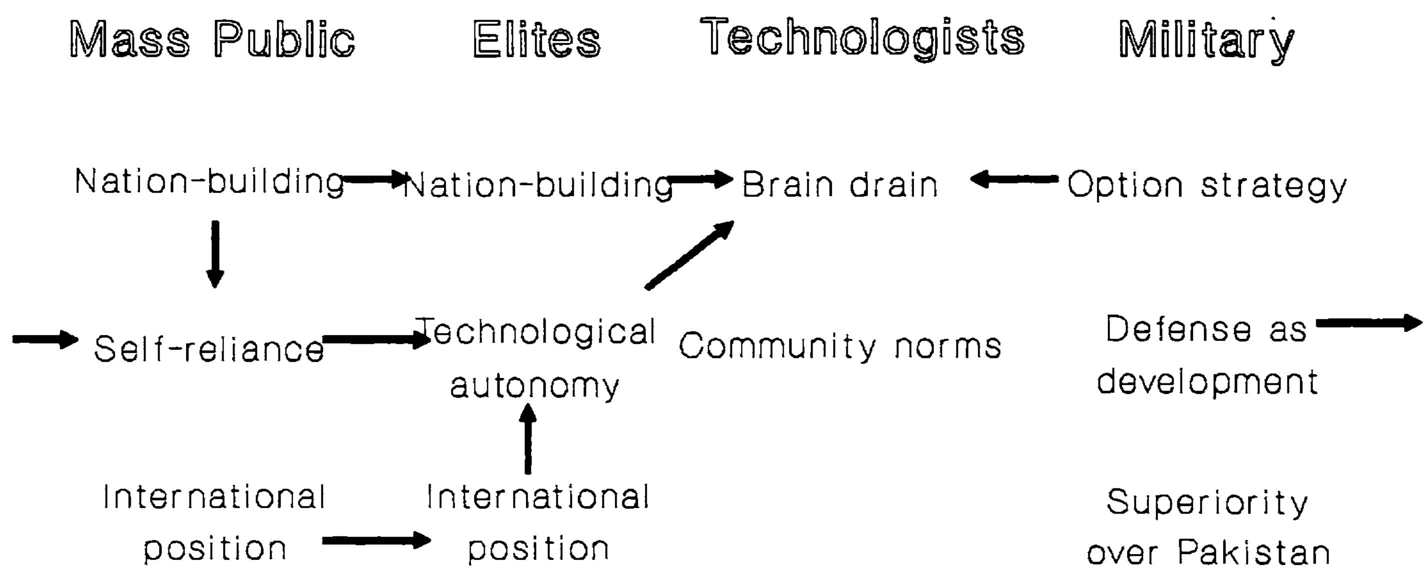
[2]On contestation, see William Connolly, *The Terms of Political Discourse* (Princeton: Princeton University Press, 1983); and W. B. Gallie, "Essentially Contested Concepts," in Max Black, ed., *The Importance of Language* (Englewood Cliffs, N.J.: Prentice-Hall, 1962), 121-46.

[3]Sources for all figures are given in the List of Figures, pp. 8-9.

[4]Nation-building is a central endeavor of any state, especially new ones. I am following Benedict Anderson here, viewing the "nation" as that odd entity which is both sovereign and delimited, constituting an imagined political community. Anderson, *Imagined Communities: Reflections on the Origin and Spread of Nationalism* (New York: Verso, 1991). See also Liah Greenfeld, *Nationalism: Five Roads to Modernity* (Cambridge: Harvard University Press, 1992). This perspective differs from, for example, Anthony Smith, *The Ethnic Origins of Nations* (New York: B. Blackwell, 1987). On Indian nationalism and nation-building, see Stanley Wolpert, *A New History of India* 4th ed. (New York: Oxford University Press, 1993); and Paul Brass, *The Politics of India Since Independence*, vol. 4 of *The New Cambridge History of India* (New York: Cambridge University Press, 1990). On nation-building and its effects on foreign policy, see Richard Sisson and Leo Rose, *War and Secession: Pakistan, India, and the Creation of Bangladesh* (Berkeley: University of California Press, 1990).



Indian Politics: Themes and Constituencies

Figure 1

itself as "Indian." It resists being isolated according to any of the divisions I just listed. Yet opposition to construction projects is concentrated in particular regions, while particular ethnic groups are over-represented in the technical elite that governs the program.[5]

The space program helps to bind the nation together, by constructing a truly national television system, for example, or by creating teams of scientists drawn from many states and regions of the country.[6] In fact, almost any description of the Indian space program includes a map, of all of India, without any boundaries whatsoever, but rather showing all of the different centers and laboratories that, working *together*, contribute to the program (see Fig. 2).[7]

Self-reliance: Self-reliance is another prominent component of the Indian

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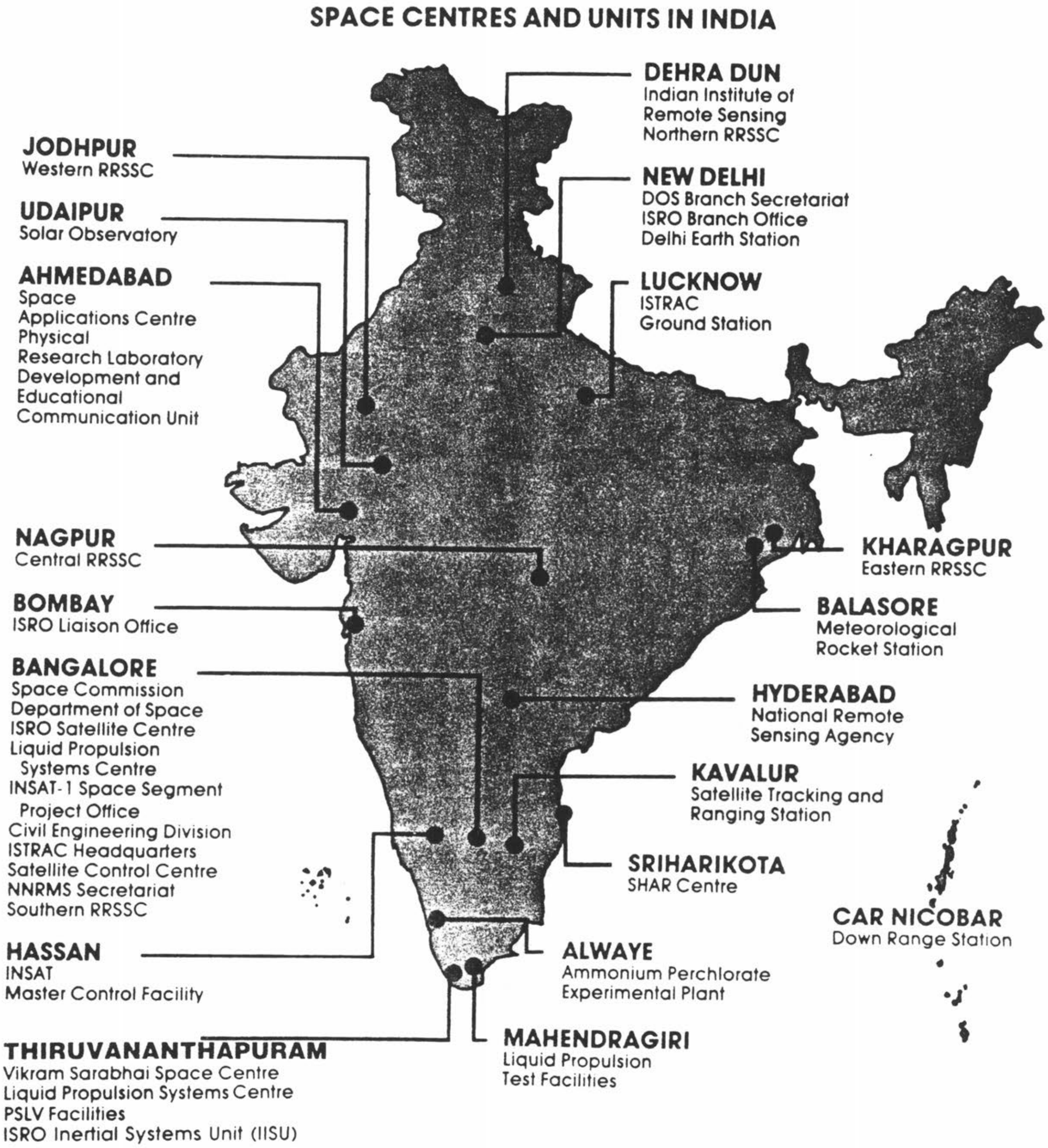
[5]On the protests in Orissa over the establishment of a missile testing range, see Indranil Banerjie, "The National Test Range Fiasco," in Banerjie, "The Integrated Guided Missile Development Programme," *Indian Defence Review* 5, no. 2 (July 1990): 99-109, 106-9. The prominent role of Tamil Brahmins in the scientific elite is part of the lore of the Indian nuclear program. The broader problem of national integration is surveyed in A. Jeyaratnam Wilson and Dennis Dalton, eds., *The States of South Asia: Problems of National Integration* (Honolulu: University Press of Hawaii, 1982).

[6]As a representative example, a leading Indian newspaper, the *Hindu*, used to be published only in one city, Madras. Now, using an indigenous Indian communications satellite, the content for each edition is beamed directly to other cities and printed and distributed throughout the country. On the role of the SITE program (Satellite Instructional Television Experiment) "as an instrument of social change and national cohesion," see Rabi Narayan Acharya, *Television in India: A Sociological Study of Policies and Perspectives* (Delhi: Manas Publications, 1987), quotation at p. 19; and Binod Agrawal, assisted by Sashikala Viswanath, *Anthropological Methods for Communication Research: Experiences and Encounters During SITE* (New Delhi: Concept Publications, 1985).

[7]At the same time, this representation could also be a form of internal colonialism and the imposition of New Delhi's will, paralleling maps of the British Empire of 150 years ago.



The Indian <u>National</u> Space Program

Figure 2

national myth. The phrase is a persistent drum beat in Indian political debates.[8] However, how to go about achieving self-reliance, or development in general, is the subject of significant disagreement. One particular form, found particularly in elite debates, is the quest for technological autonomy. Thus for example a newspaper editorial extolling the Agni missile explained that, "Successive Indian leadership has nurtured the notion that self-reliance extends beyond economic endeavour and, in fact, hinges on a quantum jump in the development of science and technology."[9] This perspective on development ties in readily with traditional notions of sovereignty, so that "the nation's freedom" can depend on a

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[8]For the place of self-reliance in India's overall development strategies, see Madan Mohan Batra, *Planning in India: Development Perspective Towards the 21st Century* (Bareilly: V.K. Publishing House, 1987). On the role of self-reliance in the defense sector, see Birla Institute of Scientific Research, Economic Research Division, *Self-Reliance and Security: Role of Defence Production* (New Delhi: Radiant Publishers, 1984). In the nuclear sector, the 1958 Constitution of the AEC declared that "India should be able to produce all the basic materials required for the utilisation of atomic energy." Reprinted in Dhirendra Sharma, ed., *The Indian Atom–Power & Proliferation: A Documentary History of Nuclear Policies, Development, and the Critics, 1958-1985* (New Delhi: Philosophy & Social Action, 1986), 1-2, 1. The progress toward this goal is documented in Bhabha Atomic Research Centre, *Annual Report* (Trombay, Bombay: Library & Information Services, BARC, various years); and compendia such as *National Symposium on Manufacture of Nuclear Components*, 7-8 April 1982, Bhabha Atomic Research Centre, Bombay, or *Catalogue of Activities at BARC Towards Achievement of Self-Reliance in Technology* (Trombay, Bombay: Bhabha Atomic Research Centre, Electronics and Instrumentation Group, 1973). In the space sector, see Y. S. Rajan, "Self-reliance in the Indian Space Programme and Sharing of Experience," *Proceedings of Workshop V, Promotion of Space Research in Developing Countries*, COSPAR 25th Plenary Meeting, 25 June - 7 July 1984, Graz, Austria. On self-reliance in the electronics sector (which is heavily integrated with the defense and atomic energy departments), see Grieco's excellent study, which shares many of the perspectives of the sociology of technology: Joseph Grieco, *Between Dependency and Autonomy: India's Experience with the International Computer Industry* (Berkeley: University of California Press, 1984).

[9]"Editorial Urges Agni Missile Test Despite U.S. 'Advice'," *The Hindustan Times*, 17 April 1989, p. 11, in JPRS-TAC-89-018, 3 May 1989, p. 18.

"struggle...not only for political independence but also for...technological self-reliance."[10]

The quest for technological autonomy thus provides guidance on what the focus of development policies should be, namely, to build up science and technology resources and industrial R&D sectors, to eliminate dependence on foreign technology and vulnerability to foreign demands, and to find solutions to Indian problems in India. While other theories of development are present among Indian elites, this version matters most to our story. In the defense sector, two Ministers of Defense have observed:

> We are yet to develop a truly indigenous capability to design and develop weapons and equipment of higher levels of sophistication and capability. A truly national technological ethos and culture must emerge and only then can it be said that the country is self-reliant in a technological sense.
>
> [Our] defense policy emphasis is on self-reliance through indigenization of our equipment and weapon systems. This is being achieved through our own R&D efforts as well as through the production of major defense systems within the country--including both indigenously developed systems and licensed production of foreign equipment.[11]

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[10] V. S. Arunachalam, "Forward," *Defence Science Journal* 35, no. 2 (April 1985): pp. v-vii, a special issue for the 60th birthday of Dr. Raja Ramanna. Similarly, Stephan von Welck ascribes to Vikram Sarabhai, the director of the Indian atomic energy and space programs in the mid- to late-1960s, the idea that "one of the principal objectives of India's space policy is self-reliance...without having to rely forever on technical assistance and--coupled with this assistance--potential pressure from other countries." von Welck, "India's Space Policy: A Developing Country in the 'Space Club'," *Space Policy* 3, no. 4 (November 1987): 326-34, 327.

[11] K.C. Pant, as quoted in Tony Banks, ed., "Country Survey: India," *Jane's Defence Weekly* (26 May 1990): 1021-42; and Defense Minister Rao, quoted in Christian Catrina, *Arms Transfers and Dependence* (New York: Taylor & Francis and United Nations Institute for Disarmament Research, 1988), 309.

International position: Another theme, which I call "international position," expresses a concern about India's relative place in the international system. This theme includes the ideas of prestige and status, but I believe it is more focused on defining what India *is* by positioning it with respect to the rest of the world.[12] Thus, many of the accomplishments of India are related according to how many other countries have achieved them before. For example, on the occasion of India's export of a single aircraft to the Mauritius Coast Guard, a New Delhi newspaper proclaimed that "India has joined the exclusive group of countries exporting military aircraft."[13]

India's international rank according to various measures is a frequent topic, with every Indian citizen knowing for example that India has the third largest scientific and technical work force in the world.[14] But rank is not the only criterion for international position. For example, the fact that the two countries acknowledged as having larger technical labor pools were both military super-

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[12]Suchman and Eyre have given substance to the vague concepts of status, prestige, legitimacy, and so on, by sketching the "institutionalized normative structures that link advanced weaponry with modernization and sovereignty." Mark Suchman and Dana Eyre, "Military Procurement as Rational Myth: Notes on the Social Construction of Weapons Proliferation," *Sociological Forum* 7, no. 1 (March 1992): 137-61, esp. 149-53, quotation at 137. See also Gerald Steinberg, "Large-scale National Projects as Political Symbols," *Comparative Politics* 19, no. 3 (April 1987): 331-46.

[13]"Hindustan Aeronautics to Export Military Aircraft," *Patriot* (New Delhi) 5 March 1990, p. 9, in JPRS-NEA-90-025, 2 May 1990, p. 50A. The plane was a Dornier-228, Coast Guard version.

[14]See Thomas, *Indian Security Policy*, 224-26. However, the most recently reported UN data show India with fewer scientists and technicians than the United States, the Soviet Union, Japan, France, or Germany. Table 5.4, "Number of scientists, engineers and technicians engaged in research and experimental development," in *UNESCO Statistical Yearbook* (Maxeville, France: UNESCO, 1991), 5-16 to 5-21.

powers served to reinforce India's position as an alternative to the East-West military confrontation. This theme helps us to understand statements such as Abdul Kalam's (the Director of India's missile program), that "strength respects strength and technology honours technology."[15]

Technologists: Two particular constituencies--beyond the mass public and the political elite--are important to our story: the technical community and the military. First, scientists and engineers in India take very seriously the Western ideals of scientific norms or ethos: for example, having rewards and incentives that are based on the internal criteria of science (publishing papers in peer reviewed journals, pursuing problems that are important by science's standards); the ideal of individual research (with the early atomic energy program possibly serving as a model or mythology); and a belief in the scientific enterprise's autonomy from political control.[16] This vision of the technical endeavor has little to do with contributing to building up the nation, creating self-reliance, and other themes in the broader polity.

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[15]Quoted in Manoj Joshi, "Agni: importance, implications," *Frontline*, 10-23 June 1989, pp. 4-9.

[16]For the role of these norms in Western science, see many of the articles collected in Robert Merton, *The Sociology of Science: Theoretical and Empirical Investigations*, edited by Norman Storer (Chicago: University of Chicago Press, 1973); and the brief overview in Trevor Pinch, "The Role of Scientific Communities in the Development of Science," *Impact of Science on Society* 40, no. 3 (1990): 219-25. A clear statement of their power within Indian debates is Y. S. Rajan, "Management of the Indian Space Programme," in *Developments in Fluid Mechanics and Space Technology* (Bangalore: Indian Academy of Sciences, 1988), 397-413. For a competing view of the mission of the science in the developing world, see Sarder Ziauddin, ed., *The Revenge of Athena: Science, Exploitation, and the Third World* (New York: Mansell, 1988). For a discussion of competing ideologies of the mission of the science, see Robert Anderson, *Building Scientific Institutions in India: Saha and Bhabha*, Occasional Paper Series, No.11 (Centre for Developing-Area Studies, McGill University, 1975).

On the other hand, the goal of creating and sustaining a strong scientific and technical capability is shared by the scientific community and the broader polity. The conjunction is most evident in concern about "brain drain."[17] Despite a surplus of researchers, government policies fight a furious battle against brain drain, providing educational and research opportunities to seduce Indian scientists to remain in the country.[18] As the science advisor to the Minister of Defense noted (or perhaps pleaded):

> The country is beginning to realise that the technologists, scientists, technicians and engineers are valuable national assets and it cannot afford to keep them as mere window-dressing or even allow them to go to other countries without itself benefiting from their capabilities.[19]

This concern about brain drain, naturally central to the leaders of the technical community, also appeals to ideas about nation-building and technological autonomy, and can therefore appeal to the broader public as well. For example in 1990, Dr. V. S. Arunachalam, then chief of the Defence Research and Development Organization and scientific adviser to the Prime Minister, appeared on Indian national television to argue that even in tough financial times, the country should support defense R&D, "much in the way families carried on supporting

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[17]See for example R. J. Thirwani, *Restricting Brain Drain: For Fastest Industrial Development in India* (New Delhi: Modernising India Consultants, 1989); and S. K. Chopra, ed., *Brain Drain, and How to Reverse It* (New Delhi: Lancer International, 1986). On the issue of brain drain in the third world generally, see B. N. Ghosh and Roma Ghosh, *Economics of Brain Migration* (New Delhi: Deep & Deep, 1982).

[18]For a sample of the battle plans, see Nandini Joshi, *Manpower Planning in Scientific Research Institutes* (New Delhi: Centre for the Study of Science, Technology and Development, 1979).

[19]Dr. V. S. Arunachalam, "The Major Weakness Is In Components," *Frontline*, 10-23 June 1989, pp. 12-13.

their children's education despite budget crunches. 'Investment in R&D is the only way to self-reliance.'"[20] The emphasis on a large reserve of technical labor and resources also meshes well with an important theme in the defense sector, namely, the option strategy.

Military politics: Within military politics, the "option strategy" usually refers to India's nuclear weapons policy.[21] Emphasizing technical capability as opposed to deployments, the option strategy permits Indian political leaders to pursue a compromise course between full nuclearization and renunciation of nuclear weapons. This strategy overcomes a lack of domestic consensus for either of the extreme positions, and also permits India to reap many of the benefits of a nuclear capability while avoiding some of the drawbacks.[22] An icon of policy for decades, the option strategy appears to apply to missiles now as well. As the director of the missile program said, "After achieving competence, one can pause."[23] The compromise satisfices a number of constituencies, including

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[20]"India: Scientist on Progress in Defense Production," *The Hindu*, 11 August 1990, p. 7, in JPRS-NEA-90-061, 23 October 1990, p. 54B.

[21]See Ashok Kapur, *India's Nuclear Option: Atomic Diplomacy and Decision-making* (New York: Praeger, 1976).

[22]For a discussion of how mutual deterrence with Pakistan can nonetheless function even under these conditions of opacity, see Devin Haggerty, "The Power of Suggestion: Opaque Proliferation, Existential Deterrence, and the South Asian Nuclear Arms Competition," *Security Studies* 2, no. 3 (Spring 1993), forthcoming. On opacity in general, see Benjamin Frankel, ed., *Opaque Nuclear Proliferation: Methodological and Policy Implications* (London: Frank Cass, 1991).

[23]"India's ICBM" (editorial), *Patriot*, 12 January 1990, p. 4, in JPRS-TAC-90-004, 9 February 1990, p. 44B. Similarly, Defense Minister Pant said that "the goals of the Agni are technological. The government would take decisions at the appropriate time about the production and operation of such missiles." L. K. Sharma, "Correspondent's Interview With Defense Ministery Pant," *Times of India*, 18 July 1989, p. 8, in JPRS-NEA-89-059, 6 September 1989, pp. 61-63, 62. See also Jasjit Singh, "The Strategic Deterrent Option," *Strategic Analysis* 13, no. 6 (September 1989): 592-97; and "Advanced Surface-To-Surface Missile Tests Planned," *AFP* (Hong Kong), 26 May 1989, in

scientists who are perfectly happy to continue working on research and development without seeing any deployments. The option strategy's emphasis on technological capability may even be spreading to apply to the defense sector as a whole.[24]

A second theme in military politics--defense as development--has achieved much greater prominence in the past fifteen or twenty years. After independence, defense expenditures were viewed as a drain on development efforts, though perhaps a necessary one. Even for those concerned with India's military strength, the standard argument was that a rising tide lifts all boats--that is, a healthy, growing economy would in the long term create more resources for defense than would a large defense budget.[25] However, sometime in the 1970s, increasing credence was granted to the argument that defense expenditures could complement development programs. Technology transfer from the defense sector received more attention; MoD public sector undertakings moved aggressively into civilian production; and, most important for our story, those defense

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FBIS-NEA-89-102, 30 May 1989, pp. 60-61.

[24]For example, for military applications of satellite technology, "India will keep its options open on the development and production of military satellites," according to Defence Minister K. C. Pant. "India would develop the satellites at an appropriate time both for surveillance and as an airborne early warning system." "Defense Minister on Military Satellites," *AFP* (Hong Kong), 17 July 1989, in FBIS-NES-89-136, 18 July 1989, p. 41.

[25]As Stephen Cohen concluded, "The present military plays no civic-action roles....Although new tasks have been taken up...[including] weapons production...these are directed toward clear-cut military objectives. Indians have no interest in a 'people's army'...or use of the army for explicitly social-welfare ends." Cohen, *The Indian Army: Its Contribution to the Development of a Nation* (Berkeley: University of California Press, 1971), 194-95.

programs which could most plausibly support technological or economic development thereby increased their chances of political success.[26]

Finally, military politics in India includes a strategic requirement not just for military parity with Pakistan, but superiority. Especially since the 1971 Indo-Pakistani war, that superiority can be defined in terms of technology, rather than manpower or overall capability.[27] The limited growth in Army personnel when compared to the growth of the Indian budget over the last ten years also points to an increasing role for expensive, high-technology systems, such as missiles.[28]

These themes are mutually reinforcing in several ways, as shown in Figure 1, especially those that derive from Indian nationalist myths. Of course, they do not

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[26]For a full discussion of the evolution of theories about defense and development in Indian politics, see Raju Thomas, *Indian Security Policy* (Princeton: Princeton University Press, 1986), 195-233, esp. 215-21. On the general debate over the effects of defense investment on development, see Nicole Ball, *Security and Economy in the Third World* (Princeton: Princeton University Press, 1988), esp. 161-394. For examples of how the argument plays out in discussions of the space and missile programs, see "Space as a Spur for National Development in India," *Space* 3, no. 4 (March-April 1987): 188-95; and "Agni: India Fires Into The Missile Age," *Asian Defence Journal* 17, no. 9 (September 1989): 70-76.

[27]See Michael O'Rourke's interview with the former Indian Army Chief of Staff, Gen. K. Sundarji, printed as "Nuclear Stand-off," *Far Eastern Economic Review* 149, no. 37 (13 September 1990): 24-25. On early Indian strategic thought, see Lorne Kavic, *India's Quest for Security: Defense Policies, 1947-1965* (Berkeley: University of California Press, 1967); its later evolution is addressed in Stephen Cohen, "Strategic Imagery of Elites," in James Roherty, ed., *Defense Policy Formation: Towards Comparative Analysis* (Durham: Carolina Academic Press, 1980), 153-73; and in Stephen Cohen, "Military Ideology: South Asia" in Frank Horton, Anthony Rogerson, and Edward Warner, eds., *Comparative Defense Policy* (Baltimore: Johns Hopkins University Press, 1974), 73-87. Technological superiority was enshrined as a strategic concept after the 1971 war. See Surjit Mansingh, *India's Search for Power: Indira Ghandi's Foreign Policy, 1966-1982* (New Delhi: Sage, 1984).

[28]Based on figures given in the International Institute for Strategic Studies' annual *Military Balance* (London: Brassey's, various years), the number of uniformed personnel has grown by 16.5% from 1980 to 1990, while the defense budget has grown by 73% (in constant dollars).

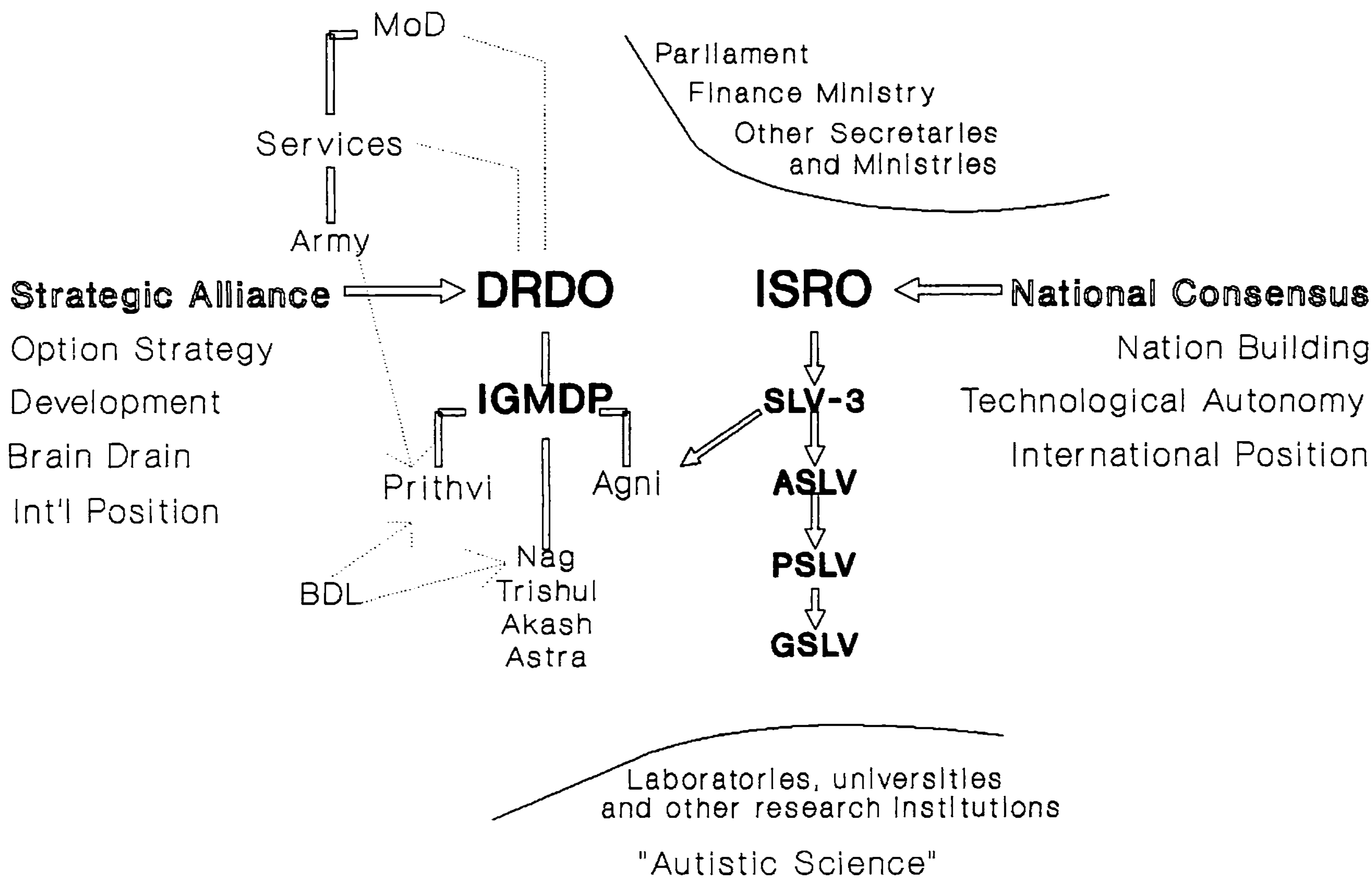
divide so neatly, and they can be strategically re-defined to support particular political or programmatic goals. Nonetheless, they provide the basic frame for what actors in Indian politics are able to accomplish, and serve as keynotes which actors can sound in order to support their claims on scare national resources.

III. The Indian Missile System: Motivations and Actors

As we tie these broad themes to specifics, we can draw an interesting comparison between missiles and space launch vehicles. These artifacts are often thought to be the same--identical in propulsion systems, airframes, staging operations, much of the launch support, and so on. While this congruence of missiles and launch vehicles may hold true in a political vacuum, technological systems never exist in such a vacuum. Their politics will always be different, and therefore so will the artifacts. In the Indian case, we can see two distinct technological styles for the space and missile programs. The ISRO relies on broadly based, mutually reinforcing themes that are already supported by political consensus; the ISRO's organizations, technologies, and artifacts reflect this context across different levels of detail. For the DRDO, support for different aspects of the system depends on smaller constituencies, are often contested, and are in general not mutually reinforcing.

Indian Space Research Organization (ISRO)--a national consensus

Themes: The space LTS in India is supported by a mass and elite consensus built around the themes listed on the right of Figure 3. As an example of the nation-



Indian Politics: Actors and Themes
Figure 3

building aspects of the space program (beyond those examples already described):

> "Educational curricula at schools of all levels include space science and technology and their application in national development and every-day life. This policy has certainly contributed to the fact that, in spite of the extreme poverty of large parts of the population, India's space policy is rarely criticized within the country, and is based on a broad national consensus."[29]

In other words, while some are creating a national consensus for space, at the same time, space helps create a consensus on the nation.[30]

Technological autonomy is a clear part of ISRO's mission, and its invocation a clear source of political support. As a long-time Director warned:

> After the concerted efforts in the late seventies and early 80's there is again a tendency...to revert to importing [equipment]...citing non-availability, schedule and performance lacunae in the Indian Industries, products--a familiar tune![31]

Finally, the space program can use India's international position to conjure up elite and public support. Witness the tattoo of references to "the space club" or the "select group of countries" who share India's particular achievement.[32] This portrayal, directed toward an enhanced self-image, gives ISRO a more legitimate claim on scarce Indian resources. But international position is not merely a matter of prestige, as in one newspaper commentary: "Such achievements will

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[29]von Welck, "India's Space Policy," 330.

[30]Recall also the discussion of satellites helping to establish a truly national media, note #5, *supra*.

[31]Satish Dhawan, *Prospects for a Space Industry in India*, Fifth Lala Karam Chand Thapar Memorial Lecture (New Delhi: Phulkian Press, for Patiala Technical Education Trust, 1988), 22.

[32]See for example, von Welck, "India's Space Policy: A Developing Country in the 'Space Club'."

give the country much-needed political and technological clout in our commercial and other negotiations...No country with achievements of the kind described can be marginalised."[33]

Organizations: The ISRO exercises an unusual degree of autonomy for a government bureaucracy. This outcome is not particularly surprising, given its direct descent from the remarkably autonomous nuclear establishment, the lack of an obvious ministry or department above it in the hierarchy, and the national consensus already described.[34] Just as a national consensus supports an independent ministry of transportation, so the Department of Space is essentially directly under the Prime Minister's office. In addition, claims of technical expertise can be useful bureaucratic pawns in warding off intruding bureaucrats.[35] For

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[33]K. Subrahmanyam, "India Enters Missile Age," *The Times of India*, 13 July 1990, p. 10, in JPRS-NEA-90-050, 14 September 1990, p. 52.

[34]The DOS is officially under the Secretary of Science and Technology, but since it has its own secretary, it is treated as an equal in the powerful Committee of Secretaries. On the bureaucratic sequestration of the Department of Atomic Energy, see Dhirendra Sharma, *India's Nuclear Estate* (New Delhi: Lancers, 1983), esp. 27-39, 118-46; and Steven Flank, "Exploding the Black Box: The Historical Sociology of Nuclear Proliferation," *Security Studies* 3, no. 1 (Fall 1993), forthcoming.

[35]This idea has long been a staple in discussions of science and technology policy. In an early example, Don K. Price analyzes how "people with scientific training...are hard to make over into passive agents of...a bureaucracy....Science...has added to the tendency of government agencies to become vested interests that guard their programs as if they owned them." Price, *The Scientific Estate* (Cambridge: Harvard University Press, 1965), 45-49. Price also confronts a Senator's accusation that "'faceless technocrats in long, white coats are making decisions today which rightfully and by law should be made by the Congress" (pp. 57-81).

Each *Annual Report* of the Department of Space includes a paragraph on "Space in Parliament." Over the span of 1986 to 1990, the primary chamber of the Indian parliament (the Lok Sabha) never submitted more than 60 questions to the department in a single year. The relevant parliamentary committee never devoted more than two meetings in a year to DOS matters. The subjects and questions in the parliamentary debates never moved beyond generalities, such as overall funding levels or planned launch dates, for example, questions about overall annual expenditures on the space program from 1984 to 1987 (Shri Vijay Patil and Shri K. R. Narayanan, Wednesday, 9 March 1988, *Lok Sabha Debates* (New Delhi: Government of India, 1988), vol. 36, the most part, ISRO's organizational autonomy is secure. But this is not to say that ISRO exists in splendid isolation, or could survive without the connections to multiple organizations that underlie its broad national consensus.

We see this necessity for consensus in ISRO's relations with external organizations such as the end-users of satellite technology: telephone, telecommunications, weather, or television. For example, the INSAT 1A satellite was proudly proclaimed as the first geostationary satellite in the world combining "the triple functions of telecommunication, direct TV broadcasting and weather watching."[36] No previous satellite featured this combination, not because it is technically difficult, but because only in India was it necessary to load the satellite with such a variety of consensus-building capabilities.

In internal organization, the ISRO is itself an alliance of many organizations, some of which predate ISRO (and some of which, e.g. VSSC, are themselves alliances of smaller, older organizations) (see Fig. 4). Because ISRO is made up of so many units, and because the linkages are "complex and time-varying, [therefore] consensus management has been mostly resorted to in decision-making through Committees, Boards, Councils, etc."[37]

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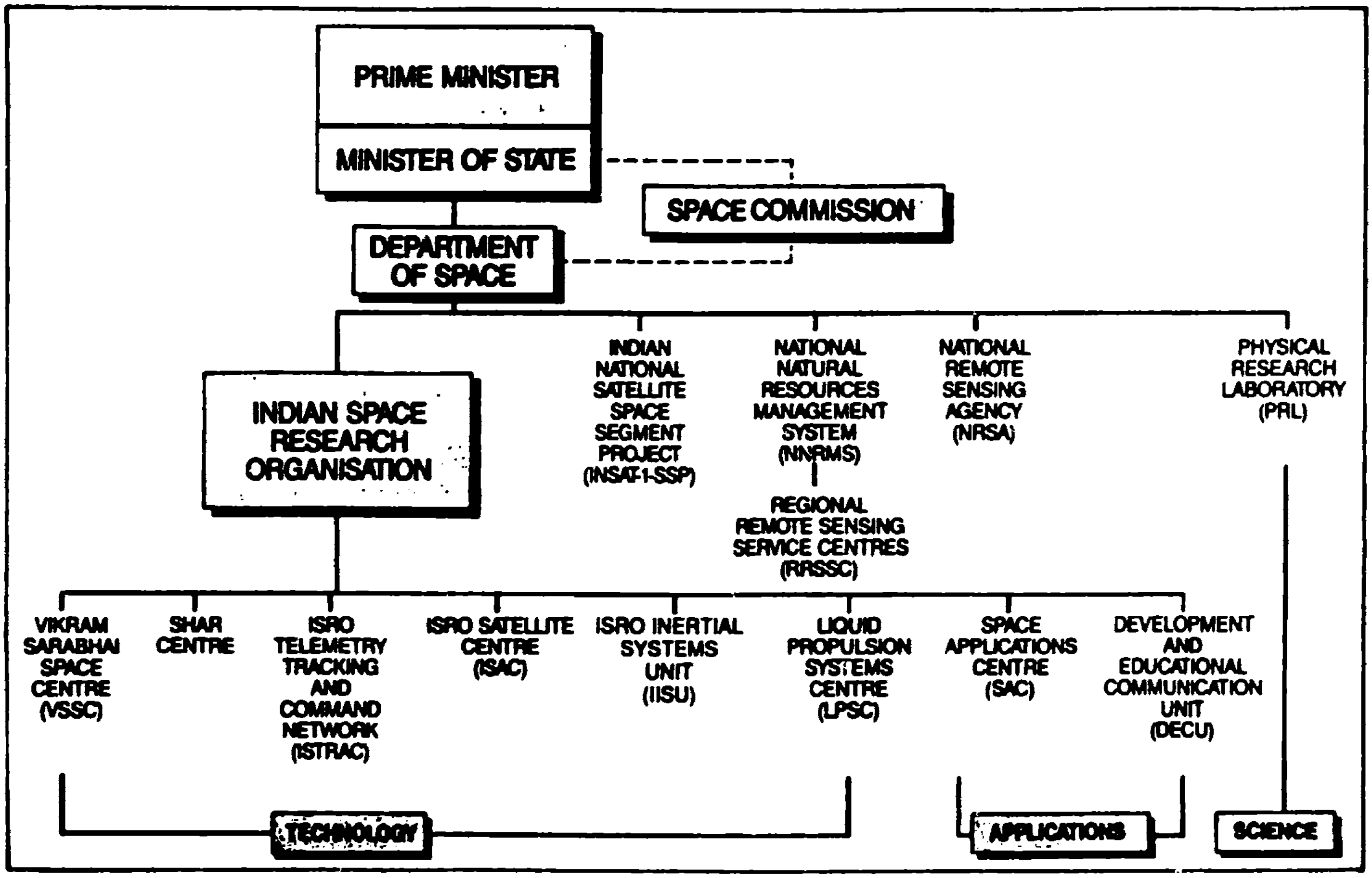
no. 11, column 218). More challenging or detailed questions, such as demands to account for the ASLV launch postponements, could be dealt with by a nod toward "extremely complex technologies involved in the development of critical systems and sub-systems leading to delay in the realisation of these subsystems" (Shri Y. S. Mahajan and Shri K. R. Narayanan, Wednesday, 23 March 1988, *Lok Sabha Debates* (New Delhi: Government of India, 1988), vol. 37, no. 21, columns 202-10).

[36]Radhakrishna Rao, "India in Space," *Space World* (March 1983): 16-18, 17.

[37]Rajan, "Management of the Indian Space Programme."



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ISRO's Internal Organization

Figure 4

Artifacts: Although the main focus of our analysis is on the long-range ballistic missile programs, even a quick look at the ISRO's space launch vehicles is rewarding. The SLV-3 was the pinnacle of India's original plans for space, placing India's first satellite into orbit on 18 July 1980. The launch vehicle is an all solid fuel, four stage vehicle, in the same class as the U.S. Scout vehicle.[38] It was capable of putting a small experimental satellite into low earth orbit.

The next vehicle, begun while the SLV-3 was still in development, is the Augmented Satellite Launch Vehicle (ASLV). The schematic in Figure 5 shows the ASLV to be an enhanced version of the SLV-3, with an increase in lift capability stemming mainly from the addition of two strap-on motors based on the first stage motor for the SLV-3. The staging operations involving these motors have been the cause of two launch failures in the late 1980s, but the most recent launch fired successfully.[39]

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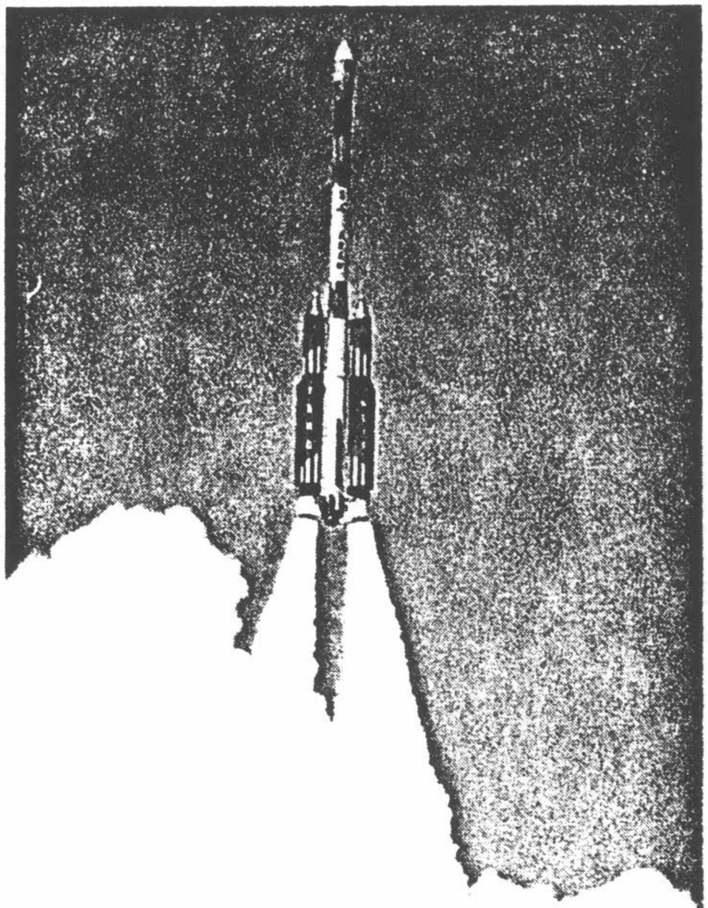
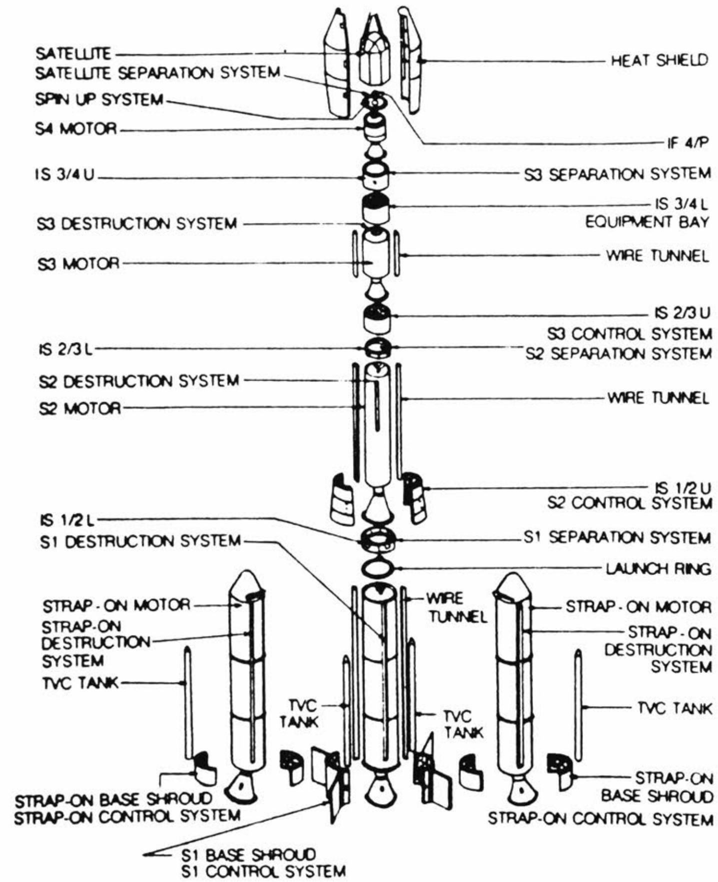
[38] Gary Milhollin has accused the Indians of copying the design of the Scout. While it is true that design information was freely available and may well have been useful to the Indian program, there is no doubt that the hard work of technology development was done indigenously. Furthermore, the sheer variety of Scout configurations and the shared criteria for how to optimize launch vehicles guarantees an external similarity between the SLV-3 and at least one version of the Scout. Gary Milhollin, "India's Missiles--With a Little From Our Friends," *Bulletin of the Atomic Scientists* 45, no. 9 (November 1989): 31-35, 32-33.

[39] Though originaly planned for launch by 1984, the first two ASLV launches, on 24 March 1987 and 13 July 1988, both failed as a result of aerodynamic instability and pressure overload after strap-on burnout. Substantial investigation and occasional recrimination followed, with an ASLV finally launched successfully on 20 May 1992. "Panel on July '88 Failure of Satellite Launch Vehicle," *The Hindu*, 11 August 1989, p. 4, in JPRS-NEA-89-064, 27 September 1989, pp. 45-46; "Teams Race for Deployment of Remote-Sensing Satellite," *The Hindu*, 23 April 1990, p. 7, in JPRS-TTP-90-006, 28 June 1990, p. 11; V.R. Mani, "Changes in Launch Vehicle Hardware, Software Viewed," *The Times of India*, 3 August 1989, p. 8, in JPRS-NEA-89-063, 22 September 1989, p. 51; Tim Furniss, "India Aims for Polar Launcher," *Flight International*, 3-9 June 1992, p. 20; and "Satellite Launch Despite U.S. Ban Hailed," *Hindustan Times*, 22 May 1992, p. 13, in FBIS-NES-92-106, 2 June 1992, pp. 47-48.



ASLV exploded view. ***(ISRO)***



Augmented Satellite Launch Vehicle

Figure 5

The Polar Satellite Launch Vehicle (PSLV) is a major step forward for the program, building on the previous launch vehicles to be able to place one ton observation satellites into sun-synchronous polar orbits (see Fig. 6).[40] Using the same facilities as the ASLV for producing ammonium perchlorate, for producing the fuel, and for casting fuel segments, the 125 ton PSLV first stage consists of five segments of 2.8 meter diameter HTPB solid fuel.[41] The second stage is licensed technology from the French firm SEP, based on the Viking motor, and is the first major liquid fuel stage in the Indian space program (see the discussion of liquid fuels for missiles, below). The third and fourth stages replicate the solid and liquid pairing of the first and second stages and are based on indigenous technology development (previous solid fuel launch vehicle stages for the third stage, and satellite liquid fuel propulsion systems for the fourth stage). Finally, the PSLV uses six strap-on motors, identical to the strap-on motors used for the ASLV.[42] Though long-delayed, the first launch of the PSLV is imminent as of this writing.[43]

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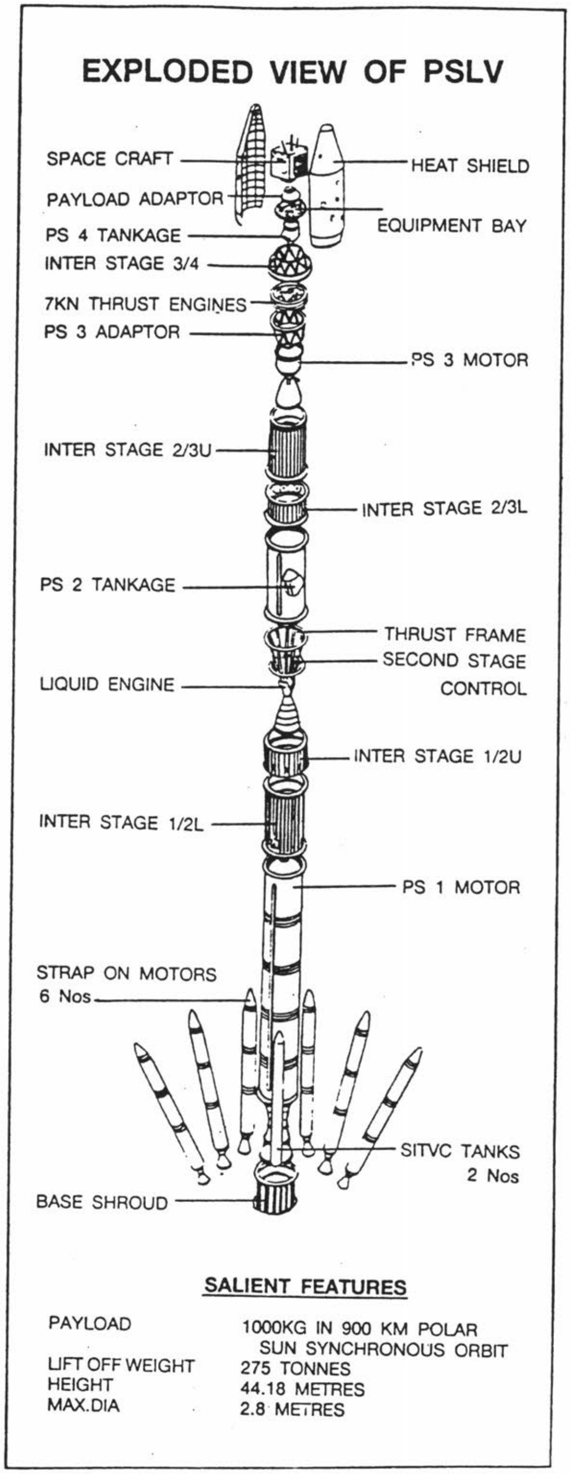
[40]Comprehensive technical overviews can be found in E. Janardhana, "Polar Satellite Launch Vehicle (PSLV) Development Programme in India," in *15th International Symposium on Space Technology and Science*, Tokyo, 19-23 May 1986, vol. 2 (Tokyo: AGNE Publishing, 1986), 1425-30; and A. E. Muthunayagam, "Some Recent Developments in Liquid Propulsion Systems in ISRO," in *41st International Astronautical Congress*, Dresden, 6-12 October 1990, IAF Paper #90-241.

[41]R. Nagappa and M. R. Kurup, "Development of HTPB Propellant System for ISRO's Motors," *26th AIAA, SAE, ASME, and ASEE Joint Propulsion Conference*, Orlando, Fla., 16-18 July 1990, AIAA Paper #90-2331.

[42]A similar progression is visible in the guidance and control software through each of the launch vehicle programs. See Gupta and Suresh, "Development of Navigation Guidance and Control."

[43]In February 1993, ISRO officials announced a planned March launch date to the press. United Press International Wire Service, "India Ready to Launch Powerful New Space Vehicle," 3 February 1993.



PSLV will provide India with an independent 1t Sun-synchronous capability. ***(ISRO)***

Polar Satellite Launch Vehicle

Figure 6

Finally, the Geosynchronous Satellite Launch Vehicle (GSLV) would be the culmination of the space program, capable of inserting one ton satellites into geosynchronous orbit. The GSLV would replace the third and fourth stages of the PSLV with a single high-performance cryogenic stage, providing sufficient lift to boost a satellite plus an apogee kick motor. The ISRO has developed some cryogenic propulsion technology for the GSLV, and is also searching for affordable foreign sources. In the concluding chapter, I discuss the recent controversy over the contract between ISRO and the Russian organization Glavkosmos for such technology.

Reflected in these artifacts is a consensus of organizations working with and within ISRO, as various components are farmed out to different development centers, production technologies transferred to industry, and resulting designs and components then integrated back into a unified whole. We see the liquid fuel second stage of the PSLV being developed by the Liquid Propulsion Systems Center at Bangalore and Trivandrum and tested at Mahendragiri; we see the solid-fuel first stage being developed and tested at the SHAR Center, with maraging steel cases developed by the defense public sector undertaking MIDHANI and produced by the private industrial giant Loursen and Tourbo. Fuel is being produced by the Ammonium Perchlorate Experimental Plant (APEP) at Alwaye, which was originally built for the SLV-3. Integration of the stages is being carried out by yet another group at the Vikram Sarabhai Space Center.

In sum, looking at ISRO's pre-eminent artifacts, their launch vehicles, we see a steady sequence from the SLV-3 to ASLV to PSLV to GSLV, in which each preceding launcher is utilized--almost absorbed--for the next in the sequence, and in which each new design can muster the support needed to add new capabilities.

ISRO's design philosophy here seems almost like a consensus of rocket stages, all of them pulling together to accomplish a joint goal.

ISRO's model of technological development is close to simple incremental growth, but with subsequent stages representing significant new development efforts as well as efficient use of existing resources. It is probably closest to the course followed by Arianespace in Europe. Contrast ISRO and Arianespace with the U.S. experience: early missile-derived launch vehicles, then the independent Saturn-5 development, followed by the all-absorbing re-usable space shuttle program which did not build particularly on either (and which may be displaced by new expendable launch vehicles loosely based on the original ballistic missile systems). We will also see the contrast of the ISRO's consensus model of development with the resource-stricken alliance model that Indian missiles have pursued.

Integrated Guided Missile Development Program (IGMDP)--a strategic alliance

Themes: Missiles in India, and high-tech defense research in general, are supported by an alliance of themes that interest particular segments of the Indian polity. The technical community is happy to have the support to work on challenging research, though as we shall see its real contributions are difficult to detect. The military is happy to develop militarily useful tactical missiles, and to extend their option strategy to include long-range missiles. Those concerned with development and with India's economic position now see missile programs as part of the defense sector's contribution to development. And finally, India's international position is substantially raised in Indian eyes by their missile successes. Note that while these themes do converge on the IGMDP, they are not mutually reinforcing in the same way as we saw for the space program, and they draw on limited communities within particular elites.

The glue that holds this loose alliance together is low cost, particularly for the long-range missile segment of the program. Our methodology reminds us that the presence or absence of financial and other resources merely represents how much support a program has from its most important constituencies. For the Indian missile programs, we see intensive efforts to reduce the resources the programs require. The costs of these programs can remain so low because of the use of already existing resources (in terms of artifacts, programs, and personnel); because the programs themselves are small; because for Agni or maybe for other missiles, no deployments are planned; and because a surplus technical work force is available. Thus, to use a quantum mechanical metaphor, the potential wall that the program must cross is relatively low, raising the probability of support for the program.

Organizations: Unlike the diffuse decision-making at ISRO, the IGMDP is tightly controlled by its parent organization, the Defense Research and Development Organization (or DRDO). Not supported by a broad popular or elite consensus, the IGMDP cannot achieve the same kind of autonomy as the ISRO. Nonetheless, the missile programs do have a high bureaucratic priority which permits them to override many standard procurement and funding procedures.[44]

Like the ISRO, DRDO has managed to insulate itself from many of the usual pressures on government bureaucracies, with little or no control exercised by executive departments, ministries, or the parliament. We might have expected

[44]Anand Parthasarathy, "A Firm Purpose," *Frontline*, 10-23 June 1989, pp. 9-14.

the DRDO to be directly under the control of either the armed services or the Ministry of Defense, especially since it is still a more contested organization than the ISRO. But for historically contingent reasons, DRDO achieves remarkable decision-making latitude. Parliament is only consulted desultorily and *post facto*, mostly as a result of a parliamentary system dominated by a single party, but reinforced by the bureaucratic pawn of technical expertise.[45] Within the Ministry of Defense, DRDO is congruent with the Department of Research and Development, one of the Ministry's three departments (the head of the DRDO is the statutory secretary of the department). This organizational arrangement means that the other two departments, namely the public sector defense industries and the military services, are organizationally detached from R&D, while the Minister's office is a further step removed from direct control of DRDO operations.[46]

The military services, which are not cowed by expertise, nonetheless exercise very little control over any of the executive departments within the Ministry of Defence, mostly for two reasons. First, the definition of security in India is considerably broader than in the United States, including internal security and economic development. Thus, the armed services have a proportionately smaller role in security decision-making, to the extent of having the service chiefs only rarely sit in on meetings of the Indian equivalent of the National Security Council.

Second, the services remain divided and competitive in their relationship with the civilian defense leadership, without any equivalent of a JCS or a general

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[45]See note #35, *supra*.

[46]Gen. S. K. Sinha, *Higher Defence Organisation in India* (New Delhi: United Services Institution of India, 1980), 8-12, 43-44.

staff system (though a substantial amount of off-line bargaining does occur among the service chiefs, the three Ministry of Defense Secretaries, and the Prime Minister, to the extent of forming something of a corporatist body).[47] In addition, for R&D issues in particular, only the Army has any expenditures under its direct control, and even in that case the level is low.[48] In sum, the services remain mostly devoid of influence in determining the direction of defense research.[49] The end result is an oversight vacuum for defense research in general, one which is shared by the missile programs as well.[50]

This decision-making autonomy for the DRDO opens a space for the formation of a strong group identity, accompanied by strategic recruitment of the alliances needed to sustain the organization. The alliance nature of the IGMDP is preserved in its relations with outside organizations. Dr. Abdul A. P. J. Kalam, the current director of the IGMDP, has adapted the "consortium approach," originated by the former Chair of ISRO, Satish Dhawan. Consortia were originally a tool for promoting both nation-building and technological autonomy by binding technological institutions in India together, instead of having them

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[47]See Thomas, *Indian Security Policy*, 119-34, and sources cited therein.

[48]"Defence Budget Reaches New High," in "Country Survey: India," *Jane's Defence Weekly*.

[49]Not included in this analysis are the apparently substantial effects of bribery, both as a means of bypassing legal restrictions on party coffers, and as a means of using contract negotiations with foreign companies for personal enrichment.

[50]This conclusion fits with India's longstanding and distinctive patterns of civil-military relations. Stephen Cohen quotes Defense Minister Krishna Menon's "widely shared" formulation that "it is wrong for the army to try to make policy; their business is to be concerned with military tactics. Military planning and arrangements and things of that kind must remain in the hands of the Government...Military matters are merely questions of expertise." Cohen, *Indian Army*, 175.

form alliances with foreign sources of technology and then competing within India.[51] Under Kalam and the IGMDP, consortia are used to protect against foreign embargoes of key technologies:

> We have already identified all critical components--about 15 of them--and formed consortia of industries, research laboratories and scientific institutions which will design, develop and mass produce these components. If we face difficulties in obtaining these components, we have already taken care of them.[52]

Interestingly, these consortia were formed at the inception of the IGMDP in July 1983, before any threatened embargoes could materialize. Many seemed to have remained dormant, to be activated only if necessary.[53] It appears to me that the IGMDP consortia are yet another technique for creating alliances for the program, this time with a large segment of India's technical sector, much as the U.S. Department of Defense carefully allocates components of controversial weapons systems to key Congressional districts.[54] For example, the missile pro-

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[51]On consortia in the space program, see Shri Vakkom Purushothaman and Shri Narayanan, *Lok Sabha Debates* (New Delhi: Government of India, 1988), Wednesday, 23 March 1988, vol. 37, no. 21, columns 216-18; and Dhawan, *Prospects for a Space Industry*. The consortium approach is attributed to Dhawan as an innovation: "a group of industries get together with an agreed sharing of the engineering and supply tasks, with one of them acting as the prime contractor....The bulk of the engineering systems and hardware work is performed within India, with very selective component acquisition from abroad...If each industry competes with the other on the basis of tie-ups with foreign manufacturers...instead of strengthening the industrial base would end up in channeling scarce Indian resources to industry abroad. This would indeed be a great pity." (pp. 22-23)

[52]"Missile Project Consortium," *Telegraph* (Calcutta), 10 June 1989, p. 4 in JPRS-NEA-89-058, 31 August 1989, p. 58.

[53]Dr. Abdul Kalam, "An Embargo Cannot Throttle Us," *Frontline*, 10-23 June 1989, pp. 10-11.

[54]See the examples given in Nick Kotz, *Wild Blue Yonder: Money, Politics, and the B-1 Bomber* (New York: Pantheon, 1988), 258-60 and passim.

ject formed ties with a project to manufacture 32-bit computer chips indigenously.[55] While such a tactic can be highly effective, it does not bespeak unanimous support for the program.

Within the DRDO, we see a network of organizations that has all the classic marks of a large technological system in formation. The Defense Research and Development Laboratory (DRDL) is the lead organization for the IGMDP and the DRDO, and is located in Hyderabad along with DRDO headquarters. Physically adjacent, to the extent of sharing a common wall with DRDL, is Bharat Dynamics (BDL), one of the MoD public sector undertakings. A few kilometers away (and physically connected by a new, high-quality road that Abdul Kalam reportedly calls his "research umbilical") is the Research Center at Immarat (RCI), an impressive dedicated research and test facility for the IGMDP.[56]

The DRDL has a long history which includes a large project in the late 1960s and early 1970s called the "Devil" program for indigenizing the Soviet-supplied SA-2 SAM as a surface-to-surface missile. This project reportedly employed

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[55]Kalam, "Missile Project Consortium."

[56]For descriptions of BDL, including the sources for the descriptions that follow, see Banks, "Country Survey: India," 1039; "Soviet-licensed Armour Rolled Out in India," *International Defense Review* (November 1987): 1557; Herbert Wulf, "India: The Unfulfilled Quest for Self-sufficiency," in Michael Brzoska and Thomas Ohlson, eds., *Arms Production in the Third World* (London: Taylor & Francis, 1986), 125-45, esp. 138; Hormuz P. Mama, "Progress on India's New Tactical Missiles," *International Defense Review* (July 1989): 963-64. The best public description of RCI is given in Parthasarathy, "Firm Purpose." See also the interview with Dr. Kalam, "Missile Project Consortium"; and Man Mohan, "Paper Details Missile Production Plans," *Hindustan Times*, 27 February 1988, pp. 1, 5, in FBIS-NES-88-044, 7 March 1988, pp. 55-56. On the spatial distribution of defense complex, including some history of some of the industries' founding, see Arun P. Elhance, "Spatial Organization of Arms Production in India: Determinants and Impacts," paper presented at the Western Regional Science Meeting, Hawaii, 13 February 1990, cited in Itty Abraham, "India's 'Strategic Enclave': Civilian Scientists and Military Technologies," *Armed Forces & Society* 18, no. 2 (Winter 1992): 231-52, 236n.

some seven to eight hundred technical personnel, with expenditures on the order of $700 million--a large program, especially by Indian standards.[57] During the course of the program, BDL was set up as a public-sector undertaking under the Ministry of Defense with the express purpose of providing a technology base and production capability for guided missiles.

However, the Devil program wound down in the late 1970s, at least officially, for reasons that are not entirely clear to me.[58] BDL received contracts for work on anti-tank missiles, and grew slowly. DRDL, though still a large organization, came under increasing political pressure itself, and was almost abolished in the mid- to late-1970s.[59] With Indira Ghandi's return to power in 1980, DRDL had an opportunity for reinvigoration. Also by the early 1980s, both of BDL's anti-tank missile contracts were at an end, and BDL was probably searching eagerly for a follow-on. Since the early 1980s, both the DRDL and BDL have expanded many-fold, and are also now tightly integrated in the design and production of at least the Prithvi and probably several other systems.[60] With the establishment of

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[57]On the Devil program, see Joshi, "Agni: Importance, Implications," 5; Pushpindar Singh, "India's Agni Success Poses New Problems," *Jane's Defence Weekly* (3 June 1989): 1052-53; and "Missile Tests Planned," *AFP*, 61. At least two Indians involved with the Devil program have contested the claim of such a large program. Personal communication, Timothy McCarthy.

[58]Zaloga, *Soviet Air Defense*, 55. Other sources claim the program was halted in 1972, but that date does not match the presumed date of some of the program's accomplishments. One interviewee confirmed a cancellation date of 1978. Personal communication, Timothy McCarthy.

[59]Parthasarathy, "Firm Purpose."

[60]"India: Plans for Missile Testing, Manufacture Told," *The Times of India*, 14 November 1989, p. 9, in JPRS-NEA-90-001, 4 January 1990, p. 50A; and "Hyderabad Company to Produce Short Range Missiles," *Delhi Domestic Service*, 23 December 1989, in JPRS-TAC-90-001, 8 January 1990, p. 13.

RCI, with a closely related mission and in approximately the same physical location, a potent ally has been added to the mix. The RCI also has the explicit mission of working with Indian industry in developing broadly applicable technologies, as we will see in the case of carbon-carbon composite materials.

Finally, the internal organization of the IGMDP itself contrasts with the consensus approach of the ISRO. The IGMDP is a set of relatively independent missile programs, bound together it seems only because they could not receive sufficient support as isolated programs. Any one of the programs, could probably be canceled with only the most minimal effects on the others. Yet the IGMDP is sold as a package deal, with the program as a whole providing protection against too close an inspection of any element therein.[61]

In general as the IGMDP matures, the programs appear to be binding themselves more tightly together, particularly through test facilities in the Hyderabad complex.[62] The IGMDP is also trying to tie its capabilities and facilities to broader defense and high-tech sectors, making itself (in Bruno Latour's phrase) an "obligatory point of passage" for other technological development projects.

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[61]The IGMDP package includes the Agni and the Prithvi, discussed in detail in this chapter, and also the Nag anti-tank, Astra air-to-air, and Trishul and longer-range Akash surface-to-air missiles. A comprehensive review of the overall program is Indranil Banerjie, "The Integrated Guided Missile Development Programme," *Indian Defence Review* (July 1990): 99-109. With major differences in propulsion, guidance, materials, and other areas, these missiles do not feature the substantive interdependence of ISRO programs. Nonetheless, from an LTS perspective, they are very much part of the same system.

[62]While one could try to insist that only humans are entitled to the status of actor, we see here that laboratories and testing facilities have active effects. Human actors might have been able to position these facilities so as to have those effects, but that interpretation ascribes a strategic intentionality to those human actors that I do not believe is present, and which is not logically required.

Through such strategies, it may be more difficult in the future to eliminate elements of the missile programs.[63]

Artifacts: As we will see in more detail later, both the Prithvi and the Agni are themselves alliances of technologies. The Prithvi missile has mostly risen from the ashes of the Devil program, carrying along its strange combination of SAM and surface-surface missile technologies, and adding the crucial supplement of new guidance technology from the ISRO (as well some other components). The Agni missile is an even more blatant hybrid, conflating the solid-fuel first stage of ISRO's first satellite launch vehicle design and a shortened version of the Prithvi, with the significant addition of advanced re-entry vehicle technology from DRDL--but crucial components of this RV system are themselves appended from the space program!

This cobbling together of components and systems--"something old, something new, something borrowed, something from ISRO"--demonstrates the mere modicum of political support that these programs can muster. A systems perspective does remind us that systems evolve and grow by slowly adding and adapting existing resources and components. But a successful LTS recruits allies to add new capabilities, transforming existing components to support the future growth of the system. The description given below highlights how a strong consensus for the missile programs could have produced optimized systems that would not have been as dependent on pre-existing technological solutions.

In sum, the technological politics of Indian missile and space programs are characterized by two different approaches, dictated by the political framework in

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[63]Latour discusses the idea of an obligatory point of passage and how testing can enforce that role in *Science in Action*, 150.

which those programs operate--national consensus for the space program, strategic alliance for the missile program. We now move to some specifics of the artifacts, and the missiles in particular, to see how far inside the black box these patterns carry through. Before that, however, we need look for the story's missing actors--scientists and engineers.

Autistic Science: Indian Research Practice

Where are India's researchers in all these systems? Despite the autonomy of both the DRDO and the ISRO, we do not see the kind of runaway proliferation of high-tech projects that afflicted the United States in the wake of Sputnik.[64] The relative restraint of the R&D sector is due, I believe, to an unusual way of doing research. Although Indian scientists pursue high-quality studies in areas that are directly applicable to military projects, the results of those studies wind up not being applied to those projects. Instead, missile and space systems tend to be developed and improved through simple engineering trial and error, while sophisticated research that could be directly relevant winds up not contributing.

I have found dozens of examples of this phenomenon in the technical literature of the space and missile programs. Mostly, the "evidence" for a systemic syndrome is an overall assessment that the adoption of certain technical solutions is inconsistent with the general state of research in that area. For example, when developing the fourth stage of the PSLV, Indian scientists encountered difficulty with their film cooling method for the engine. Despite high quality research on

[64] See Herbert York, *Race to Oblivion: A Participant's View of the Arms Race*, (New York: Simon and Schuster, 1970), 132-33.

combustion and cooling, a trial and error process resulted in the jury-rigged solution of blocking 18 out of 63 injectors to produce a more fuel-rich mixture.[65] Similarly, despite substantial effort to characterize the properties of various nozzle liner materials, when an increase in the solids loading of an ASLV stage produced too much erosion, the correction was simply a series of tests to determine how much material needed to be added.[66]

I call this practice "autistic science," where the technical community does not communicate effectively with any outsiders. As described above, most of the scientists profess a decidedly Western, Mertonian vision of scientific ideals which do not require building any particular systems, and which in some ways emphasize insularity--the elevation of the early days of the atomic energy program to the status of myth, or the belief in science's autonomy from politics.

Instead of making significant contributions to building Indian missiles, Indian scientists are mostly building research establishments and providing interesting enough work to keep their scientists in the country. While the military or the Department of Space does set the research agenda, they do not dictate any use for that research.[67] Yet because of universal support for a strong technical base

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[65]See V. Sudhakar, K. Sivaramakrishnan Nair, and K. Ramamurthi, "Development of a 7 KN Liquid Propellant Engine," in *39th Congress of the International Astronautical Federation*, Bangalore, 8-15 October 1988, IAF Paper #88-225.

[66]Compare Gangadhar De, M. Narendranath, and B.K. Sarkar, "Erosion of Nozzle Throat Inserts and Silica-Phenolic Ablative Liner Morphology," *Journal of Propulsion* 6, no. 1 (January - February 1990): 46-49, with R. Nagapa, M.R. Kurup, and A.E. Muthunayagam, "ISRO's Solid Rocket Motors," in *39th Congress of the International Astronautical Federation*, IAF Paper #88-232.

[67]I am told that similar phenomena are found in other technical fields in India as well, though I have found specific evidence only in the defense and space sectors. One can of course find exceptions, such as an ERDL study of the precise propellant formulation needed for proper ignition of a system notably similar to the Trishul missile: Harihar Singh, M. R. Somayajulu, and R. Bhaskar Rao, "Selection of an Igniter System for Magnesium-Based Solid Fuel Rich Propellant," *Propellants, Explosives, Pyrotechnics* 13, no. 2 (April 1988): 52-54.

and for combating brain drain, and because of the general autonomy of this sector, autistic science is not deemed a failure, or apparently even noticed.[68]

IV. Deconstructing Artifacts

We will now see how the political dynamics described in the first two sections are reflected in the particular stories of the key artifacts in the Indian missile program, the Prithvi and Agni missiles. While many of the particulars of missiles are not known in the United States, a healthy dose of speculation should still permit us to deconstruct illustrative features of these artifacts in detail, hopefully revealing the political and social context of their original construction.

The Prithvi Missile

Control: The most important feature of the Prithvi missile is its debt to previous work done in India on the Devil program, reducing the level of political support that had to be mustered (see Figure 7 for the visual similarities). The control systems for Prithvi may be visually the most obvious inheritance from the Devil

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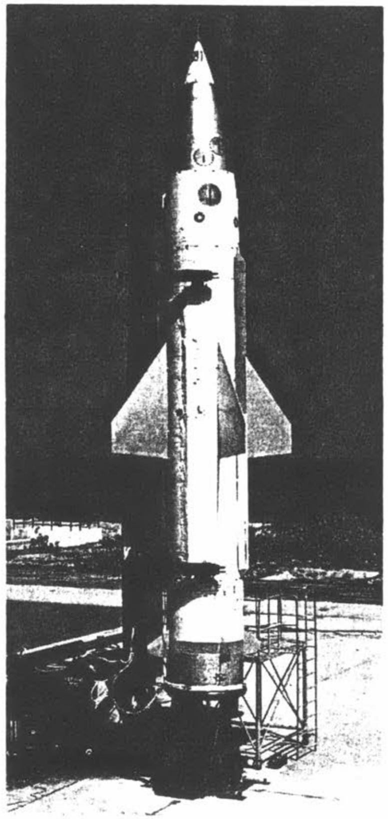
[68]Though one does find complaints, such as that of a Director in the Department of Science and Technology who opined that Indian scientists lack the "'commercial instinct' of the West." Pawan Sikka, "Forty Years of Indian Science," *Science and Public Policy* 17, no. 1 (February 1990): 45-53. It is plausible that the attitude toward the accomplishments of indigenous technology may be changing. The security elite has noted with some urgency the performance of Iraq's Soviet-supplied weaponry in its war with the United States. More broadly, the overall frustration with a socialist, centrally planned approach may spark a recognition of continual technological failures.



Prithvi SRBM mounted on a launch platform prior to launch in February 1988

Two SA-2 'Guideline' surface-to-air missiles on display in Moscow believed to be during the early 1960s (photo: US Army)

Comparing Prithvi and the SA-2

Figure 7

and SA-2 programs. Large aerodynamic stabilizers in the form of delta clipped wings are located mid-body. This configuration is highly unusual for a surface-to-surface missile--but not for a very high altitude SAM capable of shooting down a U-2.[69] In fact, many of the earlier Indian news reports on the Prithvi, apparently aware of its genealogy, referred to it as a surface-to-air missile.[70] Thus an unusual and possibly disadvantageous technological solution is adopted, probably because the Prithvi's claim on political resources was not sufficient to permit an alternative solution.

Fuel: The fact that Prithvi uses liquid fuel at all is somewhat surprising. For transportability, rapid response time, and ease of maintenance--all of which are key considerations for military applications in particular--solid fuel is unsurpassed.[71] Yet the ISRO concentrates on solid fuels, while the DRDO's Prithvi is liquid fuel. Interestingly, the Devil program cancellation came at about the same time as the selection of solid fuel for the SLV-3 design in the early 1970s, evidently a contested decision.[72] Furthermore, the resurrection of the

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[69]"Prithvi," in Duncan Lennox, ed., *Jane's Strategic Weapon Systems* (Coulsdon: Jane's Information Group, 1991), Issue-01, for example, commented that "Four clipped-tip delta wings at mid-body...are most unusual for an SRBM, and remain an unexplained point about the photograph [of the Prithvi missile] released in India just before the first flight test."

[70]This identification continued as late as 1991. "Official Briefs on Missile Deployment Program," *Patriot*, 10 August 1991, p. 1, in FBIS-NES-91-160, 19 August 1991, pp. 58-59, refers to a flight test of "the surface-to-air missile 'Prithvi.'"

[71]Indian analysts share in this conclusion. See, for example, Banerjie, "The Integrated Guided Missile Development Programme," 105.

[72]See M.R. Kurup, V.N. Krishnamoorthy, and M.C. Uttam, "Development of Solid Propellant Technology in India," in *Developments in Fluid Mechanics and Space Technology*, 337-42.

Devil came at about the same time as a rapid expansion of liquid propulsion technology at ISRO, fueled mostly by the Liquid Propulsion Systems Centre.[73]

As described in course of the introductory chapter, the Prithvi is fueled with a hypergolic (self-igniting) combination of RFNA (red-fuming nitric acid) and xylidine (also known as G-fuel).[74] RFNA is a trusted standby for Indian missile programs, and is in common use throughout the world. Xylidine, on the other hand, is something of an odd choice. After some research in the 1950s, the United States never used xylidine, even in developmental systems.[75] Nor do any currently operational systems in the former Soviet Union use xylidine.[76] In India as well, some have expressed puzzlement at the "archaic," "primitive," and "anti-

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[73]In another example of the sort of contingencies involved, LPSC's growth has received a tremendous boost from the transfer of Viking technology from France. That deal, in turn, was funded not by an allocation of scarce foreign exchange reserves, but by LPSC's provision of high-pressure transducers to France from a factory that happened to come under the Centre's control at its creation a few years earlier. See the Department of Space's *Annual Report* from the mid- to late-1980s, and Thomas, *Indian Security Policy*, 272.

[74]Hormuz P. Mama, "Progress on India's New Tactical Missiles," *International Defense Review* 23, no. 7 (July 1989): 963-64.

[75]A search of *Chemical Abstracts* revealed several dozen papers in the 1950s which discuss xylidine, such as Riley Miller, "Ignition Delays and Fluid Properties of Several Fuels and Nitric Acid Oxidants in Temperature Range from 70 to -105 F," *NACA Technical Note #3884* (1956). By the late 1960s, only non-U.S. papers mention xylidine as a propellant. For example, A. Rajendran, M. Ramanujam, "Some Developments of Lignite Based Chemicals," *Urja* 19, no. 6 (June 1986): 401-2, describes processes for manufacturing xylidine from the plentiful deposits of brown coal in India.

[76]According to Barton Wright, assisted by John Murphy, *Soviet Missiles*, vol. 1 of *World Weapon Database*, Randall Forsberg, ed. (Brookline, Mass.: Institute for Defense and Disarmament Studies, 1986).

quated" xylidine propellant when "India also has the technology for...much more powerful" propellants.[77]

Why then xylidine, and what can we learn from that choice? I believe the answer lies in the Prithvi's connection to both the Devil and the SA-2 in India. We know that the primary achievement of the Devil program was a three ton regeneratively cooled engine which was the "progenitor" of the Prithvi engine.[78] We also know that the Devil program tried to "reverse engineer" the SA-2, of which the Indians had hundreds, and for which they received at least maintenance technology from the Soviet Union.[79] As one of the most complex aspects of the missile, the engine would presumably have been copied quite faithfully. The SA-2 also used either an identical or very similar fuel, which can be traced back as far as the German experimental anti-aircraft rockets from Peenemunde.[80] Captured German scientists on Gorodomlya Island provided the

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[77]Hormuz Mama, "Improved Prithvi Missile Launched," *International Defense Review* 25, no. 8 (August 1992): 784.

[78]Manoj Joshi, "Agni: Importance, Implications"; Singh, "India's Agni Success Poses New Problems." Not only artifacts, but many engineers, moved from the Devil to the Prithvi program. Personal communication, Timothy McCarthy.

[79]Singh, "India's Agni Success Poses New Problems"; International Institute for Strategic Studies, *Military Balance* (London: Brassey's, various years); Zaloga, *Soviet Air Defence*, 55.

[80]Various sources give different data for the fuel of all of these rockets. The confusion may simply be a result of the secrecy surrounding military programs, but may also be due to variants of the missiles using different fuels, or development efforts that were not ultimately completed. For the Prithvi, for example, see Mama, "Progress on India's New Tactical Missiles"; but also the commentary by Ravnider Pal Singh, a senior research fellow at IDSA, in "Successful Test of Prithvi Missile Hailed," All India Radio General Overseas Service, 20 July 1991, in FBIS-NES-91-142, 24 July 1991, p. 47.

original plans for the SA-2 in the early 1950s.[81] They presumably based their designs on the Nazi-era Wasserfall anti-aircraft rocket, whose "outstanding feature" was the same distinctive control surfaces as the SA-2, and which used "Salbei" (nitric acid) plus either "Visol" (vinyl isobutyl ether) or "Tonka-50" (50% xylidine and 50% triethylamine) as fuel.[82]

The Indian use of xylidine as a fuel is something like a minority legal opinion which lingers in each subsequent decision--cited in India, but now rejected elsewhere, and not even implemented in India until the Prithvi missile is actually deployed. Why has xylidine lingered, and why has it found only a single application in India?

Xylidine is particularly attractive if you happen to already have a rocket engine specifically engineered for it. Changing fuel can require substantial redesign of a rocket engine, especially injector and nozzle materials and configurations. Furthermore, the state of the art--even until recently in the United States--required extensive trial and error instead of analytic development. The only modifications needed to use the existing SA-2/Devil engine for the longer range Prithvi were to increase the size of the missile body and fuel tanks, which are made of a relatively simple aluminum alloy.[83] The ISRO was willing to make a

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[81] Zaloga, *Soviet Air Defence*, 30, 36.

[82] Willy Ley, *Rockets, Missiles, and Space Travel* (New York: Viking, 1951), 239. See also *Handbook on Guided Missiles of Germany and Japan*, Military Intelligence Division, Department of War, Washington, D.C., 1 February 1946.

[83] Mohammad Iqbal, "Missile Proliferation in South Asia," *Regional Studies* (Spring 1990): 15; Mama, "Progress on India's Tactical Missiles," 963. Even here, the Prithvi was barely able to recruit needed assistance. Hindustan Aeronautics Limited (HAL) "scoffed" at the idea of meeting the necessary quality control requirements. Ultimately, the Bharat Aluminum Company (BALCO) agreed to undertake the project, but only when they were supplied with imported furnaces and other equipment. Banerjie, "The Integrated Guided Missile Development Program," 101.

similar change in the Viking engine supplied by France in design the PS-2, the second stage of the ISRO's PSLV.[84] The Indian development teams thus seem to have adopted the Devil's engine wholesale, not even performing the modifications that would be needed to use a different fuel.

In sum, both the Devil and the Prithvi needed to strengthen whatever links they could in their respective networks, and therefore tied themselves to the relatively stronger facts of existing missiles, rocket engines, and fuels. So xylidine teaches us about the comparatively weak support for the Prithvi project. But note that the use of xylidine is easier only from the developers' perspective. For example, this propellant choice entails substantial costs in terms of toxicity and ease and speed of fueling. In a conflict between users and developers, the Army seems to have less voice in the construction of this technology.[85]

The Prithvi's fuel also teaches just as many lessons by what it is not. Notice that while the Prithvi incorporated the foreign technology of the Soviet SA-2 missile, the Indian Space Research Organization's much more advanced rocket technology is nowhere to be seen.[86] The ISRO's new liquid fuels could only join the Prithvi's design by a substantial engine redesign--an effort that the Prithvi was not

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[84]Compare the data given in A.E. Muthunayagam, "Some Recent Developments In Liquid Propulsion Systems in ISRO," *41st International Astronautical Congress*, Dresden, 6-12 October 1990, IAF Paper #90-241; and Andrew Wilson, ed., *Interavia Space Directory, 1991-92* (Coulsdon: Jane's Information Group, 1991), 246-49.

[85]The lesson that we learn from the technology thus accords with our analysis of decision-making for defense-related research, described above.

[86]For example, S. R. Jain, Rama Rao, and K. N. Murthy, "Studies on the Synergistic Hypergolic Ignition of Hybrid Systems," *Combustion and Flame* 71, nos. 3-4 (March 1988): 233-43; or more generally, A. E. Muthunayagam, "Recent Developments In Liquid Propulsion."

strong enough to carry out alone and an effort in which the space agency had no interest.

Notice also that the Prithvi does not use any of its own organization's new fuels which were specifically developed to recruit new members into the missile alliance. To demonstrate how the choice of fuel here is a political technology, consider some examples of what a truly Indian program, using local technology, might look like. We would expect to see low-cost, indigenously available materials that would preferably increase productivity in the agricultural sector. In fact, we do find exactly that kind of research at the DRDO's Explosives Research and Development Laboratory (ERDL), pursuing objectives that would look completely out of place in a U.S. research program but that make sense in the Indian context. Cashew nut shell liquids and turpentine-based propellants tried to compete directly with xylidine, and would have tied important agricultural sectors to the Prithvi project. Such a mixture was tested for use in engines like the Prithvi's (that is, in hypergolic combination with RFNA in regeneratively cooled engines).[87] But the links evidently could not be forged, and the ancien regime (xylidine) prevailed.

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[87]From scientists at the ERDL, we learn that "hypergolic liquid propellants of specific interest in India are xylidine-triethylamine-red fuming nitric acid (RFNA), hydrazine-RFNA and [UDMH]-N2O4. Fuels like [these], though indigenous and energetic, are costly. In search of a low cost fuel, we found that 3-carene, a major constituent of Indian turpentine, when mixed with cardanol, a distillation product of cashew-nut-shell liquid...exhibited synergistic hypergolic ignition with RFNA as oxidizer." S. P. Panda, et al., "On Performance Evaluation of a New Liquid Propellant," *Defence Science Journal* 36, no. 1 (January 1986): 1-8, 1. Cashew nutshell liquid and turpentine mixtures for use in regeneratively cooled engines is also discussed in P. K. Dutta, G. C. Pant, and B. B. Umap, "Hypergolic Rocket Fuels Based on Turpentine Oil and Cashewnut Shell Liquid," *Journal of Armament Studies* (Journal of the Institute of Armament Technology) 12, no. 2 (1976): 108-17. India's technical defense literature contains an interesting but insignificant minority of such examples of development-oriented technology.

By contrast, researchers at the ISRO's Polymer & Special Chemicals Division at VSSC developed an indigenous solid propellant binder called "polyol." Compounds similar to polyol are usually petroleum derivatives, but the ISRO process uses castor oil, of which India is the world's second largest producer.[88] Polyol's performance was deemed to be comparable to modern Western-developed binders such as HTPB. Emphasizing low cost and domestic availability, polyol won out over more conventional binders in sounding rocket and apogee kick motor applications (though as expected in our model of autistic science, it was not applied in major programs).[89]

Finally, we can see how far xylidine is from development motivations by noting that xylidine was imported until at least 1981, even though it was used in earlier development work, and presumably included in plans for the Prithvi from the beginning of the program. Xylidine is now being produced at the ERDL at Pune. By contrast, the ISRO has developed more advanced fuels and subsequently transferred their production to industry.[90]

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[88]Hormuz Mama, "Launch Vehicle Developments," in "India--The Way Forward," *Spaceflight* (December 1986): 430-35, 433-35.

[89]My original notes on the glowing description of polyol's properties read: "also made in Garden of Eden." See V. N. Krishnamurthy and Solomon Thomas, "ISRO Polyol - The Versatile Binder for Composite Solid Propellants for Launch Vehicles and Missiles," *Defence Science Journal* 37, no. 1 (January 1987): 29-37; and E. Devadoss, "Development of a Polyurethane Binder System Giving a 'Knottable' Composite Solid Propellant," *Defence Science Journal* 35, no. 1 (January 1985): 1-10.

[90]Indian Defense Ministry, *Annual Report 1980-81*, p. 37; *Annual Report 1984-85*, p. 76. UDMH is being produced at Indian Drugs and Pharmaceuticals Ltd. and production of nitrogen tetroxide is already under way at Hindustan Organic Chemical Ltd., Rasayani. Mama, "Launch Vehicle Developments."

We have documented the strong similarities between the Prithvi missile and its predecessor in the control systems, engine, and fuel. Yet the Prithvi is a different missile from the Devil, and in those differences we may find some clues about why it has succeeded where the Devil did not. I have already mentioned some factors: 1) the renascence of liquid fuel technology in India; 2) the vastly strengthened position of the DRDO; and 3) the support of the other missiles in the IGMDP alliance.

Army: Another change is that Prithvi has found a strong outside sponsor, namely the Army. The Devil had already met its demise in the 1970s by the time a roles and missions debate arose between the Army and the Air Force. The Army focuses on strategic threats in close proximity to India's borders, choosing to deploy short-range, ground-based weapons systems. The Air Force proposes a vision of the threat with a vastly expanded sphere of interest, emphasizing power projection and long-range systems.[91] The Prithvi serves the Army well: it provides a means of carrying out some of the missions that the Air Force purports are necessary, yet the Prithvi can remain totally under Army control *as long as it remains simply an extension of artillery*, an incontestably "Army" domain.

A recent article by an Indian Army major on the future of long-range artillery makes this interservice contest clear:

> Future long range surface to surface artillery rockets will extend the land forces' area of influence deep into enemy territory, enabling the artillery to undertake interdiction tasks with more efficiency and a better assurance level than the air force. Rocket warheads carrying Durandel type runway denial munitions will be able to disrupt operations at the enemy's forward and intermediate airfields far more effectively and at a fraction of the cost

[91] See, for example, Thomas, *Indian Security Policy*, 142-43.

> of losing sophisticated modern aircraft. The entire gamut of counter-air operations will have to be reviewed in the near future.[92]

So how does the Army ensure the inclusion of the Prithvi under the rubric of the Army, and artillery in particular? Note first that the director of the Prithvi program is an Army Brigadier General, and that it is constantly identified in the Indian press as a "battlefield support" weapon. Note also the highly unusual public release of firing procedures for the missile, well before it has been fielded: an artillery command center identifies both the target and the appropriate launch site, communicates that information to a missile crew, which under the command center's direction moves into position for launch.[93] As part of the continuum from artillery to the Prithvi, the Indian Army not long ago acquired its first multiple launch rocket system from the Soviet Union (the BM-21, with a range of about 40 km), and has recently begun licensed production of that system at BDL, the same company that is producing the Prithvi.[94] And in a minor but I believe telling note, where else do you see proud claims about the *minimum* range of a

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[92]Maj. Gurmeet Kanwal, "Weapons and Technology," *Indian Defence Review* 2, no. 1 (January 1987): 127-42, 130. This interservice dynamic is not unique to India. During the Thor-Jupiter controversy in the United States, a meeting that included President Eisenhower concluded that:

> The difficulty was that the group of German scientists located at Huntsville desired to get into longer range missiles. The Army's viewpoint was that these missiles were really large mortars and that the Army was therefore going ahead and operating these missile units, even though on a sub rosa basis. He recognizes there is a large service moral problem which involves the entire future ballistic missile mission. (Mr. Wilson further allowed that he had had previous experience with a bunch of inventors.)

Major John S.D. Eisenhower, "Memorandum of Conference with the President, August 16, 1957," 20 August 1957, at National Security Archives, Washington, D.C., Nuclear History Collection, Box 1957.

[93]"India Enters the Missile Age," *Sunday*, 13-19 March 1988, pp. 35-37.

[94]"India Faces Critical Shortage of Soviet Arms," *International Defense Review* 24, no. 12 (December 1991): 1308.

missile (not coincidentally, 40 km)?[95] Prithvi becomes part of a different sort of "seamless web," as the conception of artillery extends out to 250 km.

Conventional warheads: One other feature of the Prithvi reinforces its bonds to the Army's political needs. The Prithvi development program has a strong emphasis on accurate delivery of a variety of advanced *conventional* warheads. Pre-fragmented warheads, cluster munitions, fuel air explosives, and quite possibly terminally-guided RVs have all been proposed, and to some extent tested.[96] In addition, the Prithvi has been able to use guidance systems from ISRO to achieve good accuracies over its relatively short range.[97]

This hardware matches with numerous statements extolling the virtues of "zero CEP" technology, and postulating preposterous accuracies for current superpower missiles (15 to 20 meters for the MX missile, for example).[98] It also

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[95]Singh, "Successful Test of Prithvi Missile Hailed."

[96]"India Enters the Missile Age," 37, lists five different warhead types under development; "Missile Program Upgraded," *The Hindu*, 24 January 1991, p. 9, in JPRS-NEA-91-019, 19 March 1991, p. 52, mentions tests against targets at sea and describes how a "pre-fragmented warhead, containing hundreds of small spherical steel balls has been tested by being dropped from a helicopter in the Pokharan ranges..."; also "Plans for Second IRBM Trial Told, Progress on Prithvi," *The Hindu*, 17 February 1990, p. 9, in JPRS-NEA-90-020, 3 April 1990, p. 60A; and Banerjie, "Integrated Guided Missile Development Programme," 104. On fuel air explosives, see Joshi, "Agni: Importance, Implications," 8; Manoj Joshi, "The Indigenous Effort," *Frontline*, 13-26 April 1991, p. 51; "Defense Ministry Spokesman on Research Projects," *AFP* (Hong Kong), 3 March 1988, in FBIS-NES-88-043, 4 March 1988, pp. 54-55; and Ministry of Defence, *Annual Report, 1980-81* (New Delhi: Government of India, 1981), 64; reports of terminal guidance include *Economist*, 26 March 1988, pp. 31-32; and Edmond Dantes, "Missiles in Gulf Buoy India's Defense Drive," *Defense News*, 2 February 1991, p. 3.

[97]Among other sources marveling at the Prithvi's accuracy, see "Missile Program Upgraded," 52.

[98]Joshi, "Agni: Importance, Implications," 7.

meshes with both the technology and the philosophy of the rest of the IGMDP, permitting the Prithvi to remain integrated with the other members of its alliance, despite its vastly greater range and per unit costs.[99]

Finally, conventional warheads would mostly be targetable against vehicle and personnel concentrations deep inside Pakistan's interior, and might also be useful in strikes against the Pakistani nuclear complex. In both cases, potential Air Force missions are being contested, and the Army's vision of close-range, ground combat is preserved.[100]

Defense as development: Interestingly, the Prithvi does not seem to exhibit traces of the new philosophy of "defense as development." The motor cases, tanks, and so on do not make use of any of the advanced alloys such as the maraging steel M250 developed at MIDHANI for the space program.[101] The guidance elec-

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[99]Unit costs are estimated publicly at more than Rs 1.25 crore ($740,000) per missile. The same article compares the Prithvi to the Rs. 12 crore price tag for an imported Jaguar. "Shooting Ahead: Prithvi's Flight-Trial is Successful," *India Today*, 31 March 1988, p. 170. A later commentary notes that such "sophisticated" missiles "are not only difficult to develop, but also very expensive," citing a 1.7 crore unit cost. "Successful Test of Prithvi Missile Hailed," *Delhi All India Radio General Overseas Service*, 20 July 1991, in FBIS-NES-91-142, 24 July 1991, p. 47.

[100]Despite considerable skepticism among Western analysts, I believe the Indians are serious about deploying conventional warheads for their missiles. The Army's desire to identify missiles as long-range artillery is only one component. Pursuing conventional warheads provides effective cover for those who would really like to see delivery vehicles developed for nuclear weapons, while simultaneously creating alternatives to nuclear weapons for those opposed to them. In addition, if India has not yet succeeded in packaging nuclear warheads into missile-sized payloads, then missiles with conventional warheads would still carry many of the same benefits within the context of India's option strategy. Finally, conventional warheads seem believable to me because of the substantial effort being expended on achieving missile accuracies that would be irrelevant given nuclear payloads.

[101]See Mama, "Launch Vehicle Developments," 433; and T. Chelladurai, A.R. Acharya, and R. Krishnamurthy, "An Approach for the Integrity Assessment of M250 Maraging Steel Pressurised Systems," *Journal of Acoustic Emission* 8, no. 1 (January-June 1989): S88-S92.

tronics are taken wholesale from the space program.[102] The fuel remains unchanged from the SA-2. On the other hand, the Prithvi would not be possible absent the broader effects of development thinking in the defense sector. The strength of the DRDO, the existence of IGMDP, and the alliance with BDL are all attributable in large part to their potential contributions to development, self-reliance, and technological autonomy for India as a whole. This sector-wide evolution, in turn, enables the Prithvi to succeed where the Devil could not.

The Agni Missile

Like the Prithvi, the Agni has generated support by building on existing work. But unlike the Prithvi, the Agni is a hybrid: It is both a liquid and a solid fueled missile; it is constructed out of both the missile and space programs; it depends on developments from both military and civilian organizations; it is both a technology demonstrator and an IRBM, both a nuclear and non-nuclear artifact. And it carries the physical traces of its coalition nature.

SLV stage: The first stage of the missile is an essentially unchanged first stage of the SLV-3. Practically mass-produced, this workhorse of the Indian programs has found application so far in the SLV-3, the ASLV, and the PSLV, as well as the Agni. As has been often pointed out, the Director of the IGMDP is the former

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[102]Compare "Missile Program Upgraded" and "Prithvi," in *Jane's Strategic Weapon Systems*, with the detailed description of ISRO guidance systems given in S.C. Gupta and B.N. Suresh, "Development of Navigation Guidance and Control Technology for Indian Launch Vehicles," in *Developments in Fluid Mechanics and Space Technology*, 343-57.

Director of the SLV program, which was winding down at about the same time as the inception of the IGMDP.[103]

Prithvi stage: The second stage of the missile is a version of the Prithvi, with a few differences. First, the nozzle exit ratio has been increased for better efficiency during vacuum flight, a simple modification.[104] Second, the photographs of the Agni show that the mid-body aerodynamic stabilizers have been removed, as they would be ineffective in a vacuum, along with a smaller set of movable control fins located at the base of the Prithvi (see Fig. 8). For some reason, the Prithvi design uses both aerodynamic and thrust vector control (probably another trace from its days as a high altitude SAM), so removing this second set of fins still leaves gimballed engines to control the second stage of the Agni, though presumably at the price of some precision. This modification might indicate that the optimal performance of the current configuration of the Agni is not a major concern, as might be expected of a "technology demonstrator."

The other major modification to the Prithvi stage supports this interpretation. Although the engine remains the same (and weighs the same) as for the Prithvi, the stage is substantially shortened. The result is a much lower mass fraction, that is, a less efficient booster. However, a shortened stage is the only design that does not require major changes to the SLV stage, and more significantly, the only design that preserves a 1000 kg payload. A longer second

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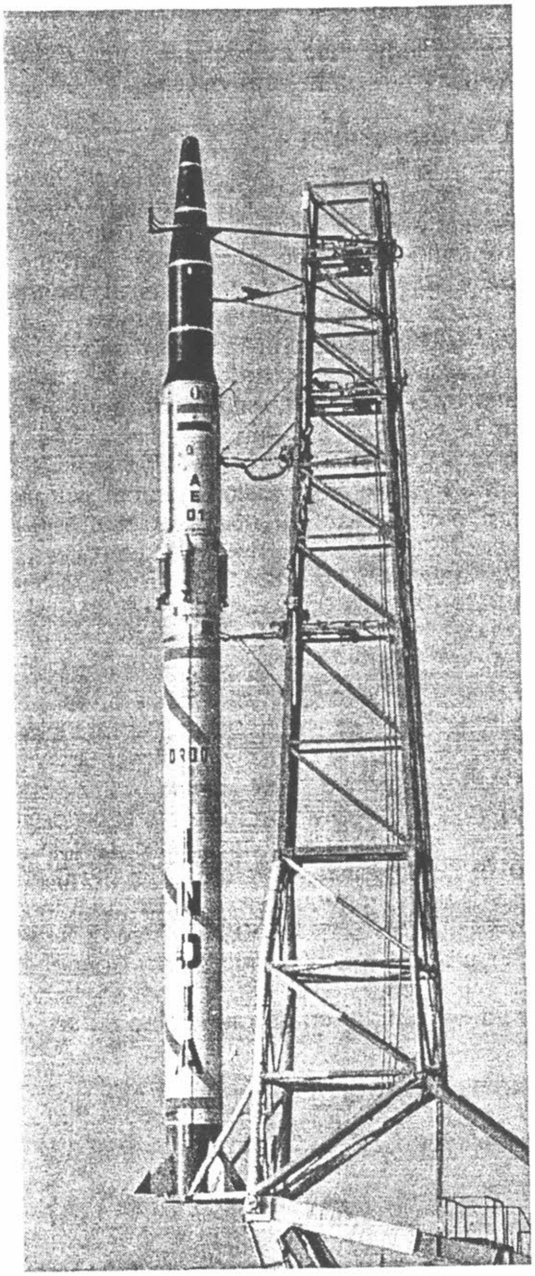
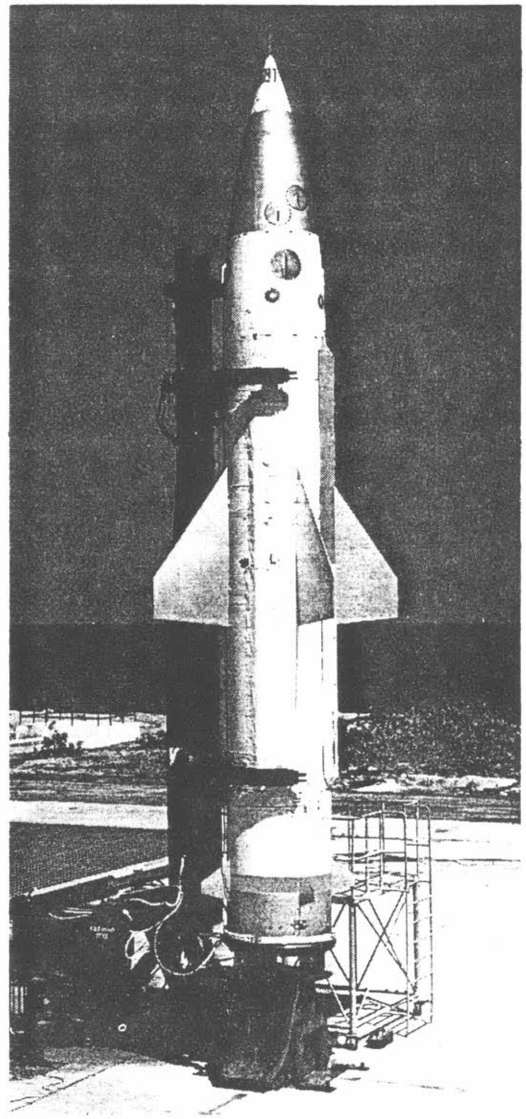
[103] Reported, with an almost conspiratorial tone, in Milhollin, "India's Missiles," 32.

[104] As described by R. N. Agarwal, the project director for the Agni, in Agarwal, "Emphasis Was on Re-entry Technology," *Frontline*, 10-23 June 1989, pp. 14-15.



The Agni intermediate-range ballistic missile, in its launch stand



Prithvi SRBM mounted on a launch platform prior to launch in February 1988

Comparing Agni and the Prithvi

Figure 8

stage might require a smaller payload, but would be more efficient, providing more bang for the buck.

Why is ensuring a 1000 kg payload so important? Perhaps because the smallest nuclear warhead the Indians have managed to design would weigh 1000 kg. But if the Agni is not going to be mass-produced, and is only intended as a technology test-bed, why bother to preserve a 1000 kg payload, unless perhaps you were testing the nuclear warhead along with it? On the other hand, if the technology being demonstrated is RV technology, and the experimental RV design requires a 1000 kg payload, then the sub-optimal missile configuration makes sense.

RV technology: Numerous Indian statements do claim that RV technology is the primary focus of the Agni missile.[105] The Director of the Agni program's technical background is in re-entry technology.[106] The lofted trajectory of the first Agni test reinforces the same point. Although the missile test demonstrated a significantly shorter range than a minimum-energy trajectory would have, it also permitted a better test of heatshield during re-entry.[107]

So if RV technology is the focus, what do the details of this technology's construction reveal about the program's political motivations? First, the RV heatshield uses fairly advanced carbon-carbon composites. The use of carbon-carbon

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[105]For example, "Scientist on December Launch," *Delhi Domestic Service*, 27 May 1989, in JPRS-TAC-89-023, 6 June 1989, p. 29.

[106]Agarwal, "Emphasis Was on Re-entry," 14.

[107]Described in "Plans for Second IRBM Trial Told, Progress on Prithvi," *The Hindu*, 17 February 1990, p. 9, in FBIS-NEA-90-020, 3 April 1990, p. 60A.

preforms does seem to be a new development in India, since earlier it was explicitly rejected as being too advanced for use in the space program.[108] While such materials are clearly effective for providing a payload with thermal protection, they also appear to be effective for providing political protection as well. DRDO scientists are conducting the relevant materials research at the new RCI facility described above, where:

> The nucleus of a joint sector production facility is taking shape. Comproc--composites production facility--will provide industrialists the infrastructure to work in the exciting new areas of advanced composites, such as 'carbon-carbon'...[and] carbon and glass fibres.[109]

The RCI facility thus uses this "technology of the future" to bind the Agni RV program to the rest of the IGMDP and to the much broader constituency of Indian high-tech industry.[110]

A second important component of the RV program is the terminal guidance system. Using purely inertial sensors (i.e., with no external information), the Agni RV corrects its trajectory for accumulated errors, particularly re-entry dispersion and perhaps thrust termination errors.[111] Although details are scanty, I

108See A. Rajamohan, H. S. R. Iyengar, and N. M. Mathulla, "Application of Random Fibre Moulded Carbon Phenolics in Rocket Nozzles," in *35th International SAMPE Symposium and Exhibition*, 2-5 April 1990 (Anaheim, Calif.: Society for the Advancement of Material and Process Engineering, 1990), Book 2, 1363-71.

109Parthasarathy, "Firm Purpose," 13.

110"Official Briefs on Missile Deployment Program," *Patriot*, 10 August 1991, p. 1, in FBIS-NES-91-160, 19 August 1991, pp. 58-59.

111The Agni RV is described in Agarwal, "Emphasis Was on Re-entry Technology"; and Arunachalam, "Major Weakness Is in Components."

believe the Indians use a two- or three-axis reaction control system (RCS) borrowed from ISRO.[112]

This description is pieced together from fragmentary information in a number of sources, mostly by asking which already developed components might be suitable for the Agni RV. ISRO has worked on a wide range of thrusters, up to 30 KN of thrust.[113] The first stage of the PSLV launcher, for example, has RCS thrusters of up to 6 KN thrust, but they are powered by hot gas from the main engine which would not be available during re-entry.[114] The Agni might instead be borrowing from the SLV-3 or ASLV RCS, which used monopropellant thrusters from 10 to 500N. But in attempting to use catalytic decomposition of hydrazine, "a major problem was encountered in that the catalyst bed got degraded by trace impurities of copper...in the hexachloroiridic acid which was used as the raw material to deposit iridium on aluminium granules."[115]

Though heavier, bipropellant thrusters seem a more likely option. For example, the 2.5 KN bipropellant thrusters (RFNA and H2N4) that were used for the

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[112]However, Banerjie, "The Integrated Guided Missile Development Programme," 106, claims that after borrowing rockets from the SLV and Prithvi, "Agni's designers have only had to design small thrust control motors for keeping the missile stable during its terminal phase," implying that DRDO scientists did the development themselves.

[113]A. E. Muthunayagam with assistance from K. Ramamurthi, "Development of Liquid Propulsion Systems in ISRO," *39th Congress of the International Aeronautics Federation*, Bangalore, 8-15 October 1988, IAF Paper #88-224.

[114]E. Janardhana, "Polar Satellite Launch Vehicle (PSLV) Development Programme in India," *15th International Symposium of Space Technology and Science*, vol. 2 (Tokyo: AGNE Publishing, 1986), 1425-30.

[115]Muthunayagam, "Development of Liquid Propulsion Systems in ISRO."

SLV were qualified for over 23 seconds of cumulative firing, and were stored in stainless steel tanks pressurized at 3000 psi with nitrogen gas.[116] Similarly, for the second stage of the PSLV, the RCS for pitch and yaw uses 2.5 KN RFNA and hydrazine thrusters, pressurized by 3000 psi N2 stainless steel bottles. These thrusters are relatively mature, not using any advanced materials or technologies, yet the space program would still be looking for opportunities for testing them before the first PSLV launch.[117] Assuming a 1000 kg RV, they also provide a 1:4 thrust to weight ratio, capable of imparting a one meter per second change in velocity in 0.4 seconds even without aerodynamic effects.

I thus conclude that the Agni missile is still more hybridized, having adapted (or adopted) 2.5 KN nitrogen pressurized bipropellant hydrazine and RFNA thrusters from the ISRO's PSLV launcher. By imparting a small angle of attack to the RV, the RCS can generate aerodynamic lift to execute larger desired trajectory corrections.[118]

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[116]Gangadhar De, M. Narendranath, and B. K. Sarkar, "Erosion of Nozzle Throat Inserts and Silica-Phenolic Ablative Liner Morphology," *Journal of Propulsion* 6, no. 1 (January-February 1990): 46-49.

[117]Muthunayagam, "Development of Liquid Propulsion Systems in ISRO." The thrusters for roll control are only 100 N. This system is similar to the N2-pressurized RCS and stage separation system for adapting the Polaris A-3 missile to space launch applications. Norman Grizzell, "Application of Fleet Ballistic Missile Components/Designs for Expendable Launch Vehicles," in *AIAA/DARPA Meeting on Lightweight Satellite Systems*, Monterey, Calif., 4-6 August 1987 (Washington, D.C.: American Institute of Aeronautics and Astronautics, 1988), 255-63.

[118]Some small confirmatory details, such as the detection of a nitrogen leak that delayed the first Agni launch, are found in "Launching of Agni Put Off Again," *Strategic Digest* (July 1989): 907; K.S. Jayaraman, "Commentary on Agni Launch," *Delhi General Overseas Service*, 23 May 1989, in FBIS-NEA-89-099, 24 May 1989, p. 53; and "India: Missile Technology State of the Art," *The Hindu*, 23 February 1991, p. 3, in JPRS-NEA-91-024, 22 April 1991, p. 46B.

If this description of the system is correct, it has some interesting features. First, it is easily capable of correcting for thrust termination errors--yet one of the reasons cited for using the liquid Prithvi stage on the Agni is to avoid the difficulty of thrust termination on solid stages. Second, it is not capable of carrying out the extreme maneuvers that a radar-mapping terminally-guided RV, for example, would require. In other words, it cannot really search for a target.

Finally, using this system for terminal maneuvering eliminates the possibility of spinning the RV, which in turn means that any ablative surfaces would lead to massive re-entry errors. Correspondingly, there do not seem to be any ablative materials used (even though Indian scientists have substantial experience in using ablative material in rocket nozzles). Instead, the RV relies entirely on its carbon-carbon heatshield, which is claimed to withstand up to 5000C.[119] The reliance on a heatshield is confirmed by the lofted trajectory used for the first test. For an ablative RV, the more severe test would have been total heat dissipated over a longer trajectory, while for a straight heatshield, the more severe test is the peak heat withstood during a higher speed, higher angle of incidence re-entry. For ablative surfaces, flying the missile at a longer range would simply require a thicker layer of ablative material. But the heatshield design is inherently range-limited.[120] Without carrying out any calculations, I would be surprised if the

[119]Agarwal, "Emphasis Was on Re-entry." The three meter heat shield was "made of carbon composite materials, fitted to the reentry vehicle," with a dummy "payload" of tungsten. Tungsten may also have served as the RV's heat sink, with a melting point of 3410C. Data from Agni's first test indicate that the surface reached 3000 degrees. "Official Briefs on Missile Deployment Program," *Patriot*, 10 August 1991, p. 1, in FBIS-NES-91-160, 19 August 1991, pp. 58-59. See also "India Joins a Private Circle," *Aerospace America* (November 1989): 6-8.

[120]Heatshield range limitations for the Agni find their parallel with the U.S. Poseidon missile. The Mk3 warhead from the Poseidon C3 could not be used on longer range Trident C4, "since it seemed that the heatsink design would be unsuitable for some trajectories at the longer ranges considered for C4." The Poseidon re-entry vehicle combined a beryllium heatshield with a graphite nose-tip. Graham Spinardi, "Why the U.S. Navy Went for Hard-Target Counterforce in Trident II (And Why It Didn't Get There Sooner)," *International Security* 15, no. 2 (Fall 1990): 147-90, 170.

Indians could extend their missiles' range by as much as a factor of two, given the current design concept.[121]

In sum, the terminal guidance of the Agni RV, which was a major focus of the entire Agni undertaking, has inherent range limitations; cannot search for a target; and corrects for an error that is not present in the Agni system. Just like the Agni propulsion systems, I believe this RV is a hybrid. Parts of the technology would make sense for a highly accurate conventional warhead on the Prithvi, fitting into the Army's political and strategic goals. Other parts of the technology would fit well with a long-range nuclear-armed strategic missile, as part of the option strategy. Still other aspects provide a boost for technological development in India, thereby providing a boost of political support for the missile program. The alliance of objectives that we see in Agni RV design, as with the Agni as a whole, simply does not make sense as part of a mass-produced, deployable missile system.

Test program: Consistent with this conclusion that Agni is not intended for production or deployment, the test program has so far consisted of only two tests.[122]

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[121] On re-entry physics and on ablative surfaces, see Matthew Bunn, "Technology of Ballistic Missiles Reentry Vehicles," in Kosta Tsipis and Penny Janeway, eds., *Review of U.S. Military Research and Development: 1984* (Washington, D.C.: Pergamon-Brassey's, 1984), 67-116; Frank Regan, *Reentry Vehicle Dynamics* (New York: AIAA, 1984); and TRW Systems Group, *ABRES Flight Test Evaluation of RV Accuracy* (Los Angeles: Space and Missile Systems Organization, Air Force Systems Command, September 1974).

[122] The first test appeared to be successful, the second less so. "Agni Missile Fails to Execute Final Maneuvers," *Delhi All India Radio Network*, 30 May 1992, in FBIS-NES-92-105, 1 June 1992, p. 48.

The program was, I believe, conceived after the other components of the IGMDP, and was funded well below the level of any of the other missiles in the program (only about 5% out of the Rs. 780 crore IGMDP budget).[123] A maximum of only three tests were ever planned (something of a canonical number in Indian testing philosophy).[124]

Numerous commentators have urged the government to carry out more tests, or even to begin production. Yet no additional tests have occurred. Perhaps U.S. and Western pressure has been sufficient to discourage further tests, particularly by denying any additional PBAN for the fuel or gyroscopes for the guidance system, though both should be produced by Indian sources soon.[125] Or perhaps the proponents of a limited option strategy are satisfied (though generally one

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[123]Rs. 30 crores for 1983-1992, according to "Plans for Second IRBM Test," 9; Rs. 37 crores according to Joshi, "Agni: Importance, Implications."

[124]"Missile Program Upgraded," 9.

[125]On U.S. technology denial strategies for ballistic missiles, see David Ottaway, "U.S. to Bar India's Buying Missile Device," *Washington Post*, 17 July 1989, p. 12; K. Santhanam, "Indian Defence Technology Infrastructure and Prospects of Indo-US Cooperation," presented at the Indo-US Defense Workshop, National Defense University, Washington D.C., 19-21 September 1989, esp. 13-16; Manoj Joshi, "Commentary on Missile Technology Control Regime," *Hindu*, 3 November 1988, p. 8, in JPRS-TAC-89-002, 19 January 1989, pp. 9-11; and K. Subrahmanyam, "Benefits of Continued Missile Development See; U.S. Attitude Hit," *Times of India*, 31 January 1989, p. 14, in JPRS-TAC-89-012, 22 March 1989, pp. 35-36. On the other hand, U.S. firms have continued to export relevant technologies. "Indian Fighter To Use Ring-Laser Gyro," *Defense Daily*, 11 April 1988, p. 235, describes the U.S. Department of Defense approving a ring-laser gyro transfer to the Indian Light Combat Aircraft program; "Development of Polar Satellite Launch Vehicle Told," *Hindu*, 25 August 1989, p. 7, in JPRS-NEA-89-064, 27 September 1989, pp. 44-45, described the PBAN binder for the ASLV first stage motor, "which had been procured from a U.S. firm, Arco Inc." Similarly, magnesium powder and other chemicals for propellant research were supplied by a U.S. multinational corporation through its Indian subsidiary. R. S. Jain, K. N. Murthy, and B. C. Thanoo, "Ignition Delay Studies on Hypergolic Fuel Grains," *Defence Science Journal* 38, no. 3 (July 1988): 273-86.

would expect a successful test to be a useful ally for more tests or an expanded program). But whether or not the remaining test in the series is actually carried out, I believe that this deconstruction of the Agni has demonstrated that mass-production for military use has never been intended for this system.

V. Conclusions

When first looking at these Indian programs, I did not know the specific stories presented here. But I did have an objective and a set of methods. I wanted to understand the politics of missile technology--the why and the wherefore, integrated across the strata of the political process, from broad national themes to internal bureaucratic contests. And I wanted that why and wherefore to grow out of the sociology of technology--an approach that avoids the two extremes that I often find in the literature: on the one hand, treating technology as an exogenous variable, unproblematically provided by Nature when the time is somehow ripe; and on the other hand, I wanted to avoid deconstructing technology into its most basic political and social components--which is sometimes a useful endeavor, but often a disconnected intellectual exercise.

What I have tried to do instead of deconstructing these technological systems, is to reconstruct them--that is, not stopping with the demonstration that technology can be viewed as congealed culture, but to use that understanding to gain a useful view of a particular political culture in operation, to understand the politics of the Indian missile and space programs through those programs' technological artifacts.

We can conclude, for example, that Indian space launch vehicles, though they are in some abstract sense "the same" as missiles, grow out of a completely different context and are not going to be transplanted somehow into the clutches of the Indian military. The Agni missile is a hybrid, RV technology test bed, a weak political alliance that is only as strong as the interstage between its SLV and Prithvi rockets. The Prithvi missile, which is far more likely to become a deployed, mass-produced system, has had its political essence defined by its relationships to the Army, to long-range artillery, and therefore by necessity, to conventional, non-nuclear warheads. These conclusions make the Indian space and missile programs far less problematic from the perspective of U.S. policy. While it is feasible for traditional political analyses to reach these same conclusions, most analyses seem to wind up being far off the mark instead.

What does the future hold for the Indian space and missile programs? Will these technological systems hold together? The space program in India seems supported, as a space program per se, by a broad national consensus. Assuming the ISRO continues to satisfice its main constituencies, I see no basis for a shift in that consensus. Continued launch vehicle failures could have a negative effect--in fact, all the concerned parties might be happier if the ISRO's launchers avoided more failures by just staying in perpetual development, despite the cost of contracting for outside launch services.[126] The one interest that might desert the space coalition is the "option strategy." If the DRDO develops long-range

[126]These failures in the Indian space (and missile) programs exhibit some of the features typical of high-tech Indian programs. One frequently sees in India a cycle of incomplete indigenization of weapons systems, followed by expensive imports; projects slipping far behind their planned schedules, or not working at all, and finally being canceled. This pattern does not contradict the fact that India has some of the best scientists and engineers in the world, and does sometimes turn out quite advanced pieces of technology.

ballistic missiles, then space launch vehicles would no longer serve as surrogates for nuclear delivery vehicles. But so far, the signs of competition between ISRO and DRDO are very weak.

For ballistic missiles, no production is planned for the Agni. We may not even see more tests. Prithvi has much stronger history and allies, though it shows enough traces of that history to question the strength of its independent support. If the Prithvi were integrated into the Army and into BDL, it could do well in terms of the numbers produced. On the other hand, I see no clear direction for any Prithvi follow-on.

As for future plans for other ballistic missiles in India, the RV technology from the Agni is clearly a solution in search of a problem.[127] Prithvi may satisfy its need for an ally. But the two Agni tests so far may have satisfied some of the crucial members of its political alliance, such as the option strategy or international position. After all, the single nuclear test at Pokharan seems to have kept nuclear alliance members sufficiently satisfied, at least in terms of further testing, since 1974. In that sense, the Indian missile program may already be as much of a success as it needs to be.

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[127]One report states that the heat shield was "developed by the defense scientists quite some time ago and was being tested for the first time by Agni." Jayaraman, "Commentary on Agni."

CHAPTER FOUR

Israeli Military R&D: Technology's Battles

(or, Two Missiles, Three Opinions)

I. Introduction

The story of the birth of the Israeli military-industrial-technological (MIT) complex is the struggle of a small, brave band to acquire military capability in the face of a hostile environment. But the intrepid heroes were the leaders of the three leading Israeli defense industries, and the opposition with which they had to contend often consisted of the military services, the Ministry of Defense, and the extremely limited economic resources of the Israeli state. Those indigenous weapons systems which survived into the light of day bear birthmarks as the offspring of this struggle.

In the previous two cases, the analysis focused on a small number of complex artifacts, such as the VLS or the Agni, reading the social and political context out of these pieces of congealed culture. In the Israeli case, the basic question remains the same: Why did Israelis build the missiles they did? Unfortunately, the same kind of detailed technical information is not yet available for the analogous artifacts in this case, the Jericho long-range ballistic missiles and the Shavit space launch vehicle. Instead, this analysis looks more broadly at the system for producing missile technology in Israel; that is, it reifies the LTS that produces missiles, treating it as an artifact itself.

According to the social construction of technology (SCOT), there should be no theoretical difference between an individual artifact and a well-described large-scale technological system. Both are a product of their social and political context; both are capable of playing the role of an actor; both have the same obduracy; and both have the same coagulated dependence on history, through the static artifacts they have incorporated as components and through the political compromises they have accumulated.

Therefore, by ascending to a higher level of analysis, we should still be able to shed light from the new vantage point, in both directions. Examining the Israeli MIT should clarify the social and political context of its formation and evolution; examining the system for producing missile technology should illuminate the patterns and characteristics of existing Israeli weapons. At the same time, we can continue to deconstruct individual artifacts when the detail of available information permits it.

Theoretically, one of the implications of looking at a whole system is to create a natural meeting ground for the sociology of technology and the bureaucratic politics paradigm. The move from artifacts to systems, while using SCOT techniques, is in large measure equivalent to the move from government bureaucracies to technological systems, while using bureaucratic politics techniques. As discussed in the first chapter, the sociology of technology is more consistent with the bureaucratic politics paradigm than the practice of bureaucratic politics studies has been. As SCOT takes on the traditional territory of bureaucratic politics, we are merely extending the reach of the analysis to an area--technology--that had been previously taken as exogenous and unproblematic. Again, SCOT retains its distinctive view of technologies and artifacts as actors, and its interpretive bent.

This chapter also differs in its research methodology. It necessarily relies less on published information because of the strict military censorship in Israel (including on the scientific publications that provided much of the information in the previous chapters). Fortunately, a research grant enabled me to travel to Israel and conduct dozens of interviews with people involved in developing military technology, from working-level scientists to the heads of industries. As expected, classification constraints remained a major problem, but did not prevent gathering enough information for this preliminary study.

Unfortunately, out of all of these interviews I am only able to identify a few academics and journalists. The others are quoted anonymously and identified only generally. Note that the identifications do not correlate with specific individuals; thus someone who is identified as "an industrialist" for one quotation may be identified as "a leading industrialist" or "a long-time defense researcher" for other quotations, depending on the context. For more information, please contact the author.

This analysis examines the overall Israeli system for developing missile technologies, delimited across three variables: time, weapons systems, and actors. First, it concentrates on about a twenty year period from the late 1950s through the mid-1970s. In this early period, the military services and the Ministry of Defense were remarkably passive (as they remain in some ways even today). This focus permits us to draw clearer system boundaries--the defense industries are the primary system-builders, while the IDF and the MoD are more akin to an external environment.

The balance between the defense industries and the government bureaucracies shifts after the Yom Kippur War, as other actors sought and acquired the expertise to open the industry's black boxes. At the same time, the bureaucratic battleground shifted. Acquiring high-tech systems became the baseline assumption. The competition moved toward choices about which high-tech systems to acquire and what their characteristics would be. (The battleground with the Arab states also shifted toward the high-tech, but that may have had less impact). The bureaucracy now generates requirements and analyses that are less dependent on the defense industries and that reflect other priorities. Furthermore, the industry's successes have convinced most actors that Israeli industry can do whatever is needed, given enough money. Despite such changes, many features of this analysis carry over into later periods and up to the present day.

The second limitation of this study is its focus on missile technologies. The conclusions may well apply to other systems, such as combat aircraft or main battle tanks, but data from such systems are not included. Mostly due to the vagaries of data collection, the analysis that follows also gives short shrift to air-to-ground, anti-tank, and anti-ballistic missile missiles.

Finally, three defense industries receive the main spotlight, to the exclusion of other important actors: the Armaments Development Authority (Rafael), Israel Aircraft Industries (IAI), and Israel Military Industries (IMI, or Ta'as). Rafael, IAI, and Ta'as are all state-owned and to some extent state-controlled (or state-controlling).[1] They account for the bulk of the military technologies

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[1]On Rafael, see Munyah Mardor, *Rafael: be-Nitive ha-Mehkar v'ha-Pituah le-Bithon Yisra'el* (Tel Aviv: Ministry of Defence, 1981); on Ta'as, see Yosef Evron, *Magen ve-Romah: Sifriyah shel ha-Ta'asiyah ha-Tzvi'it be-Yisra'el* [Shield and Spear: The Story of Israel Military Industries] (Tel Aviv: Ministry of Defence, 1992). Unfortunately, no single work covers the history of IAI in similar depth. For a journalistic account of the early history, see Arnold Sherman, *Lightning in the Skies: The Story of Israel Aircraft Industries* (London: Stone, 1973). On all three industries, see Yosef Evron, *Ha-Ta'asiyah ha-Bithonit be-Yisra'el* (Tel Aviv: Ministry of Defence, 1980). The in-house journals for all three industries as well as parts of the IDF or the Ministry of Defence give a good flavor for the concerns, working environment, and overall perspective of these actors. See the various issues of *B'Ta'as* (which unfortunately ceased publication about 15 years ago), and the quarterly Rafael journal *Hazit ha-Yed'ah* [Frontlines of Knowledge]; see also *Romah* [Spear], *Be-Ya'af* [Flight], *Hel ha-Avir* [Air Force], *Ma'arahot* [Battles], and the English language *IDF Journal*. The best overall account in English of the development of the industries is Stewart Reiser, *The Israeli Arms Industry: Foreign Policy, Arms Transfers and Military Doctrine of a Small State* (New York: Homes & Meier, 1989); see also Shimon Peres, *David's Sling* (London: Weidenfeld and Nicolson, 1970). For a good picture of the current situation of the defense sector, see Aharon Klieman and Reuven Pedatzur, *Rearming Israel: Defense Procurement through the 1990s*, Jaffee Center for Strategic Studies Study No. 17 (Jerusalem: Jerusalem Post Press, 1991). Unless otherwise stated, translations are my own. My thanks to Aryeh Cohen and Thomas Bernauer for assistance with transla-

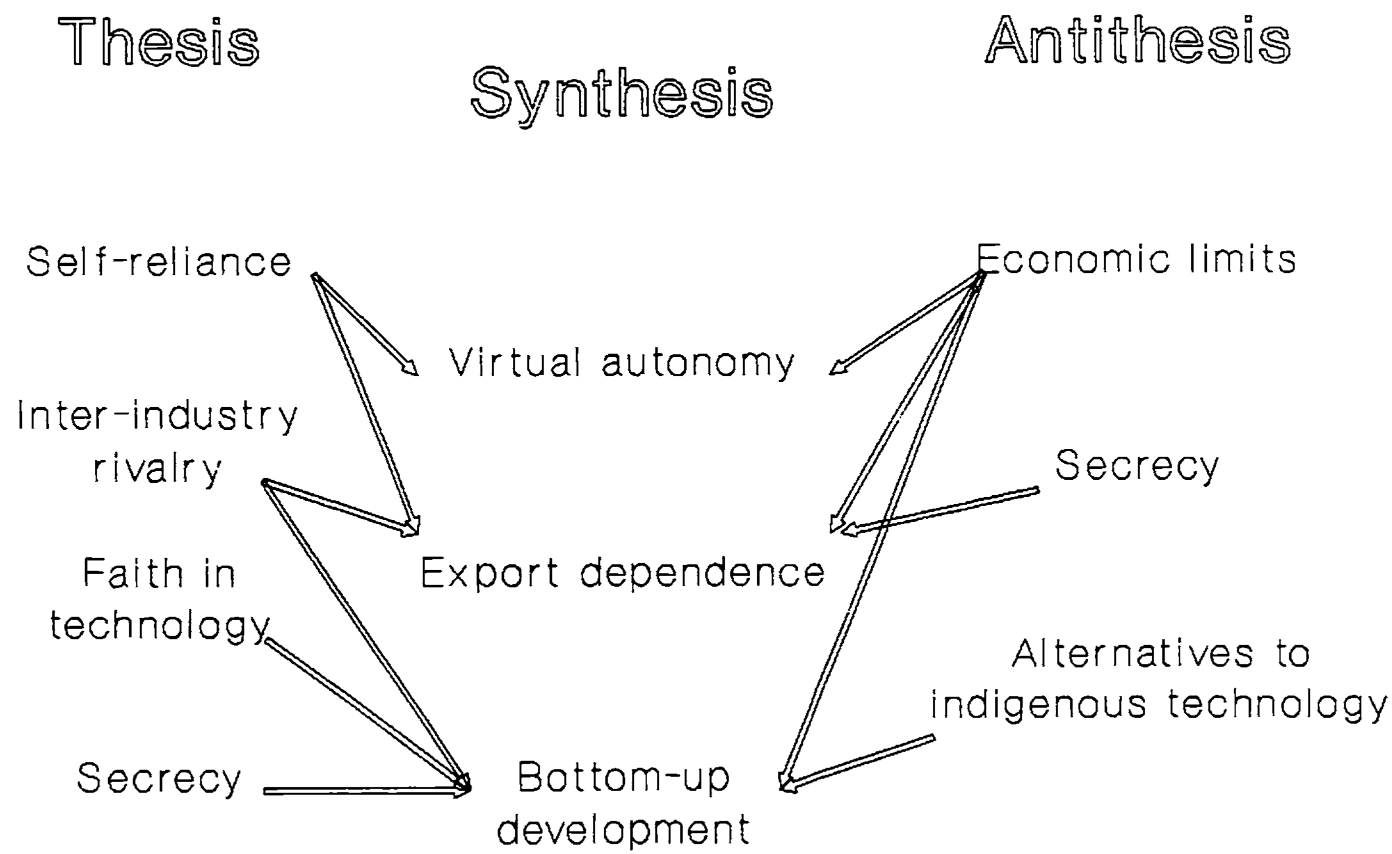
developed in Israel, and both personnel and data from each are relatively accessible. The analysis does consider the Ministry of Defense and its slowly evolving R&D offices (such as Office of the Chief Scientist of the Ministry of Defense), but they are less relevant during the period in question. The military services (the Army, Air Force, and Navy) also have their influence, individually (in their choices for providing development funding), competitively (through interservice rivalry), and collectively (mostly in the person of each new Chief of Staff and his entourage).[2] But the main characters that the reader needs to recognize in the stories that follow are Rafael, IAI, and Ta'as.

II. Thesis: Forces Promoting the Development of Military Technology

Four forces in the Israeli political system promote the development of new weapons systems and new military technology: self-reliance, inter-industry rivalry, faith in technology, and secrecy (see Fig. 1). These forces are structural, in the sense that their power spans more than the single issue of security, and in the sense that they are not likely to change quickly as a result of events only in the arena of security. Nonetheless, they are the product of the same sort of contingent historical evolution as any other strand of this story, and are thus subject to change, reinterpretation and subversion. The ways in which they promote the

tions from Hebrew and French, respectively.

[2]For a good overview of the current structure of the MoD and the IDF, see Klieman and Pedatzur, *Rearming Israel*, 106-24. Their description is particularly useful for understanding who controls what portions of the decision-making processes. Unfortunately for our purposes, they do not focus on the R&D establishment.



Contesting the Development of Military Technologies

Figure 1

development of military technology vary considerably, and they only have such an effect in the aggregate.

Self-reliance

The theme of self-reliance is a common one for any state, and has already been treated in the chapters on Brazil and India. In Israel, the historical experience of the state and its population reinforces the desire to avoid dependence on any outside power to ensure the survival of the state. The ways in which this independence is to be achieved in the Israeli context fall into three broad categories: economic strength; indigenous capability for military production; and a sound scientific and technological work force.

Boycotts and Embargoes: The most direct justification for self-reliance in military production is the past history of Israeli attempts to obtain arms from foreign producers. From the clandestine beginnings of the pre-independence Israeli army, to the French embargo after the Six-Day War, through the constant minor tussles over U.S. arms that continue today, Israelis have come to believe that they should depend on no one other than themselves to provide the arms they need.[3] Israelis

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[3]The founders of the state acquired their taste for self-reliance through Israel's remarkable accomplishments in obtaining weaponry during the War of Independence. See Ze'ev Schiff, *A History of the Israeli Army: 1874 to the Present* (New York: Macmillan, 1985), 21-45. Israel's difficulties in acquiring a main battle tank represent the broader problem. For example, for the Chieftain tank, a British contract was canceled in 1969 just days before its expected signing. Reiser, *Israeli Arms Industry*, 48. For the manipulation of American arms sales, see Nitza Nachmias, *Transfer of Arms, Leverage, and Peace in the Middle East* (New York: Greenwood, 1988); and David Pollock, *The Politics of Pressure: American Arms and Israeli Policy Since the Six Day War* (Westport, Conn.: Greenwood, 1982).

who favor a policy of self-reliance in arms production use these stories of international persecution as a valued political ally, and they have become part of the core mythology of Israeli defense philosophy.

Shimon Peres's selective account of the development of Israeli defense industries, written by one of the industries' chief architects, is still the most compelling account of this perspective. As he puts it, "What water is to agriculture, armaments are to security. Israel suffers from a shortage of both." From the war of independence, "Israel had to face the invaders alone, and with her hands tied by an arms embargo; the invaders already enjoyed a preponderance of arms, and could get virtually unlimited additional supplies....Beleaguered Israel had the utmost difficulty in securing even simple rifles, to say nothing of tanks and planes."[4]

As we saw in the cases of Brazil and India, some Israelis are quite explicit in their acknowledgement of the benefits that Israeli defense industries have received from boycotts and embargoes, saying "It did us a lot of good." Similarly, the title of an article on the formation of Israeli industries for producing missiles

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[4]Peres, *David's Sling*, 31, 32. As noted in Chapter 3, I use the term "mythology" in accordance with the modern anthropological usage of "narrative," denoting the historical stories which actors repeat to themselves and others in the process of sustaining and promulgating a world view. See Edward Bruner, ed., *Text, Play, and Story: The Construction and Reconstruction of Self and Society*, 1983 Proceedings of the American Ethnological Society, Stuart Plattner, proceedings ed. (Washington, D.C.: American Ethnological Society, 1984). By "mythology," I do not mean to imply that the history of boycotts and embargoes is somehow false or unimportant. See Roland Barthes, *Mythologies*, Annette Lavers, ed. and trans. (New York: Noonday Press, 1972). On the clash of coexistent narratives, see Jean-Francois Lyotard, *The Postmodern Condition: A Report on Knowledge*, Geoff Bennington and Brian Massumi, trans. (Minneapolis: University of Minnesota Press, 1984). On the durability and flexibility of such narratives, see Hugh Gusterson, "Endless Escalation: The Cold War as Postmodern Narrative," *Tikkun* 6, no. 5 (September-October 1991): 45-49.

is "Thanks to De Gaulle."[5] These stories are told not only to buttress arguments for self-reliance before Israeli audiences; by recounting such tales of Israeli resourcefulness, one can lessen the need to replicate them. As one industrialist recounted:

> [The] people developing air-to-air missiles were like the...[Israeli Army, asking,] "Why should we develop [IR detectors] ourselves? We'll buy them from Westinghouse."
>
> We bought them from Westinghouse--the first ten. Then another ten. But when we ordered fifty: "Oh, what do you need fifty for?"
>
> [We answered,] "For our research."
>
> "What kind of research?"
>
> "No, we [can't tell you]...sorry." The Americans stopped delivery. OK, if they don't give it, we'll do it ourselves. After two years or so, we did. Then the Americans say, "Hey, what's going on? We can deliver [IR detectors to] you, why you have to do it yourselves?"
>
> [We tell them,] "No, now it's too late. We do it ourselves. We can sell it to you--it's cheaper!"
>
> Every American general that visit our institute--and there were many--we tell the same story: "You cut off our supply of detectors, or anything, and you cut your own throat. It's no use."

Despite the apparent clarity of the requirements for self-reliance, the concept is really quite flexible. As we will discuss below, "indigenously produced" weapons systems can nonetheless include major foreign-supplied components (such as aircraft engines). Conversely, the requirements can expand to include avoiding not just boycotts, but avoiding even questions about Israeli purchases. As one industrialist recalled:

> We had some trouble in developing the pyrotechnics. But I said, "We cannot be dependent on importing pyrotechnics from the Americans." Because one day, the Americans said, "Why do you want it? What do you

[5] Dov Goldstein, interview with Gavriel Gidor, Director-General of IAI, "Israeli Aeronautics: Thanks to de Gaulle," in *Israel Yearbook, 1982* (Tel Aviv: Israel Yearbook Publishing, 1982), 255-63.

> want it for?" And I suggested that we tell them the truth. Say we want it for missiles. Because everybody knows that Israel wants missiles. And some idiot says, "We want to try cutting trees with it." The Americans said [sarcastically], "We didn't know you had some many trees." Idiots!
>
> ...But anyway, since anybody wanted any official excuse, we should be able to make it ourselves. Exactly the whole point. If there is a possibility that somebody should ask too many questions, or should be able to say yes or no, we don't want to be dependent on it.

The belief in the necessity of self-reliance is reinforced by a general feeling of international isolation, a feeling which Israelis do not universally hold. Many Israeli business people who are involved in international trade have a largely favorable view of interdependence. Many European-descended members of Israel's elite feel a strong affinity for and connection to Europe, while others are quite willing to bind the future of the state to its relationship to the United States. Many Israelis of all political stripes recognize an ultimate dependence on U.S. support, with or without arms supplied. They find it difficult to envision Israeli economic survival without U.S. aid, loans, and the international financial benefits which are implicitly conditioned on continued U.S. support.[6]

In sum, Israel's history as a target of international arms boycotts and embargoes is a powerful force favoring the indigenous development of military technology and weapons systems. The political survival of the general belief in self-reliance depends in part on a strong, oft-repeated mythology about international boycotts; on a flexible definition of the requirements of self-reliance, which we will later examine in detail; and on a general feeling of international isolation, which is not universally held.

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[6]Sharkansky points out that "the Israeli economy is also dependent on what happens outside the country to an unusual extent. The country's ratio of imports to GNP was .7 in 1978, while the comparable ratio was .15 for a group of developed countries and .21 for a group of developing countries." Ira Sharkansky, *The Political Economy of Israel* (New Brunswick, N.J.: Transaction Books, 1987), 12.

Economic Strength: The development and growth of the overall Israeli economy is an important element of the push for self-reliance. Throughout the development of Israeli military industries, the benefits of investing in those industries have been seen as extending beyond the specific weapons systems they produce. The perception of military technology as economic development buttresses government support for the largest military industries, which are themselves under varying degrees of government ownership and control. Even economists assert that:

> The expansion of local production of military items will effect the development of the metal, machinery, transport equipment, electronics and optical industries...Working for the defense establishment may bring about considerable changes in the organization, production technology and quality level of supporting industries, which will also undoubtedly effect production for the civilian market and contribute to the expansion of their exports.[7]

The association has become so tautalogical that Defense Minister Ezer Weizman, in expressing his own concern about building a strong enough economy to support Israel's high military burden, said, "That is why we developed an aircraft industry and a military industry."[8] Israelis frequently view the military industries as the foundation for crucial sectors such as electronics, metals, and

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[7]State of Israel, Prime Minister's Office, Economic Planning Authority, *Israel: Economic Development: Past Progress and Plan for the Future* (Jerusalem: Government Printer, March 1968), 427, quoted in Reiser, *Israeli Arms Industry*, 90.

[8]Transcript of meeting between Minister of Defense Ezer Weizman and Iranian Vice Minister of War H. Tufanian, 18 July 1977, p. 8, as printed in The National Security Archive, *Iran: The Making of U.S. Policy, 1977-1980* (Alexandria VA: Chadwyck-Healy, 1990), originally printed in Volume 19 of *Documents from the U.S. Espionage Den*.

machinery.[9] The importance of the military sector in promoting high-tech industry in particular is discussed below, as part of a broader "faith in technology."

The understanding of the broader economic contribution of Israel's military industries stems partly from those industries contribution to civilian production. For example, in 1988, 25% of IAI's production was for civilian markets, while only about 15% of the sales of Koor Industries (then the parent company of Tadiran and Soltam) were military.[10] Even the Ministry of Defense's primary research laboratory and a leading producer, Rafael, is planning to boost its civilian sales to 10% of its annual total.[11] Furthermore, technologies developed within these companies are frequently applied to civilian production.[12]

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[9]For electronics, see "In Short," *Innovation*, no. 193 (December 1991): 5. Similarly, "from the start, Israel's military industry has served as the backbone of the country's metal and machinery sector." *Israel's Metals, Machinery and Automotive Industries, Agricultural Equipment and Inputs* (Tel Aviv: Kompass Israel, 1992), 1. These perceptions have impressive statistics as their underpinnings, such as the fact that "defense-related demand now accounts for about 80 percent of the increase of production by the metal and electronics industries." Naftali Blumenthal, "The Influence of Defense Industry Investment on Israel's Economy," in Zvi Lanir, ed., *Israeli Security Planning in the 1980s: Its Politics and Economics* (New York: Praeger and Jaffee Center for Strategic Studies, 1984), 166-77, 171.

[10]Stockholm International Peace Research Institute (SIPRI), *SIPRI Yearbook: World Armaments and Disarmament* (New York: Humanities Press, 1990), 325-29.

[11]Rafael's plans call for $50 million worth of civilian sales out of a $550 million total by 1994. "The Rafael Armament Development Authority," *Jane's Defence Weekly* (8 June 1991): 979.

[12]"A large portion of the accumulated information and of the sophisticated technologies that were developed for defense requirements have been transferred in different ways to the civilian area." Arie Lavie and Robert Lawrence Kuhn, *Industrial Research & Development in Israel: Patterns and Portents* (New York: Praeger, 1988), 31. See also Robert Lawrence Kuhn, *Commercializing Defense-Related Technology*, (New York: Praeger, 1984).

More important is the military industries' contributions to Israeli exports. Exports add to overall military sales, permitting the defense industries to prosper and therefore serve Israeli military needs far better than they could if they relied only on domestic sales. Arms exports are also supported because they add to foreign currency reserves, which has been a chronic problem for Israel.[13] Many of Israel's largest companies earn the majority of their revenues through military sales abroad.[14]

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[13]In 1985, for example, the outward flow of foreign currency was such that "financial reserves were approaching the point at which there might not be enough for imports of food and industrial raw materials." Sharkansky, *Political Economy of Israel*, 93; more generally see Nadav Halevi, *The Structure and Development of Israel's Balance of Payments* (Jerusalem: Falk Institute, 1983). On the role of arms sales in shoring up currency reserves, from the early years of the State to the 1980s, see Aharon Klieman, *Israel's Global Reach: Arms Sales as Diplomacy* (Washington, D.C.: Pergamon Brassey's, 1985), 18-19, 61-63. Al Schwimmer, the founder and long-time head of IAI, has been quoted as saying, "IAI has two primary and overriding objectives. The first is to serve the defense needs of the country, but the second, and no less important requirement, is to bring in vital hard currency." Arnold, *Lighting in the Skies*, 194.

[14]Of the three largest defense industries, $1.3 billion of IAI's $1.6 billion 1991 sales were for export; for IMI in 1989, $384 million of $655.6 million of sales were exports; Rafael exported $110 million out of $400 million in total sales in 1990, and was planning to expand the proportion to $210 million out of $550 million by 1994. "High-Flying Israel Aircraft Industries," *The Israeli Commercial Economic Newsletter* (8 February 1991): 1; *DunsGuide 10,000: Israel's Business Directory* (Tel Aviv: Dun & Bradstreet (Israel), 1992), 2169; and "Rafael Armament Development Authority," 979. Other defense industries can reach similar proportions so that, for example, "over 50% of Elbit's avionics systems [are] designed for export." Foreign Defence Assistance & Defence Export (SIBAT), *Israel At The Paris Air Show*, (Tel Aviv: SIBAT, 1991), not paginated. According to the OTA, for defense industries as a whole, exports as a percent of sales in 1985, 1987 and 1989 were 47%, 55%, and 59%, respectively. U.S. Congress, Office of Technology Assessment, *Global Arms Trade: Commerce in Advanced Military Technology and Weapons*, OTA-ISC-460 (Washington, D.C.: U.S. Government Printing Office, June 1991), 85. More recently, some 1992 estimates have Ta'as exports at $300 million out of $480 million total sales; IAI with $930 million out of $1.55 billion; and Rafael exporting $140 million of a $460 million total, with plans to reach $200 million in 1993. Neal Sandler, "State-run Sector Fights for a Future," *Jane's Defence Weekly* (6 February 1993): 29-30.

Military industries also contribute to regional economic development within Israel:

"Successive governments have also sought to use arms industries as a means for developing the outlying regions of the country and encouraging settlement by providing employment....The government has encouraged the move to remote areas, including the West Bank and the Golan Heights, and has sought to double or perhaps triple the number of employees in government-owned plants in the development towns."[15]

Numerous instruments exist for this express purpose, such as:

"The Law for the Encouragement of Investments [which] is designed to stimulate foreign investment, [and] to direct the flow of investment to underdeveloped regions by reducing taxes and duties and providing grants and credit at concessionary terms. The implicit subsidy [of defense industries] given through credit channels has been high. Government incentive programs are the major source of long-term finance for industry since private equity markets are developing too slowly."[16]

Specific examples include:

- Strong government support for the chronically unprofitable Bet Shemesh aircraft engine factory in Be'ersheva;[17]

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[15]Gerald Steinberg, "Israel: High-Technology Roulette," in Michael Brzoska and Thomas Ohlson, eds., *Arms Production in the Third World* (London: Taylor and Francis, 1986), 163-92, 173. An interview with a current Ministry of Defence official responsible for allocating research funds confirmed the impact of regulations about having to support industries in development towns, sometimes even overruling the users' perspective. Regulations dictate how high a priority regional development must take, what percentage of funds need to be allocated where, and so on.

[16]K. Nagaraja Rao and Jack Ruina, with Anselm Yarom, et al., *Disarmament and Development, The Case of Relatively Advanced Development Countries: Possible Economic Payoff from Military Production--The Case of the Aircraft Industries in Brazil, Israel & India*, Discussion draft (Cambridge: MIT Center for International Studies, August 1980), III-7.

[17]Reiser, *Israeli Arms Industry*, 176-78; mostly citing State of Israel, *The State Comptroller's Report 1982* (Jerusalem: Government Printer, 1982), 384-404.

- Government-supported high-tech centers for military industry in Haifa as well as in Carmiel and other development towns;[18]
- Dedicated technology transfer institutions for military technologies, such as the Technion R&D Foundation or the Rafael-run start-up company, Galram;[19] and
- The government's recent decision to move all Ta'as operations to the Negev explicitly for the purposes of economic development.[20]

While some might view the mingling of regional development concerns and security concerns as a distortion of proper decision-making, a constructivist view recognizes that the growth of any system depends on such heterogeneous alliances.[21]

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18 Lavie and Kuhn describe the government's development strategy for high-tech concentrations around Haifa Bay, in the Dan region, near the Weizmann Institute, in Jerusalem (where development "A" status "catalyzed significant development"), and in "Region 2000" in the western Galilee. Under such plans, "companies will be able to benefit from sophisticated services and to rely on scientific foundation and infrastructures present in these institutions." *Industrial R&D*, 103-6.

19 "Rafael--From Weapons to Sewing Machines," *Israeli Commercial Economic Newsletter*, 21 June 1991, p. 9. "Rafael has for some time been seeking to diversify into the civilian market [through...] a number of products under development by its subsidiary Galram." The Technion Research and Development Foundation Ltd. was established in 1952, and has "truly come of age" as an institution promoting technology transfer and international collaboration. See the 40th anniversary issue of *TDRF News*, 3, no. 2 (Summer 1992). This perspective on economic development was entirely consistent with my interview with the head of the foundation, Professor Arnan Seginer. For parallel developments in less military-oriented sectors, see "Weizmann Incubator Creates High-Tech Jobs," *Israel Business Today*, 17 April 1992, p. 17.

20 "Military Industries Going South," *Israeli Commercial Economic Newsletter*, 6 December 1991, p. 16, describes how the move would create 4,500 jobs for providing services for re-located workers near Be'ersheva, which was simultaneously granted 'Development Zone A' status.

21 According to Emanuel Gil, the president of Elbit, "The defense minister must consider factors unrelated to economics, such as politicians seeking reelection, party pressures and so forth. Without these commitments, he could make more balanced decisions." But without these commitments, Elbit might not get funding at all. Klieman and Pedatzur, *Rearming Israel*, 129.

These beliefs do not exist in isolation. Dissent has existed throughout the brief history of the industries, and if anything is now growing.[22] Economists, industrialists in non-military sectors, Finance Ministry officials, and others view investment in the defense industries as weakening the rest of the Israeli economy. They criticize the military's monopolization of R&D funding, government subsidies to technology development and unprofitable production lines, and what they see as an over-emphasis on arms sales as Israel's primary export. Using the same rhetoric of economic survival and self-reliance, they argue that a diversified economy more oriented to the private sector would better support the economic strength that Israel needs to support its heavy defense expenditures.

But even credible dissent is deflected in part by a lingering belief in 'Zionist economics', where industries that are crucial for building up the new nation do not need to make a profit, and where foreign support and debt are reasonable foundations for whole sectors of the economy. In some sense, the structure of the defense industries in Israel is merely as unrealistic as the rest of the economy, making criticism difficult.[23]

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[22]For critiques over the last ten years, see Yoram Peri and Amnon Neubach, "The Military Industrial Complex in Israel" (Tel Aviv: International Center for Peace in the Middle East, January 1985); Ariel Halperin, "Does Military Technology Affect Economic Growth?", in Shai Feldman, ed., *Technology and Strategy: Future Trends* (Tel Aviv: Jaffee Center for Strategic Studies, Tel Aviv University, 1989), 117-20; Halperin, "Military Force Buildup and Economic Growth," *Rivon le-Kalkalah* 34, no. 131 (February 1987): 990-1010; and Blumenthal, "Influence of Defense Industry Investment." Steinberg, citing various Israeli newspapers, generalizes that "some analysts affiliated to the Labour Alignment have warned against 'putting too much faith in high technology based in military industries.'" "High-Technology Roulette," 189.

[23]For a scathing but affectionate account of Israeli economics, see Sharkansky, *Political Economy of Israel*.

In sum, the theme of self-reliance through economic strength promotes indigenous defense industries. Defense industries are seen as promoting economic strength in general; they are seen as generating earnings and foreign exchange through exports; and they effectively resist dissenting voices raised against them.

Brain Drain: Just as a strong economy is a frequently cited prerequisite for a strong defense, so a large pool of scientific and technical workers is a foundation for developing advanced weapons systems. As in many other developing countries, including Brazil and India, many Israelis are concerned about losing their best technical people to Western Europe and the United States. The particular strategies that Israel has adopted to combat brain drain stimulate the development of military technology.

Because of the historical and cultural oddities of Israeli demographics, the nation has always had a generous supply of high-quality scientists and engineers. Because of their quality, and because they often have strong family or cultural ties to other countries, these scientists and engineers are particularly mobile. Combating brain drain therefore equates with providing sufficiently compelling employment opportunities within Israel. For example, during the state's first serious economic downturn from 1965 to 1967, the government passed special funding for grants to scientists and engineers in order to prevent emigration. At the same time, the leaders of IAI successfully argued for funding for the production of the Arava aircraft on the basis of preventing brain drain. According to Reiser, the reasoning at the time was that "the project would help retain IAI's engineers and technicians during the serious brain drain to the United States caused by the severe economic recession in 1966-1967....[Therefore, Schwimmer decided to proceed] so that IAI would not lose its top-echelon aircraft engineers and technicians."[24]

Similarly, Steinberg concludes that "the original basis of the Arava aircraft project in the 1960s...[was] Israeli concerns about brain drain....Israeli decision-makers feared that instead of suffering through the closure of production lines or development teams, or the conversion of some defense industrial capacity to civilian applications, many scientists or engineers would simply leave. Thus, when the Arava project was near its end, IAI successfully negotiated the manufacture of the Kfir fighter was a follow-on project for the same design team." The same dynamic accounts for the origins of the Lavi fighter (then called the Aryeh), begun as the Kfir project was winding down.[25]

Below the level of a follow-on imperative, concerns about brain drain account for many smaller projects and innovations in defense technology. Unlike the U.S. system, workers in the defense industries are not dismissed when cyclical variations lead to a reduced work load. To prevent both emigration and economic disruption, they are instead kept on the payroll.[26] These internally displaced workers become an essentially costless resource within the defense industries, and often engage in work that would ordinarily be too risky or expensive. An Israeli industrialist, in describing why he was willing to pursue a particular new development, told me that:

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[24]Reiser, *Israeli Arms Industry*, 55, 60.

[25]Steinberg, "High-Technology Roulette," 172.

[26]The extent of military secrecy also means these industries are not accountable to anyone about their personnel policies. Such policies would probably only surface as a political issue if there were significant cutbacks.

> it's a question of people, nothing more, and I'm not going to sack the people...We are not working in the American way, that if you have tomorrow less orders, you immediately release a few people. We don't work that way. Therefore, it didn't really cost me any money.

Such people are also often freer to pursue research simply because it is interesting, in a technical or scientific sense, rather than contributing immediately to a high priority project. This pattern contributed to the origins of fiberglass motor cases, the Arava aircraft, and other technological developments, some of which are recounted in more detail later in this chapter.

Within academia, the same sorts of pressure lead to an emphasis on advanced technology in defense-oriented research. Israelis' self-image requires world-class scientific research. As one academic scientist who is heavily involved in defense-related research told me:

> It's your scientific pride which wouldn't allow you to do mediocre experiments.
>
> *That attitude helps keep people in Israel?*
>
> Well, I wish we could do more of that.
>
> *You think it's a problem?*
>
> I know it's a problem! Quite a number of good people are...they usually go for post-doctoral positions in the States, or in Europe, and don't see jobs that they think they would like for coming back. So they stay there. The temptation is high. This is *exactly* the point. If you run fast, and try to keep abreast, you can attract more of your post-docs.

Finally, Zionist ideology increases the political potency of concerns over brain drain. The Zionist view of the development of the state of Israel has emphasized the role of people, as opposed to the mere enabling role of resources or investments. Israeli history features a constant struggle to encourage and absorb immigration, and to avoid emigration.[27] The very words used to describe

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[27]Chaim Waxman and Michael Appel, *To Israel and Back: American Aliyah and Return Migration* (New York: Institute on Jewish-Israeli Relations, American Jewish Committee, September 1986). For a typical example, see J. Kagon, "Aliyah and Yeridah," *Midstream* (November 1981): 40-41: "The only viable way to curtail the damaging exodus from Israel is to create a new private industry. The Zionist backers of America will be doing a great deed to organize...a program of action." 40. My thanks to Nancy Norton on this point. See also Shlomo Avineri, *The Making of Modern*

the phenomenon give some of the ideological flavor of the enterprise: immigration is called *aliyah* (ascent), while emigration is called *yeridah* (descent).[28] By tying into the broader philosophy of the state, the fight against brain drain can stake a more secure claim to political priority.

In sum, brain drain, as the component of self-reliance that focuses on people, directs the resources put into the defense industries toward new technologies and weapons systems. Israeli methods of fighting against brain drain result in a follow-on imperative for design teams; plentiful human resources for pursuing new projects during periods of slack in individual industries; and an emphasis on the most advanced research in academically-oriented work. Zionist ideology helps to reinforce the political importance of this aspect of self-reliance.

Inter-industry Rivalry

The three largest Israeli defense industries, IAI, Ta'as, and Rafael, began life in disparate spheres. IAI was involved in maintenance and then production of aircraft; Ta'as produced the ammunition and other low-tech supplies that the Army needed; and Rafael was the IDF's science-corps-turned-national-laboratory. By

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Zionism: The Intellectual Origins of the Jewish State (London: Weidenfeld & Nicolson, 1981); and Bernard Avishai, *The Tragedy of Zionism: Revolution and Democracy in the Land of Israel* (New York: Farrar Straus Giroux, 1985), especially chapter 3 ("The Conquest of Labor"), 67-98.

[28]For a brief sociological study of the reasons for immigration and emigration and the difficulties of absorption, see Jack Cohen, "The Two-Way Stream: Israel and the Diaspora," *Reconstructionist* 43, no. 2 (February 1977): 17-22. On the other hand, it is also commonly said that Israel cares about aliyah, not the olim (the immigrants) themselves. See for example E. Eyal, "American Aliyah is Losing Momentum," *National Jewish Monthly* 87 (January 1973): 36.

the 1960s, however, all three became progressively more involved in overlapping areas of military technology, especially missiles. The rivalry among them is one of the primary forces favoring the development of new military technology in Israel.

The idea of competition as a spur to technology development is hardly new.[29] The literature on this dynamic in the U.S. military context focuses on interservice rivalry.[30] But in Israel, the historically contingent overlap of the

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[29]Joseph Schumpeter, "The Process of Creative Destruction," ch. 7 in *Capitalism, Socialism and Democracy* (New York: Harper, 1942), 81-86 esp. 84-85; Frederick M. Scherer and David Ross, *Industrial Market Structure and Economic Performance*, 3rd ed. (New York: Houghton Mifflin, 1990), 613-60; and Richard Nelson, "Institutions Supporting Technical Change in the United States," in Giovanni Dosi, et al., eds., *Technical Change and Economic Theory* (London: Pinter, 1988), 312-29. My thanks to Sybil Francis for pointing out these sources.

[30]However, the dynamics do not always match the perspective used here. For example, Arnold Kanter writes that "functional [interservice] rivalries frequently are stimulated by technological development--particularly new weapons capabilities--which disrupt the existing division of labor." He would not be able to recognize how the Indian army, for example, is using the Prithvi missile to secure missions from the Indian air force. Arnold Kanter, *Defense Politics: A Budgetary Perspective* (Chicago: University of Chicago Press, 1975), 136n. Owen Cote argues that competing services often prefer collusion and cooperation when circumstances permit, but that otherwise technological innovation can help a service to expand its missions or overcome threats from other services. Cote, "Nuclear Vulnerability and Radical Doctrinal Change: The Interservice, Intraservice, and Civil-Military Politics of Military Innovation" (working title), Ph.D. diss., MIT, 1993, forthcoming. Harvey Sapolsky implicitly argues for the technological benefits of interservice rivalry in Sapolsky, *The Polaris System Development: Bureaucratic and Programmatic Success in Government* (Cambridge: Harvard University Press, 1972). Much of the rest of the literature on interservice rivalry views it as evil and a prime cause of waste and inefficiency, including even more sophisticated analyses such as Michael Armacost, *The Politics of Weapons Innovation: The Thor-Jupiter Controversy* (New York: Columbia University Press, 1969). Practitioners, however, recognize that such structures can be manipulated intentionally. When the U.S. Air Force and the National Reconnaissance Office were assigned overlapping responsibilities, one of the participants has later written that "a competitive situation was created to ensure that this technology would grow at a pace limited only by human creativity." Albert Wheelon, "Space Policy: How Technology, Economics and Public Policy Intersect," MIT Program in Science, Technology, and Society, Working Paper Number #5, p. 58.

three largest defense industries is both more intense and more important than interservice rivalries.[31] There is some alignment of the industries with the different services, with IAI and Rafael working primarily for the Air Force and secondarily on Navy projects, while Ta'as views its core role as supporting the Army. Nonetheless, these effects are relatively minor compared to the general phenomenon of inter-industry rivalry, which often seems to resemble interservice competition in the United States. For example, when IAI heard that Tadiran was planning on producing RPVs, according to one insider, their reaction was a classic "roles-and-missions" response: "Airplanes? That's us!" So IAI formed "a small group, which started working on the mini-RPV."

The opening salvo in inter-industry rivalry in Israel is usually taken to be the competition between IAI and Rafael over the continued development of the sea-to-sea version of the Luz missile project, which became known as the Gabriel.[32] One engineer who was at IAI at the time recalled how technical papers on the project that were supplied by Rafael to IAI had had their references cut-off; his job was to try to find the relevant published articles. This early controversy also

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[31]The latter of course exist. For example, an air-to-sea version of the Gabriel missile might have some strong operational advantages, since aircraft are far more mobile launch platforms than ships. But the Navy does not fly airplanes in Israel, and the IAF is not interested in anything that takes place at sea, so an air-to-sea Gabriel does not exist. One veteran of the national security establishment told me that the title of Josephus Flavius' first century history, Milhamot ha-Yehudim ("The Wars of the Jews"), was now used to refer to interservice rivalry.

[32]Mardor suggests that everything was peaceful until the other industries started to be more interested in Rafael's missile projects. Despite a roles and missions document that was drafted in the Ministry to preserve some order, rivalry, sometimes intense, became the order of the day. Mardor, *Rafael*, 265-66. Some evidence suggests that the sacrifice at Rafael in giving up the project was considerably eased by the award of significant new missile projects. See the discussion of early work on the Jericho program, below.

exhibited a common feature in subsequent cases: the role of officials in the Ministry of Defense was primarily to settle disputes that the industries could not settle themselves. The same dynamic is visible in Ministry interventions to require dual-sources for production of the Shafrir missile, or settling on Rafael as the producer for the third stage of the Shavit satellite launch vehicle. In other words, the Ministry only enters the 'black box' of the defense industries when the actors inside cannot succeed in keeping a controversy closed. Otherwise, intervention requires too much expertise or other forms of authority in order to open the black box.

The existence and intensity of inter-industry rivalry is not sufficient to explain technology development. The particular way in which the industries define critical problems and reverse salients points toward increased indigenous military R&D and production, toward higher-tech systems, and toward incremental industrial capacity, especially their own. In aircraft, missiles, tanks, and other weapons or platforms, Israeli industries have started with a limited maintenance operation, with the explicit aim of gradually building up their capabilities until they can develop and produce the entire system. For IAI's leaders in particular, their drive to become the primary system-integrators in Israel has led them to acquire whole divisions in order to bring additional capabilities under the IAI umbrella.[33] Rafael's early mission of development without production, and its

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[33]For example, Rafael managers recall an on-going development effort for inertial components was transferred wholesale from Rafael to IAI in the mid- to late-1960s, involving forty to fifty scientists plus additional support staff. This project became the Tamam Precision Instruments Industries, a subsidiary of the IAI Electronic Division. By the late 1970s, Tamam employed 350 engineers and scientists, 300 technicians, 500 skilled workers. In 1988, Tamam had approximately 1000 employees and public sales estimated at $63 million. Rao and Ruina, *Disarmament and Development*, III-I/3; *DunsGuide Israel: Business Directory 1990* (Tel Aviv: Dun & Bradstreet International, 1989), 1411.

subsequent competition with the industries to which it had previously transferred its projects, led it to emphasize new, advanced systems as its best claim to a lead status on any given project.[34] As Ta'as began to move from their arsenal status as a low-tech subcontractor, it had to demonstrate advanced technical capabilities to prevail over Rafael and IAI for production and prime developer contracts, as in the case of anti-tank missiles.

In sum, just as new technologies are seen as a valuable ally in surprising and defeating an enemy on the battlefield, so are new technologies an ally in these industries' attempts to expand their own roles, frequently at the expense of each other. As one analyst with extensive contacts with all the defense industries commented:

> Here, I'll tell you a military secret. The biggest secret, or the biggest security problems, on such meetings [involving representatives of the defense industries] is not what the Arabs will know of the meeting. It is what Rafael will know about what is cooking at IAI! Believe me, it's true!

Faith in Technology

The third major force promoting the development of military technology in Israel is a set of beliefs held by different sectors within the Israeli elite about technology. These cultural interpretations of a mythical unity called "technology" do not relate to specific weapons systems or specific institutions. They represent more general understandings and causal stories about the struggles and controversies important to the daily lives of these different audiences.

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[34]See the discussion of the third stage of the Shavit, below. In the case of an ATBM system, however, this strategy did not succeed for Rafael, perhaps because of the prominent role of the United States in selecting the Arrow over Rafael's AB-10 system, as discussed below.

Academically-oriented Science: Among scientists, we have already described the generic value of technology in providing interesting work that can prevent brain drain. In numerous additional ways, developing new military technologies helps scientists to adhere to the norms of the international scientific community and to earn that community's respect--goals which are central to the enterprise of academic science in Israel. For example, numerous academic scientists that I interviewed made clear their desire to do work which would help their country. As one told me:

> Here in the faculty, we try to do, first of all, interesting and relevant scientific work. And, basically, we're good Zionists, good Israelis. We try to do things which we feel, or we know, might have been of use to Israel.

However, when I then asked this scientist how members of his department could optimize across these multiple criteria, he replied, "We don't optimize. The only relevant criteria is the pleasure of the research, to be honest." Thus, the scientists' intent operates within the constraints of their definition of good science, namely work which is theoretically oriented, has not been replicated elsewhere, and which will earn them international recognition and approbation in their fields. In one scientist's description:

> You're racing, I think, the scientific community. That when you come to a conference, and tell about your findings, you're at the forefront. You're not doing something that the British have done, or the French, not to mention the Americans and the Russians, have done already twenty years ago.

A reinforcing requirement, also based on obeying scientific norms, is the prohibition of classified research within academic institutions. Defense-oriented research, which is of course quite common, must therefore focus on more basic, less mission-specific, projects.

Finally, in order to attract the support and labors of the best scientists, defense-oriented projects must include well-respected members of the academic scientific community. Thus, in the early history of Rafael, one turning point was the recruitment of Ephraim Katzir as Chief Scientist in January 1960, along with his brother, Aharon Katzir, then the head of inorganic chemistry at the prestigious Weizmann Institute. Their presence, along with selected other scientists, gave the young organization a new stature with which to attract other scientists and the best recent graduates.[35] Conversely, some scientists criticized the reputations of the leaders of the Israeli space program. In one interview, a scientist involved in space research referred to another scientist, saying:

> He's a cockroach, excuse me for that expression. He's a cockroach, nothing. How many papers he himself published? You know how many? All of them are written here [holding out the open palm of his hand]. Nothing. I don't even want to say all of them are written here--none! One of the things that people don't understand vis-a-vis the scientific community, is that if...[particular scientists are chosen as the leaders] of the Israel Space Agency, that inside the scientific community, the academic community, the Space Agency is baptized as a joke. Because they know, if serious people would think it is important, *they* would do the job. And it's mediocre people are doing the job--then the conclusion is trivial. ...[Some of these scientists]--they don't exist scientifically. I don't talk about...[others who are] excellent. So you need also, leading personalities, the contributions of which to the scientific community is sufficiently large to attract people.

In general, the participation of academic scientists in the defense sector means that projects will tend to take on the characteristics valued by the scientific

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[35]Reiser, *Israeli Arms Industry*, 58. The director of Rafael at the time, Munyah Mardor, in Mardor, *Rafael*, 195-201. Aharon Katzir, by time of his death in 1972, was "one of the driving forces in the then flourishing Israeli nuclear weapons program." Seymour Hersh, *The Samson Option: Israel's Nuclear Arsenal and American Foreign Policy* (New York: Random House, 1991), 26, citing "Leading Scientist Killed," *Jerusalem Post*, 1 June 1972, p. 3.

community: research-intensive high-technology projects that do not merely build on existing systems or replicate the achievements of other nations.[36]

The status of Rafael as an intermediate institution offers a special case. From its origins within the Weizmann Institute to its leadership by Ernst David Bergmann, the leading Israeli visionary of science, Rafael has played a mediating role between the scientific community and the defense industries.[37] Until the late 1960s, Rafael was prohibited from producing the weapons systems that it developed, instead emphasizing the technological achievements of its projects in order to differentiate itself from competing organizations and thus receive more support. Its status as a 'national laboratory' (in imitation of the U.S. system of national laboratories) kept the focus on advanced technology and on the scientific quality of its personnel.[38] Rafael scientists, like academic scientists and unlike those at IAI or Ta'as, are granted sabbaticals every seven years. Rafael

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[36]As one industrialist said, "How do such things develop? Among other ways, it's because people have one system, and he says, 'OK, before I get annoyed with what I have, and become so monotonous, let's do something else.'"

[37]On the mixed roles of scientists in positions of responsibility outside of science, see Don Price, "The Spectrum from Truth to Power," in Thomas Kuehn and Alan Porter, eds., *Science, Technology, and National Policy* (Ithaca, N.Y.: Cornell University Press, 1981), 94-131. On the work of maintaining boundaries between scientific and other institutions, see Thomas Gieryn, "Boundaries of Science," in Sheila Jasanoff, et al., *Handbook of Science, Technology and Society* (Beverly Hills, Calif: Sage, 1993, forthcoming).

[38]Despite Rafael's participation in industrial production for more than 20 years, its special status remains politically potent even today. Knesset member Eliyahu Ben-Elissar, then chair of the Foreign Affairs and Defense committee, wrote in 1989: "Unlike IMI and IAI, Rafael's purpose is to develop original weapons, even for the seemingly distant future. Products such as these are not all cost-effective, and therefore, cannot be expected to pay for themselves....This isn't a spare parts factory which is rated by immediate yield, norms and premiums, and anyone who thinks along these lines does not understand the nature of defense R&D." Cited in Klieman and Pedatzur, *Rearming Israel*, 152.

also has more extensive cooperation with the Technion, and according to an interview with a former Rafael administrator, at one time even advocated distributing all Ministry of Defense funding for academic research through Rafael. Research at Rafael thus responds to many of the same norms as research at academic institutions, and has a similar vision of what technology in general should be like.[39] While Rafael's close contact with the military obviously reduces the relative strength of those norms, Rafael's prominence in the development of military technology means that even diluted, they are still important.

Economics: In the challenging economic circumstances facing Israel, "technology" in general has taken on something of the role of savior. Technology's slogan, repeated in a large number of interviews, is, "you can't go on exporting only oranges."[40] This belief has been present among some leaders (usually termed "visionaries" by their supporters) since the founding of the state. One retired

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[39]As a long-time manager at Rafael told me, referring to all the uncertainties surrounding missiles in the late 1950s and early 1960s, "As far as they [the Air Force] were concerned, they didn't believe in it. As far as we [scientists at Rafael] were concerned, we saw it as a challenge, to try and do it. We saw it as a challenge, and we believed we could do it!"

[40]On the other hand, a scientist who opposes some large-scale technology development projects in Israel commented that "in my view, we are dependent...in so many aspects...I mean, we survive because the Europeans buy our oranges!" In 1987 (the most recent UN data available), Israel exported approximately 354,000 metric tons of oranges, valued at over $120 million, which were sent almost exclusively to Europe. Overall Israeli agricultural exports were $788 million out of total exports of $8.475 billion (11%). Statistical Office of the United Nations, *1987 World Trade Annual*, vol. 1 (New York: Walker and Company, 1992), pp. I-17, I-369, I-466. Israeli exports have gone from 26% agricultural and 70% manufactured goods in 1970 (out of total exports of $776 million) to 11% agricultural and 87% manufactured goods in 1990 (out of total exports of $12.0 billion). United Nations Conference on Trade and Development, *Handbook of International Trade and Development Statistics* (New York: United Nations, 1992), p. 149.

industrialist who had been involved in the early efforts to set up defense industries described David Ben-Gurion as a man who "believed in the Jewish genius and that R&D will bring miracles...At the time when there was not enough money to buy food, Ben-Gurion found money for the Chemed," the predecessor of Rafael.

In the current context, any endeavor (military or otherwise) which advances Israeli high-tech capabilities must tautologically be good for the country. As two scientists who are advocates of the growing Israeli space industry told me:

> You have to be at the forefront of technologies, and we can't say even today what it's for. But it's good for it, we know it's the trend of the world, and we have to be in it.
>
> I think that there is a realization that you have to run very, very fast in order to keep your position at the forefront of science. Science is becoming more and more expensive over the years; it's becoming harder and harder. But nevertheless, you have to keep up, keep abreast of the others.

This faith in technology has more concrete aspects as well. Advocates see investments in military technology as carrying numerous specific benefits, though again simply by virtue of their being "technology." According to this mythology, developing military technology leads to: civilian spin-offs, particularly in electronics and in medical technology; a downstream industry populated by high-tech subcontractors which absorb technologies from the defense industry giants and then expand on their own; a revolution in quality control that spills over into all aspects of Israeli industrial production; and in strong resonance with Zionist thinking, people (through training, experience, and skills). While connected with the idea of military technology as economic development discussed above, the emphasis here is on high-tech as a special case, where development refers almost exclusively to increasing technological sophistication.

As one of the key figures in the establishment of the Israeli MIT, I give extra weight to the view of Shimon Peres:

> The setting up of local industrial and research organizations, however, it not only a political and strategic concern, but is also of far-reaching economic significance....The defence system of a State is bound, of course, to have a major impact..., both immediate and long term, on the entire industrial development of a country. [The defense sector can] exercise a direct influence in raising general industrial levels. For the army is duty bound to be uncompromising in its demand for scrupulous standards in quality, price and time of delivery....The standards insisted on by those responsible for defence tend, with time, to become the generally accepted standards of industry.
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> The unremitting competition between States for weapons superiority, or at least equality, is the drive that makes military research the most daring, comprehensive and far-reaching of all fields of research. Many of the latest discoveries in materials, instrumentation, organizational and administrative systems, are the result of the diverse demands of modern armies, who must engage in the relentless but adventurous climb from one technological peak to another.[41]

War: A minority in the security elite believes that technology can serve as a talisman for preserving Israel's military strength. Especially academics and outside analysts see Israel's qualitative edge over Arab militaries as the only way to overcome disadvantages in financing, force size, and strategic depth.[42] Thus Moshe Arens, a former director of IAI, saw the launch of the Israeli Ofek satellite as "proof of Israel's technological superiority."[43] Similarly, Ze'ev Bonen, a former

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[41]Peres, *David's Sling*, 113-14.

[42]See the discussion in Dore Gold, "U.S. Policy Toward Israel's Qualitative Edge," JCSS Memorandum #36 (Tel Aviv: Jaffee Center for Strategic Studies, Tel Aviv University, September 1992).

[43]"Official Communique Issued," *Nuclear Developments*, 12 April 1990, p. 16.

director of Rafael, has said that "Israel...has been able to affect the Mideast battlefield by springing technological surprises upon its adversaries."[44]

In the early days, the Israeli military had little patience for high technology. Leading figures in both the Army and the Air Force were quite clear about their faith in indigenous technology:

> Dayan emphasized that although he saw the value in long-range weapons projects, he doubted Emet's capability to implement them. During one visit to Emet in response to an invitation by Mardor, the chief of staff told Mardor, 'You invited me, so I came, but you know that I don't believe in any of this.'"[45]

One who was present at the time recounted a similar story:

> We had of course various tests in the Negev, at the testing range. At one of them, Ezer Weizman, who at the time was Commander of the Air Force, came for a visit. And he made a joke of it. You know, he was a great joker. And he said, well, he didn't believe in anything, he was ready to sit on the target. And we prevented him from doing it--because if he had sat there, he would have been killed! That's it.[46]

Even today, many within the military would probably subscribe to General Ben-Nun's statement while he was Commander of the Air Force, that "quality of technology however has only third priority in the IAF. First priority is quality of personnel, second is quality of tactics and techniques."[47] Similarly, Shai Feldman argues that:

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[44]Ze'ev Bonen, "Participation of Israel's Defense Industry in the Western Defense Community," In Feldman, *Technology and Strategy*, 121-25, 122.

[45]Munyah Mardor, quoted in Reiser, *Israeli Arms Industry*, 57.

[46]Confirmed in multiple interviews. Also told in "Israeli Missiles: First Report," 267.

[47]Joris Janssen Lok, "Rabin: Meeting the Missile Threat" *Jane's Defence Weekly* (10 June 1989): 1141-49, 1149.

> Technology is not *the* dominant factor in determining force effectiveness....Performance in wartime will continue to be affected first and foremost by the wisdom of the tactical, operational and strategic concepts developed; by the quality of the command implementing these concepts; and by the willingness and motivation of the individual soldier to fight.[48]

Nonetheless, technology does play a role as a signifier of capability and status within the security elite. For example, in what must have been a common reaction, Yigal Allon is reported to have responded to his first tour of Israel's strategic missile deployments with great pride:

> 'Allon got all excited,' one Israeli observer recalled. 'Here's a man who had fought in 1948 with only a British submachine gun, and now--twenty years later--here is Israel building nuclear missiles. We're a people...who have come back from the dead.'[49]

In interviews, the Army's preference for guided missiles over artillery was ascribed to a desire for sophisticated, pin-point accuracy, apart from any assessments of military utility. This kind of technological prestige plays a role among rank and file soldiers as well. Thus, in describing the non-military value of the hastily assembled Ze'ev rocket:

> The point is, you didn't have to use it. Our soldiers, when they came down and saw it, said, 'We've got something!' You see, the soldiers, when we crossed the [Suez Canal, we knew that]...we had artillery at our backs...That's what happened in those days. They had mortar, and then they *had* to develop the Ze'ev.

Interestingly, the most consistent representation of the value of technology in enhancing security was in accounts for American Jews. Evidently, when fund-raising for large academic projects for technology development, the security

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[48]Shai Feldman, "Technology and Strategy: Concluding Remarks," In Feldman, *Technology and Strategy*, 126-34, 127.

[49]Hersh, *Samson Option*, 173-74.

benefits of technology serves as a strong selling point. As one academic fund-raiser explained:

> Usually among Jews in the United States, the security of Israel is close to the heart....I don't want to use bombastic words, but it is very important to the security of Israel. So it is this kind of argument that convinces.

Special military projects may have benefited from similar support.[50]

In sum, strong beliefs about the value of technology in general increase support for the development of specific military technologies. Among academic scientists, new and advanced technology helps them to observe the norms of scientific research. Among those concerned about the economy, new and advanced technology helps Israel overcome its global disadvantages. Among the security elite, some believe that technology helps the Israeli military to cope with its strategic situation, while others place value on technology as an index of capability or status. These beliefs have little to do with the merits or drawbacks of particular development efforts, relying instead on the cultural meanings of technology as a category.

Secrecy

Understanding the "centrality of security" is essential to understanding the Israeli military system. In Israeli mythology, the state survives because of the unques-

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[50]Around 1960, Shimon Peres formed the "Committee of Thirty," a special group of trusted and discreet donors, as part of a fund-raising effort for the "special weapons" program. Peres claimed hyperbolically that "not one penny [for Dimona] came from the government budget. The project was financed from contributions I raised from Jewish millionaires who understood the importance of the issue." Hersh, *Samson Option*, 66-67, citing Roni Hadar, "Who Forgot the Father of the Israeli Atom, and Why?" *Tel Aviv Magazine of Yediot Ahronot*, March 1991.

tioned priority of security over other political issues. At the same time, diverse definitions of the elements of security and how best to achieve them result in a rough-and-tumble politics commensurate with other aspects of Israeli society. One repercussion of this "kedushat ha-bithon" (sanctity of security) is a presumption of secrecy for any information relating to military issues.[51] The resulting limitations on publication and speech, compartmentalization within the bureaucracy, and procedures limiting discussion and access constitute one of the strictest censorship regimes within any political system that is nonetheless recognized as democratic.[52]

Secrecy as Exclusion: Secrecy plays a role in Israeli security policy that is strikingly parallel to technology, and that in many ways helps to promote the development of military technology. Both secrecy and technology can serve as a political resource for the legitimation of hierarchy and authority within a democratic system, primarily by excluding otherwise rightful participants from the

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[51]Both these two phrases--centrality of security and kedushat ha-bithon--are staples of the Israeli debate. See Yoram Peri, *Between Battles and Ballots: Israeli Military in Politics* (Cambridge: Cambridge University Press, 1983), 1. See also Dan Horowitz, "The Israeli Concept of National Security and the Prospect for Peace in the Middle East," in Gabriel Sheffer, ed., *Dynamics of a Conflict* (Atlantic Highlands, N.J.: Humanities Press, 1975), 235-75; and Edward Luttwak and Dan Horowitz, *The Israeli Army*, 2nd ed. (Cambridge, Mass.: Abt Books, 1983).

[52]The most accessible discussion of secrecy in Israel is Itzhak Galnoor, "Israel," in Galnoor, ed., *Government Secrecy in Democracies* (New York: New York University Press, 1977), 176-200. See also Avner Bar-On, *Ha-Sipurim she-Lo Supru: Yomano shel Ha-Tzenzur Ha-Rashi* [The Untold Stories: Diary of the Chief Censor] (Jerusalem: Yediot Ahronot, 1981). On the establishment of military censorship, see Menachem Hofnung, *Yisrael - Bithon Ha-Medina Mul Shilton Ha-Hok: 1948 - 1991* [Israel-Security Needs vs. The Rule of Law: 1948-91] (Jerusalem: Navo, 1991), 79-81; also 179-89.

decision-making process.[53] In addition, restrictions on who may discuss what, and when and where it can be discussed, enhances the status of those issues shrouded by secrecy and reinforces their claims to political priority.

In the Israeli case, secrecy clearly acts to limit the participation of the general public in the security debate (a participation already greatly limited by the mythology of kedushat ha-bithon, which grants privileged status to the security "priesthood").[54] Secrecy's effects on public participation may not have a large impact, because there is no strong evidence to suggest that the public's views would be significantly different from those of current decision-makers. For example, the supporters of the Shavit launch vehicle advocated greater release of information to the public "in order to convince people that we need more money."[55] Similarly, the public would probably continue to support the role of the defense industries in economic and technological development, or the practice of not laying off workers in the wake of temporarily declining military sales. Finally, some suggest that topics such as Arab nuclear proliferation or the future of the

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[53]David Dickson is among those who have noted the similarity in the past. He opens his chapter on "Science and Society: Public Participation vs. Democratic Control" by observing the ironic symbolism of appointing the former head of the counterinsurgency task force for Southeast Asia as the National Science Foundation's new special assistant for the ethical implications of modern science. Dickson, *The New Politics of Science* (New York: Pantheon, 1984), 217-60.

[54]Anecdotally, it seems appropriate that the national university library computer catalog in Israel has no works listed under "Israel--National Security--Public Opinion."

[55]According to a scientist involved in the debate over releasing the information. Their judgment appears to have been sound: when people on a beach near Tel Aviv saw the unannounced first launch of the Shavit, they reportedly stood and cheered. John Kifner, "Israel Launches Space Program and a Satellite; Spy Craft Are Expected to Be Main Emphasis," *New York Times*, 20 September 1988, pp. A1, A12.

Middle East region are absent from public debate, not for a lack of channels for understanding and discussing them, but for a lack of the psychological stamina for doing so.[56]

A plausibly more important effect of secrecy is the exclusion of economists, finance ministry personnel, and other bureaucrats from procedures in which they would be included for any issue other than defense.[57] Their beliefs about the costs and benefits of investments in military technology are frequently diametrically opposed to those within the security elite. Much of the criticism of the current system comes from economists.[58] On more limited issues, the financial scrutiny might be even more pointed.

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[56]"The [Israeli] leadership itself appears to be deeply uncomfortable with and ambivalent about nuclear weapons...The refusal to issue nuclear threats...serves also as a mechanism of detail. It saves the leadership of the country from having to deal with an issue too uncomfortable to invoke....The public silence is not only, not even mostly, the result of the heavy hand of military censorship....The public appears as inhibited about nuclear weapons as the political leadership. The absence of public debate of nuclear issues is a manifestation not so much of ignorance of the existence of these weapons, but of a profound discomfort with them." Avner Cohen and Benjamin Frankel, "Opaque Nuclear Proliferation," in Frankel, ed., *Opaque Nuclear Proliferation: Methodological and Policy Implications* (Portland, OR: Frank Cass, 1991), 14-44, 28.

[57]For example, while the Education Council was considering a proposal to fund academic space sciences research, some Council members raised the objection that satellites might be too big a project for Israel to undertake, and thus space sciences research should not be funded. I asked one participant in this process if the Ofek satellite were already funded at that point. He answered with a chuckle, "Yes, it was. But the [Education] Council wasn't privy to that information!"

[58]See most of the sources cited in note 22, above. One critic complained that not only were outsiders deprived of information such as export figures, even though "most, or many, export deals in Israel just lose money," but that "more important, no one knows the economic performance of the industry," including insiders. Those with access to the information that would be needed to make such an analysis simply are not interested in the question.

For example, one government advisor related how one of the industries in Israel came to the Ministry of Defence sometime in the 1980s with a new missile that they wanted to develop. When asked where the money would come from, they responded that a South American customer would finance it--"Right here we have the draft of the contract. They are going to pay $80 or $90 million." However, a financial analyst who was there objected that such a sum was not sufficient to develop that missile, despite the industry's claim that they would be cheap and efficient enough to do it. It was then noticed that the contract called for payment in bonds, usually worth 10 to 40 percent of their face value. As this advisor concluded:

> The people in that industry, they understood that if they will get the contract, then there's going to be an obligation for Israel to develop this, and test it....It was not really important to them if Israel will sell this system to South America and what will be the price. The main element is, if Israel will get involved in this project...then we will find a way to finance it."

In general, the blanket of secrecy shields defense R&D decisions from such examination. Secrecy can even exclude the Ministry of Defense or the IDF from certain decisions. Though (almost) unheard of today, in the earlier history of the defense industries, some projects were funded and nurtured in secret, until they reached a point in their development where both feasibility and authorization seemed more likely.[59]

Secrecy and Strategic Weapons: Far more than for conventional weapons, Israelis treat strategic systems not just as part of kedushat ha-bitachon, but as part of a taboo subject. Hidden behind the thickest veil of secrecy, and treated

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[59] See the discussion of bottom-up development, below.

with a high degree of respect and deference, nuclear weapons and long-range ballistic missiles seem to prompt the same sorts of slow, hushed tones that one would expect of people talking in a cemetery.[60] Throughout the world, nuclear weapons and long range missiles are often portrayed as a kind of forbidden fruit, but in Israel, their taboo status grants them highest priority, and grants their initiates almost papal authority--an effective form of "missile defense."

Given the shelter of this opacity, strategic programs can seek additional protection by extending the period for which they are considered R&D programs, thereby avoiding the usual bureaucratic and doctrinal procedures for production and for deployment. As Cohen and Frankel comment:

> This concealment of a nuclear weapons program behind the veil of R&D is a bureaucratic device to avoid hostile scrutiny by critics in the government. The program remains opaque not only to the public but even to most elements within the government. The coterie of the nuclear elite enjoys an unusual degree of autonomy and control in their activities...Under conditions of opacity, the risk of having technological creep and bureaucratic momentum determine the shape and size of a country's nuclear arsenal is greater than in the visible mode.[61]

III. Antithesis: Forces Inhibiting the Development of Military Technology

Three forces in the Israeli political system inhibit the development of new weapons systems and new military technology: economic limitations, the

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[60]Seymour Hersh told me that as he talked to more and more Israelis about nuclear weapons, he re-read Volume 13 of Freud's Collected Works, *Totem and Taboo*.

[61]Cohen and Frankel, "Opaque Nuclear Proliferation," 22, 34.

availability of alternatives to indigenous development, and secrecy (see Fig. 1, *supra*). These forces are structural, in the sense that their power spans more than the single issue of security, and in the sense that they are not likely to change quickly as a result of events only in the arena of security. Nonetheless, they are the product of the same sort of contingent historical evolution as any other strand of this story, and are thus subject to change, re-interpretation and subversion. The ways in which they inhibit the development of military technology vary considerably, and only have such an effect in the aggregate.

Economic Limitations

The most prominent roadblock in Israeli development of military technologies is a lack of funding. At every stage of the process--research, development, and production, as well as training, infrastructure and testing--those favoring new technology and new systems must battle for the necessary resources, often settling for the barest minimum they can envision. At the same time, others from the military, other branches of the government, or the general public, complain of the impossibly high financial burden imposed by defense requirements.

Development funding, for the period we are considering, could come from several sources. Probably the most important for anything other than the largest projects was the internal funding generated by the defense industries themselves. Research could be self-financed, either officially or unofficially, by diverting people and other resources from the projects to which they were nominally assigned; by using overhead or capital funds on specific development projects; or by using revenues from sales of existing systems, especially exports, to support new projects. For example, for the first rocket system developed by Ta'as (see below), the motors were funded by a contract from the West Germans, while the rest of the system was funded by "stealing budgets from here and there." Such funding was necessarily meager.

More officially, development funding could come from the Ministry of Defense. The organization that now provides a central development budget is known as Mafat (Administration for Research and Development of Weapons and Production Infrastructure).[62] In theory, Mafat not only supports needed R&D projects, but also establishes priorities and initiates research in critical technologies and weapons systems. But especially before the late 1970s, the central development budgets were quite small, and Mafat was lacking in the expertise and resources needed to direct the overall R&D efforts of the Israeli defense industries. Nonetheless, particularly when the largest projects became well-established, development funding did come directly from the Ministry of Defense (for example, for the Shafrir 2 air-to-air missile). Major infrastructure investment could also come from the Ministry, such as the wind tunnel constructed at the Technion in the 1980s, or new propellant mixing equipment at Ta'as.[63]

Even after successful development, economic limitations remain severe. The small size of the Israeli military, and its unwillingness to rely solely on indigenous

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[62]"Established as an R&D unit and central science bureau, with the participation of the MOD and the IDF, Maphat was authorized to be coordinator of planning and operational policy for defense establishment R&D." Klieman and Pedatzur, *Rearming Israel*, 123n. An earlier smaller office, established on the advice of the Katzir commission, was previously known as MoP (Mehkar ve-Pituah, or Research and Development), and was founded in July 1972. Ze'ev Schiff and Etan Haber, *Leksikon l'Vithon Yisra'el* (Tel Aviv: Zemorah, Bitan Modan, Hotsaah le-Or, 1976), 310.

[63]Funding from the Ministry put Technion over the top for building their wind tunnel with a 5 megawatt arc plasma generator from Aeroflow, a facility that is also used by Rafael and IAI. On infrastructure and investment at Ta'as leading up to the Six Day War, see Evron, *Magen ve-Romah*, 138-49.

equipment, often dictated low-quantity production, vitiating any possible economies of scale. Particularly when a new system was to be introduced (for example, a longer range anti-tank missile), the services might be convinced to purchase the system, but only in small quantities for specialized units. Negotiations might then follow, where the defense industries would object that production at such low levels would be impossible, while the services would plead poverty as well as satisfaction with current systems. The possibility of exports tempered this dynamic to some extent, but the international market is similarly sensitive to price. Thus the resources available for production were often as limited as those available for development.

Some in the Israeli security elite also recognized the larger resource burdens of an extensive technological system. Beyond the cost of individual projects, building up new capabilities and infrastructure involves a commitment to using, sustaining, and modernizing an economic and technological totality. For example, some of those who objected to the establishment of Israel Aircraft Industries understood the commitment that was necessary to make IAI a successful enterprise. For the foreseeable future, IAI would consume a large fraction of both available capital investments funds and technically competent workers and engineers. Similarly, the IDF and El Al would need to purchase military and civilian systems from IAI, even when other systems might appear more attractive.[64] More recently, some opponents of the Lavi fighter aircraft program explicitly wanted to avoid creating the vested interests and the employment implications of an R&D effort and production line.[65]

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[64]Peres, *David's Sling*, 126-27.

[65]Eli Levita of the Jaffee Center recalled in an interview that Yuval Ne'eman, then a cabinet member, made this argument against the Lavi.

Available Alternatives

Economic limitations only make political sense in the context of the available alternatives. As discussed in the case of Brazil and India, money is very much a dependent variable, representing the degree of political support that a program enjoys within communities that have the authority to provide funding. By almost any measure, Israeli society devotes a tremendous fraction of its overall wealth to its military.[66] Any perceived limitations therefore indicate disagreement over relative priorities, rather than some mythical economic reality. (In many ways, Israel has been ignoring economic reality since before its founding--see the discussion of Zionist economics, above.)

The available alternatives reveal how the perspective of the Israeli defense industry differs from other segments of Israeli society. The first question is how high a priority to assign to defense as a whole--a question that Israeli society has answered with more emphasis on the military than almost any other nation in the world. But a very large fraction of the resources devoted to the military are not directed toward purchasing weaponry, but to alternative investments in people, operations, and non-weapons equipment (such as dispersing supply depots to enable rapid mobilization). Particularly in the stress on personnel and training, these priorities reflect Zionism's emphasis on people, as discussed above. Then-Defense Minister Yithak Rabin, in referring to Israel's strengths in personnel,

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[66]For a somewhat dated but still interesting quantitative analysis of the factors correlated with overall defense spending, see Alex Mintz and Michael Ward, "The Evolution of Israel's Military Expenditures: 1960-1983," Program in Arms Control, Disarmament and International Security, University of Illinois at Urbana-Champaign (December 1985).

reasoned, "That is probably why the Arabs went to push-button SSMs [missiles], so that they can avoid the confrontation in the areas of quality of motivation."[67]

Even when agreement is achieved on the resources that would be appropriate to devote to weaponry, the technological character of that weaponry is still open to dispute, further limiting the resources available to the defense industries for developing new technology. Particularly in the early years, the entire enterprise of technologically advanced weapons was suspect. One industrialist reminded me that:

> You must realize at that time the military and the Air Force did not believe in missiles. In the Shafrir 2, one major specification was that it shouldn't interfere, in *any* way, with entering a gun battle...So they say, "OK, you play your games, but we want to be able to go into gun battle."

Today, that basic philosophical difference is gone. As one long-time manager said, "The fear of the '50s and '60s--that it was just good money going down the drain--that's not the case now." But for specific weapons systems, the advantages of expanded capabilities or more sophisticated technologies are not necessarily clear to all concerned parties. One industrialist offered a hypothetical depiction:

> We come to the Army and we say, "You want a new projectile for the tank." They said, "Why?" [We answer,] "Because it has a better penetration, da, da, da." Then you arrange for a demonstration, where you put up [the target] or whatever it is, and you bring in all the old kind....If the demonstration is without any problems, and shows the advantage of your new projectile, they'll all say "OK, now let's consider how much you want for such a projectile. Let's consider what it means, re-arming the tanks....Then they might say, "OK, the first ten thousand for a certain type of tank or a certain type of unit."
>
> ...Before funding and everything else, first of all the Army must be satisfied that what is there offered, is something they need, and it's feasible to produce.

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[67]Lok, "Rabin: Meeting the Missile Threat," 1141.

> *How do you satisfy them of that?*
>
> You need to invest your own money. You invest your own money, by making some kind of very simple test.
>
> *Just the concept is never enough, you need some hardware?*
>
> Of course the concept is not enough! Don't forget, your Army people are not scientists [i.e., they do not share in the construction of this technical knowledge]. They are officers! Not only that, you explain to him why you think it's better than what he has. [He might answer,] "I've got a TOW--what's wrong with a TOW? Why do you think what you have is better?" And you say, "The range is higher." He says, "OK, when do I want the higher range? Four kilometers is not enough? Seems plenty. And how often will I hit with your contraption, as opposed to what I hit with [the current] version?" And then they'll say, "OK, maybe we'll give it to very special units." Then you say, "Very special units are not enough for me. I can't produce for very special unit, it's not enough."
>
> ...The idea is, does the Army really consider this as a viable thing? As a *necessary* thing? Don't forget that, as we said before, the Army has solutions to most of the problems they envisage now. They don't really envisage whether the solutions are...[better] or not than something else.

Finally, the most important disagreement, which most constrains the resources available for the defense industries, is over the source of high-tech weapons systems. Even if the defense industries can gain acceptance of the need for a particular type of system, a large number of factor militate against the approval of Israeli development or production of new technology or weapons systems:

- Disbelief in Israeli mastery of advanced technologies;
- Uncertainty in the ultimate quality and capabilities of a not-yet-developed system;
- Differing time horizons for the military and the industries; and
- The willingness of foreign suppliers (mostly France and then the United States) to offer known, tested, currently available advanced weapons systems.

The constant, though often implicit, comparison with foreign weapons systems has often proven to be the most difficult hurdle for Israeli developers, and the source of the most constraining of the "economic realities."

The early history of the Israeli defense industries is replete with examples of leaders of the IDF dismissing their ambitions. During a visit to Emet (the predecessor of Rafael) at the invitation of Emet's president, Munyah Mardor, chief of staff Moshe Dayan told Mardor, "Look, you know that I don't believe in any of this, but you invited me--so I came!"[68] Much later, in a speech by Yithak Rabin, the Chief of Staff told Rafael personnel, "We are already in the 1960s, and you have been operating for more than 20 years. What have you contributed to the IDF? Nothing!"[69]

Those categorical denials diminished with time and accomplishment (though a leader of one of the defense industries told me that "the 1982 war was the first war where we really had a lot of materiel developed and produced in Israel that gave very good results.") Even more recently for specific programs, the same dynamic remains in evidence. For example, when the Technion sought funding for a hypersonic wind tunnel, the response as recounted by one scientist involved at the time was "You are crazy!...Israel in space, hypersonics? Crazy!" Even the industries did not support the proposal, because:

> Industry was *always* lagging behind. We were predicting what the industry was going to do, but the industry didn't believe us. This is a process that happened all the time--we [academic scientists] were always one jump or one step ahead of the industry.

Approximately eight years later, IAI did begin its own hypersonic wind tunnel.

68The 1956 visit is described in Mardor, *Rafael*, 149-50.

69Klieman and Pedatzur, *Rearming Israel*, 73.

Similarly, throughout the history of the space program, advocates were unable to overcome a basic incredulity about Israel's technological pretensions. A scientist who was present on a tour given by Shimon Peres to Prime Minister Levi Eshkol of a test facility in the Negev told me of the following exchange:

> Shimon Peres told him proudly, "You know, once this is set up, this place, it can also even be used for launching satellites."
>
> He [Eshkol] said, "What?" [Peres answered,] L'shageyr lavyanim [to launch satellites].
>
> [Eshkol repeated,] "What?" He said, he [Peres] used the English word, "L'shager satelitim, satelitim!"
>
> [Eshkol answered,] "Satelitim?! Far vus stam darf haben?!"

This scientist translated the Yiddish for me, accompanied by banging his fist on the table: "What do we need it for?!"

Even into the 1970s and even among personnel at Rafael, scientists who favored investment in space technology were told, "Look, why are you wasting money on things of space. Israel will never do space, it's too big for us--forget it!" Still today, among scientists who are currently involved in the space program, a certain sense of trespass lingers, for example in one scientist's reaction to seeing IAI's facilities for satellite construction: "Very impressive. You go to U.S. or Europe, and you expect it, but you visit the sites in Israel, and it's surprising."

This underlying questioning of Israeli technological capabilities reinforces the uncertainties that attend any challenging project in its early stages, before the black box has been closed. Particularly in contrast to the sureties of purchasing existing weapons systems from foreign suppliers, indigenous weapons systems can appear as dubious gambles. As one industrialist phrased the IDF's usual position: "We know that this is the response of the Air Force: 'If I buy it from the States, I know what I buy. Tell me what you're giving! And you're speaking of still five years before you have the missile.'"

In general, the defense industries and the military services operate under dramatically different time horizons. As one industrialist told me,

> The major difference being that our army feels that it has to be ready to fight next morning.[70] And therefore they feel their responsibility to give first, all the necessary resources for immediate readiness. And the

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[70]Note the metaphoric content: morning is what comes after the dark and uncertain night, and is when you discover that your situation has changed.

> further you go in time--less and less. This, of course, is completely against all long-range development. If you were in a country which is at war, which every few years has a war, it's of course very easy to understand.

Countering the military's perspective can be quite difficult for the defense industries: "It's not easy to tell the Army, 'No, you can't have the money, I want the money for something which will be in ten years.'" Even among outside analysts, certain axioms reinforce the demands of short time horizons: "All materiel must be 'in place' prior to the initiation of hostilities...There would be no time to develop new systems during the conflict."[71]

To combat all these questions, defense industries respond by following a number of conservative development practices, which will be described in detail later. One additional phenomenon can help us to understand the dynamic nature of the contest between forces promoting and inhibiting the development of military technology. Artifacts, such as rocket motors, can play the role of actors in these contests. Past technological successes serve as important allies in overcoming disbelief just described, by adding to the developers' cycle of credibility.[72]

For example, a recent news report quotes Professor Haim Eshed, director of projects at the ISA, "who has been called crazy more than once for pushing for a space program in Israel, [as saying,] 'I am sure the satellite [Techsat] will work.

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[71] Benjamin Peled, "Technology and the Future of Air Operations," in Feldman, *Technology and Strategy*, 44-49, 45. Similarly, then-Chief of Staff Shomron wrote that "It is dangerous...to procure ordnance that might take years to integrate into our armed forces and combat doctrine. But a war could break out in the interim." Cited in Klieman and Pedatzur, *Rearming Israel*, 113. Also note the interesting similarities to the argument made by some economists, that by focusing on the military industries, Israel is sacrificing long-term economic strength for short-term military benefits.

[72] See "Cycles of Credit," ch. 5 in Bruno Latour and Steve Woolgar, *Laboratory Life: The Social Construction of Scientific Facts* (Beverly Hills, Calif.: Sage, 1979), 187-233.

Just like Ofek 1 worked and then Ofek 2 and like the Amos will work.'"[73] Eshed is using these past successes as allies for future projects. Similarly, one industrialist at Ta'as described in general terms some strategies for garnering support for large projects:

> We always invested, Ta'as always invested a lot of its own money into it, that's clear. But for the heavy programs, the larger programs, you had to get the money from someone, from the Minister of Defense.
>
> *One technique was to have already done some work?*
>
> You are right, we always said we can do it. We had to prove it by some things, by other developments that were related.
>
> *For example?*
>
> We made the big motors for the satellite, so it was quite clear that we could make the Hetz as well.

Finally, the willingness of foreign arms suppliers to export to Israel operates as a crucial control valve for the resources flowing to indigenous weapons development. As the mirror image of the boycotts and embargoes discussed above, foreign suppliers can threaten to eliminate established, major programs in a single stroke. For example, one scientist involved in the Shafrir program described just how dependent the program was on U.S. unwillingness to supply the Sidewinder missile (the U.S. equivalent of the Shafrir).

> The Americans had an embargo on sophisticated weapons at that time...nobody wanted to sell missiles. So once we developed them, and the Americans saw that we had missiles, they immediately offered to the Air Force, "OK, you get Sidewinders if you want them." So the reaction of the--and I think this letter must still somewhere be lying around--the head of the Air Force wrote to the head of Rafael, "Cancel the program. We don't need it anymore, we get Sidewinders." Finished!

Foreign-supplied systems would frequently be more expensive than Israeli systems, especially in terms of foreign currency. But they could overcome the dis-

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[73]"Miniature Satellite Program," *Israeli Business Today*, 29 November 1991, p. 23.

advantages of indigenous systems described above, with predictable cost, performance, and delivery. Purchasing foreign systems would also avoid creating the vested interests and employment implications of an R&D effort and production line. Lastly, foreign systems, particularly from the United States, carry an undeniable cachet. For example, even though Ta'as produces a high-quality multiple launch rocket system similar to the U.S. MLRS, the Israeli army nonetheless "lusts" after the American version instead.[74]

In sum, while economic limitations provide a first order explanation for the forces limiting Israeli development of military technologies, a deeper investigation reveals disagreements over the need for that development. Even within the context of a polity that grants security issues the highest priority, technology development in particular nonetheless suffers from some of the same sorts of political weaknesses found in the case of Brazil or India. Most threatening to the indigenous defense industries is the possibility of meeting security requirements without high-tech weapons, or by importing the needed systems.

Secrecy

While some of the effects of secrecy promote the development of military technology, secrecy also inhibits that development by interfering with internal technology transfer and by blocking high-tech exports. Again, the political foundations of secrecy, such as kedushat ha-bithon ("the sanctity of security"), are mostly independent of specific controversies over indigenous weapons development.

[74]As "proof" of an Israeli system's quality, one former official described how even the Swiss wanted to buy it: "The Swiss don't have any sentiments, this is known. They are as hard as nails. They buy it because it's quicker, it's cheaper, and it's the best product on the market."

Secrecy is thus a structural factor, as described above, but one whose different facets cut both ways with respect to developing military technology.

In a defense industry such as Israel's, with multiple centers of innovation and production, secrecy reduces the chances that people who might be interested in recently developed technologies will know about them. What internal technology transfer that does occur is mostly at the level of components, often at the prompting of Mafat in the Ministry of Defense, according to interviews with Ministry officials. Basic research, and certainly work that is conducted at an unclassified level, is usually known within the appropriate circles.[75]

More important is the effect of secrecy on military exports. Exports of older systems are not severely limited by secrecy, and can help to supplement the small production runs ordinarily needed for the Israeli military. But for newer systems, and especially systems still under development, secrecy can rule out the exports that otherwise could provide crucial capital (see the examples of foreign funding for development, below). One industrialist described the dilemma:

> If...the army hasn't got any money, then the army will say, "Look, if you can finance it, then I don't mind if you do it, and I'll cooperate in looking at it, coming to the tests, and everything else, I'll cooperate. I'll even, if you want, make one officer monitor it."
>
> *At that point, you look for export potential?*
>
> No, not yet! Ah, foreign potential, that's very difficult. Because if it's good, the [unintelligible] says, "No! Of course not." That's one thing that Rafael, and even Ta'as, come very often to the Minister of Defense, and say, "You can't on the one hand say, 'This we cannot sell abroad, and on

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[75]For example, Prof. Alon Gany's post-doctoral research at Princeton in the mid-1970s on particle agglomeration in aluminized fuels was already well-known within both Rafael and Ta'as by the time he returned to Israel. See Alon Gany and Leonard Caveny, "Agglomeration and Ignition Mechanism of Aluminum Particles in Solid Propellants," *Proceedings of the 17th International Symposium on Combustion* (Pittsburgh: The Combustion Institute, 1978), 1453-61.

> the other hand you not give us any money.' Because we *can* make some money by selling it abroad."
>
> *Has the balance changed over time? Can you now sell more than you used to?*
>
> No, we can sell less than we used to...The Ministry doesn't have a say in it; the Army does. The Army says, "This is yet something I want to keep a secret."

While the IDF sets the basic policy in this area ("military people, you know, say an automatic 'No'"), the Ministry has overturned IDF rulings on a number of occasions. Presumably, such instances are kept to a minimum. Secrecy thus acts as a serious constraint on sales and on raising development capital, and might even serve as a tool for the military services in regaining some control over the defense industries' development efforts.

IV. Synthesis: Patterns in the Israeli Development of Military Technologies

Combining the themes described in the previous section, we have a picture of a systematic push in favor of developing military technology, operating within strong constraints against such development (see Fig. 1, *supra*). In this section, we will describe how the characteristics of resulting artifacts are determined largely by a synthesis of these conflicting forces, rather than any specific military capabilities. When an innovation manages to squeeze its way through the constraining forces, then just like an extruded bar of steel, it bears the shape of what it was squeezed through.

The resulting patterns in Israeli military technology are heavily biased: they are all ways of overcoming the forces inhibiting development. Logically, we observe patterns only for those systems which actually get developed. When promoting and constraining forces in this dynamic equilibrium are directly paired, then we can observe a classic thesis-antithesis-synthesis structure (of which "virtual autonomy," described below, is the most striking example). Otherwise, the resulting patterns are more complex, but are still functionally adapted to meeting the simultaneous demands of conflicting forces.[76] By examining the resulting patterns, we can read out the social and political context that engendered them, just as we would for the resulting patterns in a particular artifact.

Virtual Autonomy

Virtual autonomy is a synthesis of the themes of self-reliance and economic limitations, attempting to satisfy the contradictory beliefs of different constituencies.

Definitions of Autonomy: As discussed above, Israeli society has not reached a consensus on the need for self-reliance or autonomy. Economists, many businessmen, Americophiles, Finance Ministry personnel and bankers, and many scientists, all saw interdependence or economic strength as preferred goals, both

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[76]This account is explicitly functionalist, using as its homeostatic or self-regulating hypothesis the need for continued funding in order for a program to survive. Positing the existence of a homeostatic force in the Israeli case is supported by the relative success of Israeli development programs, in contrast to those of India or Brazil: some process of winnowing does seem to be taking place within the crucible of Israeli defense politics. The account given below attempts to include the historical and cultural contingencies which account for the selection of a particular outcome out of a larger set which meet the functionalist requirements. For a general discussion of the limitations and prerequisites of a functionalist argument, see "Functional Explanation: In General," ch. 9 in Gerald Allan Cohen, *Karl Marx's Theory of History: A Defence* (Princeton: Princeton University Press, 1978), 249-77.

as appropriate defense policy and as good policy for the country as a whole.[77] Even among those who favor autonomy, there are competing, and contradictory, definitions.

1) Freedom of military action. For many members of the military, autonomy demands using what little money you have to buy, immediately, the greatest number of working weapons systems with the greatest known capability. The weapons in your order of battle at any given point determine your freedom to act independently. Those who use the weapons systems, and those whose image of Israel's security requirements is one of immediate need, favor this definition. (See the discussion of time horizons and uncertainties in the previous section.) Some of the costs of this option include always having to import the next round of equipment and the loss of any developmental or export benefits of the defense industries. These costs appear acceptable, because immediate security needs outweigh future costs, and because putting resources into development in other areas will produce more economic benefits than investment in defense (with those benefits also becoming available later to contribute to defense needs).[78]

2) Technological autonomy. Unlike in Brazil or India, the idea of technological autonomy does not seem to be a powerful one in Israeli discourse. Usually, in the developmental context, achieving technological autonomy means acquiring the indigenous capability to innovate systems and artifacts in order to meet evolving national needs and priorities. Israel made the transition to that capability

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[77]For a summary of this point of view, see Klieman's and Pedatzur's discussion of their "Model II," in *Rearming Israel*, 161-68. See also Tsevi Ofer and Avi Kober, eds., *Mehir ha-Otsmah* [The Price of Power] (Tel Aviv: Misrad ha-Bithon, ha-Hotsaah ha-Or, 1984); and the works cited above in note 22.

[78]This latter argument is similar to the "rising tide lifts all boats" theme in the Indian debate.

immediately after independence, with the move away from an agriculturally-based economy. While the change was wrenching ideologically because of the way it altered the society's relationship with the land, it was accomplished quickly, easily, and with a relatively strong consensus.[79] But technological autonomy is not the same as autarky, so that the choices for Israel involve applying general capabilities to create systems that meet specific needs. The Israeli elite acknowledges that Israel can be technologically autonomous in any sector it desires--just not in all sectors at once.

3) **Autarky.** The goal of autarky simply does not appear in the mainstream debate in Israel. None of the common political perspectives require such complete independence and isolation. The constant conversational refrain that "Israel is a small country," and the immigrant status of so much of the population (approximately forty percent), also probably limit such desires. However, as described above, the concept of self-reliance is elastic, and sometimes expands enough to impinge on autarky. Thus, in discussing Israel's requirements for satellite reconnaissance data with someone involved in the space program, I was told that Israel should not have to depend on the United States for any photorecon at all, even at SPOT-level resolutions. Nonetheless, such opinions do not represent the overall perspective of any individual whom I interviewed, much less that of any significant segment of the polity.

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[79]Peres argues that "When the initial steps...[of the founding] of the State of Israel, the first act was laying the foundation stone of the agricultural school in Mikveh Yisra'el. This reflected the central aim of the Zionist movement--the return of the nation to its soil....But when the State came into being, the accent in the world's economy was already going over from agriculture to industry. Moreover, the need for...independence meant that it was not enough for a nation to grow its own bread. In our case, it had also to produce its own shield and sword." *David's Sling*, 113.

4) Virtual autonomy. Finally, the definition of autonomy that has achieved hegemony within the Israeli security elite is "virtual autonomy." This strategy requires investing heavily in infrastructure and in general areas of technological capability, without worrying so much about specific capabilities, or how long it will take to get them. The costs of this strategy include: dependence on outside funds for investing in these capabilities; dependence on those systems or components which are not yet produced indigenously; and dependence on either foreign sales or foreign aid to keep production lines open, to keep a specialized, high-tech labor force employed, and to cover R&D overhead.[80]

These costs are acceptable, because "autonomy" in this context means *potential* autonomy, at some indefinite time, maybe ten or fifteen years in the future. Furthermore, that potential autonomy does not need to be realized--*ever*. Merely having this potential for the future means that if the political situation gets much worse, then the state has the option of going it alone thereafter. Such an eventuality would be much more expensive, but if it were to become necessary, it would at least be possible.

This strategy does not require ever planning or spending specifically to achieve complete autonomy, because acquiring a capability in any given sector can always remain somewhere in the future. Just like virtual particles in high-energy physics, if you try to find this variety of autonomy at any particular place or time, it is not really there. Yet tremendous energy goes into creating it.[81]

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[80]For a different vision of a workable strategy that contains elements of both dependence and self-reliance, see Klieman and Pedatzur, *Rearming Israel*, 176-202.

[81]A similar use of the phrase "virtual sword" appeared in "Will the Bangs End with a Whimper?" *The Economist*, 2 November 1991, 79-82, 81. In discussing the future of the U.S. nuclear weapons laboratories, the article remarks that a nuclear weapons "capability can be kept by making 'paper weapons' and a few prototypes--virtual swords."

Implications of Virtual Autonomy: Virtual autonomy is a synthesis of the opposing forces of self-reliance and economic limitations. It is more than a compromise, because it provides a way out of the contradictions of opposing forces. By placing such a strong emphasis on capability and potential (with actual systems being optional), while at the same time buying foreign components and systems, a strategy of virtual autonomy combines both self-reliance and economic limitations; both U.S. willingness to supply advanced weapons and concerns about embargoes; both faith in technology and the requirements of short time horizons.

In its quest for virtual autonomy, Israel has accepted numerous forms of dependence. Crucial funding for investment in technology-intensive infrastructure came from outside the state: from U.S. aid, from export revenues, from international loans, from the donations of world Jewry, and during a critical period in the 1950s, from German war reparations.[82] As one industrialist noted, for just the funding from the United States, "once you depend on American money, there's no self-sufficiency."

The United States plays a special role in Israeli export dependence. It is simultaneously the largest funder for development and the largest potential market; but it is also the largest competitor, and holds tight reins on exports of Israeli weapons systems that include U.S.-supplied components. Klieman discusses the "virtual stranglehold retained by the United States over key areas of

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[82] On the latter, Reiser reports that "The breakthrough in capital acquisition...and the formation of a modern weapons industry came with the Reparation and restitutions Agreements with...Germany in 1953." Reparations started at $40 million in 1953, reaching $199 million in 1961. *Israeli Arms Industry*, 18-19.

the Israeli military sales program," citing the difficulties that Israel has had in selling its Kfir aircraft abroad:

> The Kfir has a General Electric J79-17 engine...[so] each transaction is subject to veto by the American government...In February, 1977, the first foreign order for the Kfir--twenty-four fighters by Ecuador--was vetoed by President Carter. Shortly before the 1980 elections the administration announced that Israel would be allowed to offer the Kfir to Mexico, Columbia, and Venezuela, but by then they had contacted alternative suppliers. In June, 1978, when the United States allowed the sale of up to sixty Kfirs to Taiwan, public disclosure forced embarrassed Chinese officials to reject the offer.[83]

Similarly, support from the United States essentially dictated both the possibility and the demise of the Lavi project.[84] The negotiated agreement for ending U.S. subsidies included taking the lead in funding Israeli development of an anti-tactical ballistic missile. In effect, the U.S. Department of Defense selected an IAI system, the Arrow, over a system that had been in development at Rafael, the AB-10.[85] Subsequently, in negotiating the next phase of develop

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[83]Klieman, *Israel's Global Reach*, 184-85. On the other hand, former officials recall that Israel's "Popeye" air-to-surface missile averted cancellation in the mid-1980s only because Rafael received contracts from the United States in the nick of time.

[84]Klieman and Pedatzur cite the Lavi as "confirmation of increasing, rather than diminishing, arms dependency." *Rearming Israel*, 164n, citing State Controller of the State of Israel, *Annual Report 1986*, no. 37 (Jerusalem: Government Printer, June 1987).

[85]According to "IAI, Rafael Seek SDI Funding for ATBM Systems," *Aerospace Daily*, 28 May 1987, p. 321, Rafael was lobbying for its AB-3 and AB-10 shorter-range systems that are based on the AB-2 Barak ship-based anti-missile system. Neither IAI's or Rafael's system had been test fired, and both were hoping to be built with the United States in a joint venture. The Ministry of Defence was evaluating both, with an eye toward which one would best garner funding from the U.S. Congress. When the Arrow program won out, some even cried foul, accusing Defense Minister Moshe Arens (a former director general of IAI) of unfairly favoring IAI's Arrow. "Rafael Armaments Plans Its Future," *Israeli Commercial Economic Newsletter*, 20 December 1990, p. 17. Rafael continued its opposition to the Arrow, joined by large portions of the IAF who were concerned about resources being diverted from other important areas. "Israel Stands Firm Against Arrow Project," *Flight International*, 26 March 1991, p. 11. See also Marvin Feuerwerger, "The Arrow Next Time? Israel's Missile Defense Program for the 1990s," Policy Paper #28 (Washington, D.C.: The Washington

ment, continued U.S. funding was secured at the price of severely restricting the Israeli exports of missiles and missile technology.[86]

Israel also remains dependent on foreign suppliers for important components in their ostensibly indigenous systems. Every Israeli aircraft, up to and including the Lavi fighter, used engines from either the United States or France. The Merkava tank uses engines from the United States. As the same industrialist noted, "You'd have to spend hundreds of millions of dollars if you really wanted to build the Continental engine for the tank. So there's no self-sufficiency here." Overall, a financial advisor to the defense ministry estimated that under 25% of the equipment in the inventory of the IDF as of 1985 was manufactured in Israel.[87]

Yet while these forms of dependence might be in contradiction with a strategy of self-sufficiency, they are completely compatible with a strategy of

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Institute for Near East Policy, 1991); and Reuven Pedatzur's forthcoming study on the Arrow, to be published in 1993 by the Jaffee Center for Strategic Studies, Tel Aviv University.

[86]See "Israel Finally Signs Missile Treaty," *Flight International*, 9-15 October 1991, p. 5; and Neal Sandler, "USA Brings Israel Into Line on MTCR," *Jane's Defence Weekly* (12 October 1991): 644. For a broader discussion of U.S. pressure and the effects on Israeli industry, see Gerald Steinberg, "Israel: Case Study for International Missile Trade and Nonproliferation Project," to appear in William Potter and Harlan Jencks, eds., *International Missile Trade and Capabilities* (forthcoming), draft, 4 April 1992. Steinberg writes that "according to the regulations, an Israeli scientist working in the area of solid fuel for rockets would be prohibited from lecturing abroad about his research, even if this research had been published" (p. 23). Eli Levita of the Jaffee Center claims that the United States put an extreme amount of pressure on Israel to sign a bilateral agreement, and that Israeli industries have viewed the ever-expanding dual-use lists with despair and anger.

[87]Similarly, the U.S. General Accounting Office cited Israeli officials who estimate that Israeli arms exports during 1981-82 had an import content of about 36 percent. General Accounting Office, *U.S. Assistance to the State of Israel*, (Washington, D.C.: GAO, 24 June 1983), ID-83-51, p. 43.

virtual autonomy. At the chronically money-losing Bet Shemesh plant, plans for licensed production of jet engines are continually negotiated and canceled; the IAI and the Aerospace Engineering department at the Technion conduct extensive research on engine design and performance; the Bedek division of IAI routinely overhauls the most advanced foreign-made engines. Thus the industries generate the capacity for indigenous development, while avoiding the costs of real projects and still satisfying all the major constituencies.

By pursuing virtual autonomy, the Israeli military takes every possible advantage of the willingness of the United States to supply specific technologies and technologically-advanced weapon systems. Israel imports the F-15 and F-16 aircraft, the Harpoon, Sidewinder, and Patriot missiles, and countless other smaller items. Yet their emphasis on technological potential permits them to be simultaneously fighting against the threat of embargoes or boycotts. The Israeli understanding is that the U.S. willingness to supply such weapons remains completely dependent on Israeli capability to produce them on their own were Israel to be denied such a supply in the future.

This strategy ('build it and they will supply') is based on just as potent a historical mythology as Israel's concerns about embargoes. The classic cases include the Israeli/American pairs of the Merkavah and M1 tanks; the Shafrir and Sidewinder air-to-air missiles; and the Gabriel and Harpoon sea-to-sea missiles. The litany features countless smaller items, and may soon add photoreconnaissance data:

> The Americans will not give us--that was our argument--not give us hardware unless we can show that we can do it ourselves. Same thing applies to the satellite, by the way. The moment that we have our own satellite: "Why do you have to do that? We [will] give you all that you need." OK, that's how it goes.

The result, according to one former Mafat official,

> is the philosophy of the military R&D: "Hey, let's develop new weapons. Then the Americans will give us, somebody will give us." Even if you don't go to manufacturing, but if you have the possibility of manufacturing such missiles, then the opportunity to purchase such weapons is much better.

Virtual autonomy also provides justification for continuing research efforts and successive generations of existing systems. According to one industrialist, who was describing why Israel has continued to buy both the indigenous Shafrir air-to-air missile and the comparable American-made Sidewinder, "We had always one or two steps ahead of what the Americans would give us. We had always Sidewinder C, you had already E or F in the U.S. In the [end,] we suggest that maybe the Americans will buy from *us*."

Finally, virtual autonomy bridges the gap between faith in the long-term benefits of investing in technology, and the short-term requirements of the Israeli military. In the unlikely event that the embryonic autarky embodied in virtual autonomy were to have to be brought to maturity, then lengthy development periods would certainly follow. But while the autonomy remains only virtual, the military enjoys the privilege of seeking immediate redress for emerging needs by purchasing foreign weapons systems, while still supporting an indigenous base. Thus, when the 1973 Yom Kippur War brought home the realization that an effective medium-range air-to-surface missile could have a significant multiplier effect for the Air Force, the IAF could both solicit the Israeli defense industries to develop such a missile, and seek to meet their requirements through purchasing the Maverick missile from the United States. Meanwhile, what eventually became known as the Popeye missile remained in development for over a dozen years, until the U.S. Air Force paid for completing its entry into production.

Beyond the period of study, virtual autonomy survived intact at least until the mid-1980s. The twin body-blows of hyperinflation and the cancellation of the Lavi project led some people within the defense establishment to the conclusion that the strategy "went amok." The Lavi project in particular may have overstepped the bounds of the construct in attempting to realize too much autonomy.[88] Interestingly, the project was born out of a refusal by the United States and General Dynamics to permit Israeli co-production of the F-16 fighter, which would have been more in consonance with a strategy of virtual autonomy.[89] At any rate, no compelling replacement has yet arrived on the Israeli political scene, and the contradictions that the strategy helps to avoid still remain, so that virtual autonomy even today is something of a default strategy for the defense industries.[90]

Export Dependence

Like virtual autonomy, export dependence is a synthesis of the conflicting forces

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[88]There is already a large literature on the Lavi project and its cancellation. The history is ably summarized in Ralph Sanders, "The Lavi: Israel's Limits to Weapons Development," *Technology in Society* 13, no. 3 (1991): 345-58. See also the series of articles by Reuven Pedatzur, "The Lavi, Security and the Economy," *Ha-Aretz*, 12, 14, and 16 February 1984. For an interesting comparison with other development projects in Israel, see Gerald Steinberg, "Large-scale National Projects as Political Symbols," *Comparative Politics* 19, no. 3 (April 1987): 331-46.

[89]Steinberg, "Israel: High-Technology Roulette," 168.

[90]For a somewhat similar analysis that questions the long-term viability of Israel's current strategy, see "Israel's Defense Industry: Evolution and Prospects," ch. 5 in Office of Technology Assessment, *Global Arms Trade*, 85-103.

described in the first sections of this chapter. With enough exports, the Israeli defense industries can achieve self-reliance within existing economic limitations. By drawing in billions of external dollars, the defense industries can:

- Generate economical production runs (escaping the small size of the domestic Israeli market);
- Find benefactors to support specific technology development projects (which the IDF would not be interested in supporting); and
- Acquire enough sales revenue and organizational slack to be able to self-finance their own development projects (which the Ministry of Defense would not be willing or able to fund).

The initial move toward export dependence was not a conscious strategy. The new synthesis was a bottom-up process that provided a way out of a whole set of contradictions. According to one industrialist, when the philosophy of self-reliance achieved hegemony following the French embargo in 1967:

> Once you embrace such a policy...you cannot sustain it economically just on an Israeli basis. You must go to exports.
> *This wasn't realized at first?*
> It was not!

At the start, the best way to reap the benefits of exports was not even clear. One industrialist criticized the way that Ta'as entered the export market:

> They never understood the theory of know-how. They didn't understand that know-how, you don't sell cheaply. But they were in such a euphoria of being able to sell *fifty thousand* projectiles--the idea was that if you buy fifty thousand projectiles, you get the know-how to produce it yourself. Now everybody in the world has these projectiles, of course, because they are the best--there is no question as to that. And everybody can produce it, because everybody found that the cheapest way of getting know-how [from Ta'as] is to buy fifty thousand projectiles.

Those who did understand the benefits were mostly to be found in the defense industries, not among the planners at the Ministry of Defense. When asked if the Ministry in the early and mid-1970s encouraged exports, a retired industrialist answered,

> Yes. But it was mainly our own encouragement--we wanted to exist, and we wanted to grow, and we wanted to prosper, which we did. The market was there, and we had very good product.

As export dependence grew, it became a lynch-pin of Israeli defense industrial policy. As noted above, by the mid-1980s, exports absorbed the majority of the defense industries' output. In 1985, when the internal contradictions of the Israeli economy and the defense industries exploded into hyperinflation, then-Defense Minister Yitchak Rabin reportedly told a meeting of the leaders of the defense industries, "If you want to survive, you have to export." At the same time, the Ministry promulgated a more liberal policy regarding export licenses.[91] As one Israeli economist put it, exports had come to be seen as "the chicken that laid the gold egg."

In terms of the development of military technology, one of the most important roles of export dependence was the Israeli success in finding foreign supporters for development projects. While earlier foreign funds had been channeled into defense industrial infrastructure (for example, the German war reparations), by the mid- to late-1960s, projects which could not attract Israeli funding got their start on the basis of foreign support. For instance, the first rocket system developed in Israel was the 290 mm system requested and funded by the West Germans, while subsequent rocket systems also found the support abroad that they could not recruit among the Israeli army (see below).

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[91] Interview with Gerald Steinberg at Bar-Ilan University. See also "How Arms Policy is Made in Israel," ch. 6 in Klieman, *Israel's Global Reach*, 92-122.

In fairly short order, the defense industries were using foreign funding for everything from small, fundamental development to the largest strategic systems. An Israeli steel company used South African funding to develop new alloys for use in armored systems, while Israel has also negotiated with Iran for funding to develop new long-range surface-to-surface ballistic missiles.[92]

The industries also learned to use exports to avoid scrutiny from the Ministry of Defense. In what appears to be an unexceptional case, one of the defense industries came to the Ministry for permission to develop a new missile system. Ministry officials asked,

> "Where the money will come from?" They said, "We've found a solution: some country in South America will finance it. Right here we have the draft of the contract."

However, according to an advisor of the Ministry, the contract upon closer inspection turned out to be insufficient to fund the development, so that either internal or Ministry funds would need to be committed sometime in the future. According to one industrialist, this technique is one way *l'sabeh* ("to intertwine") the defense bureaucracy, "to involve them in something that later it will be difficult to climb out of it."

Exports can even taken on the same "virtual" characteristics as autonomy. The potential market for Israeli-manufactured space technology has powered large investments, especially at IAI.[93] Officials involved in the program argue

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92"Has Congress Doomed Israel's Affair with South Africa?" *Washington Post* (22 February 1987), pp. C1,C2; National Security Archive, "Weizman-Tufanian Transcript," 16-17. For expensive, strategic systems, the U.S. has more recently become a key funder, including the Lavi and Arrow projects (see below).

93According to "IAI to Boost Civil Shavit," *Flight International* (19 December 1990 - 1 January 1991): 11, IAI "will continue its efforts to enter the civil space launch market with versions of the Shavit booster...'We were aware of the limitations but still we decided to join the competition to signal our intention to stay in this potential market,' says IAI." IAI is also investing in other infrastructure, such as an image receiving and processing facility that "enhances IAI's growing reputation as a member of the international space services community, as well as its Electronics Division's penethat capturing only a small fraction of the world space market would be a major economic gain for Israel, as well as propelling Israeli industry to a new level of technological sophistication and quality control.[94] Thus the mere possibility of future exports has acted as a kind of lode star, prompting massive investment of internal IAI funds as well as government spending for everything from satellite launches and ground facilities to university programs in the space sciences.

If the global market for Israeli military sales continues to contract, the U.S. veto over numerous Israeli exports will have to be the subject of extensive negotiations, both within Israel and with the United States. Entry into the U.S. market, on a competitive basis, would probably provide all the financial support that the Israeli defense industries need in order to continue their current strategies of virtual autonomy and export dependence, although the dependence would become even more concentrated than it is now. Any other outcome would probably require an extensive restructuring of Israeli defense industrial policies.

Although the synthesis of export dependence has allowed Israeli defense industries to escape contradictions in their overall policies, some problems may

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tration of the international space market." For several projects, "marketing costs alone have run into millions of dollars." See "IAI Station to Receive Satellite Images," *Israel Commercial Economic Newsletter* (21 December 1990): 1. Similarly, despite the "slim chance" that NASA would select a foreign launcher for the commercially oriented COMET program, IAI spent $1 million preparing for the tender, even moving its U.S. office from New York to Washington for the purpose. "NASA Says No to Shavit Rocket Launcher," *Israel Commercial Economic Newsletter* (14 December 1990): 4; and "Israel Eyes U.S. Launch Market," *Space News* (8 September 1991): 2.

[94]Akiva Bar-Nun, the ISA director, describes the Israeli space program as economic, not military, wanting only "a slice" of the $10 billion a year space market. After all, "you can only sell so many oranges." Simson Garfinkel, "Israel Shoots for a 'Moon': Civilian Space Program Claims to Target Economic not Military, Goals," *Christian Science Monitor*, 15 May 1990, p. 13.

bring those contradictions back to the fore.[95] First, Israeli export success has come to rely more and more on the technological quality of its weapons. But Israel has never been able to export its most advanced systems (except sometimes to the United States). As Ze'ev Bonen, a long-time President of Rafael, explains the dilemma:

> Israel...has been able to affect the Mideast battlefield by springing technological surprises upon its adversaries. 'Any situation which causes the premature exposure of such systems, would mean losing this major advantage of surprise in future wars.' Israel, unfortunately, cannot easily trade away this advantage in exchange for economic gains.[96]

While this self-imposed limitation interferes moderately with sales of weapons systems that Israeli defense industries have already developed, the more important effect is to dampen the bottom-up processes by which foreign funding promotes the development of new technologies and weapons systems that Israel needs for its own military requirements. Thus, one industrialist complained:

> The technology that comes out of [these development programs is] very specific, so the army won't permit it to be sold [for export]..., even small things, like tank protection.
>
> *Does the IDF buy things like that for themselves, at least?*
>
> They don't have money!
>
> *But they want the capability?*
>
> They want the capability. They want to know that if necessary we can make, but *they* don't have the money.

The second difficulty with export dependence is that it is a form of dependence. A manager at one of the defense industries for many years outlined the problem for me:

95For a good discussion on this point, see Klieman and Pedatzur, *Rearming Israel*, 79-83.

96Bonen, "Participation of Israel's Defense Industry," 122-23.

> One of the big problems of Israel today is the fact that military industries are too geared for exports. Because the fact that exports are seventy, seventy-five percent of the business of each of the big industries means that they're much more responsive to the needs of foreign countries. And this is not why we started the whole damn thing.
>
> *You started the industries to be independent, and now you're dependent on foreign markets?*
>
> That's not the point. We wanted to have the industries in order to be independent. And we became *responsive* to foreign markets. *That's* the point. We always thought, "Yes, but after all, we do it for ourselves." We don't do it for ourselves anymore.

In other words, the intimate connections between exports and technological development in the Israeli system undermines the emphasis on latent technological options that is the bedrock of virtual autonomy, as well as undermining the original justification for continued state support of the defense industries. In some ways, however, the financial dependence on foreign sales merely parallels the foreign dependence of the overall Israeli economy, and can be contained within the synthesis of virtual autonomy. Exports as an opportunistic funding mechanism do not inherently undermine the *potential* ability of Israeli defense industries to meet the needs of the Israeli military.

Bottom-up Technological Development

The distinction between top-down and bottom-up innovation is both intuitive and well-developed in the literature.[97] In a top-down system, requirements and

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[97]For a discussion of such pattern in both political processes and technological development, see Matthew Evangelista, *Innovation and the Arms Race: How the United States and the Soviet Union Develop New Military Technologies* (Ithaca, N.Y.: Cornell University Press, 1988), 22-82, esp. 27, 52 and 59-61, and the works cited therein. See the plea for a recognition of bottom-up processes in the formation of security policies, in Michael Barnett, "High Politics is Low Politics: The Domestic and Systemic Sources of Israeli Security Policy, 1967-1977," *World Politics* 42, no. 4 (July 1990): 529-62, esp. 529-35.

incentives are set from outside the organizations that have the responsibility of generating technology (although those requirements may be prompted by information produced within those organizations). For example, the crash post-World War Two effort of the Soviet Union to produce jet interceptor aircraft may have been based on some initial successes within Soviet design bureaus, but was organized and enforced by outside, higher-level organizations on the basis of outside priorities.[98] By contrast, a bottom-up system accommodates those programs that originate within the same organizations that develop the technology, with outside organizations playing a passive, responsive role. For example, the Skunk Works of the Lockheed Corporation in the United States has originated and received permission to developed numerous systems of its own conception, including the innovative U-2 and SR-71 reconnaissance aircraft.

A bottom-up system is over-determined in Israeli society. The explanations range from loose generalizations about the anti-authoritarian style of all Israelis ("The goyim are more disciplined. Here, it took some time before you accepted when you were told, 'No'") to the idea that garbage-can processes dominate in an environment heavily populated by contradictions. In this analysis, we will continue to examine syntheses--that is, the results of the conflict of forces promoting and inhibiting the development of military technologies.

Resource-cheap Development: To overcome the forces inhibiting technology development, the Israeli defense industries attempt to limit severely the resources needed to develop new systems. A variety of techniques serve to reduce the requirements for money, technology, time, and political authority.

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[98]Evangelista, *Innovation and the Arms Race*, 69-79.

1) Money. The official sources of funding for developing military technologies are the Ministry of Defense and the military services. As described above, the Ministry controls a central development budget, while the services have the responsibility for funding projects that are in full-scale engineering development or production. By lowering the apparent costs to the Ministry or the IDF, the defense industries increase the probability of receiving approval for their projects (or in a bottom-up system, they decrease the probability that they will be forced to stop working on a project).[99]

One main technique is to use funding from sources that do not appear in any bureaucratic budgets. For example, defense industries can use funds taken from their own profits to support other projects, as any private corporation would try to do. Even though the three major Israeli defense industries are all government-owned in some sense, the rest of the government would sometimes not even be aware of the projects being funded in this way.

One example from the early history of the industries, when such practices were far more common than today, involved outright violation of policy, and has entered into the official mythology of technology development in Israel. In the mid-1950s at Rafael, scientists led by Professor Yaacov Ziv continued to develop a transistorized receiver for the Luz missile, against "explicit instructions...not to base operational weaponry on transistors. Ya'acov Ziv...disobeyed these orders. He had faith in the future of the transistor....His success exceeded all expecta-

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[99]Note that this analysis contradicts conventional wisdom, which holds that "Israel's scientific community and military industries developed an impressive knack to 'deliver the goods,' coming up with timely, quick and perhaps even stunning and innovative solutions to real world IDF battlefield problems, *never mind the cost.*" Klieman and Pedatzur, *Rearming Israel*, 53, emphasis added.

tions: the transistor receiver, now an accepted fact, was introduced into the 'Luz' in 1958."[100] Today, violating specific directives would probably be grounds for dismissal, but investing corporate revenues in projects that have not been approved by the government certainly continues.

Similarly, personnel or resources assigned to other projects may be diverted to a different development effort. While such practices might be labeled waste, fraud, or abuse in the United States, they were tolerated and even admired, though for the most part only during the earlier history of the industries. For one such project, one of the managers described how he succeeded by "stealing budgets from here and there in order to make [it], because we were so certain, it's a good system, it's a necessary system, that we went ahead and did it....and the results were very good."

Foreign funding is also an excellent technique for reducing the apparent costs of a development program. Examples cited in the previous section further demonstrate how foreign support--even meager funding that cannot fully support a program--can act as a screen to protect programs from an unwelcome examination of the ultimate development costs. Through these techniques, money-cheap development programs are relatively likely to succeed, because the Ministry and the IDF in general welcome the new systems but are simply unwilling to pay full price for them.

By flaunting the benefits of military technology for general economic development, the defense industries can again lower the apparent costs of funding new programs. As discussed above, having defense expenditures do double-duty generates a powerful political ally for advocates of indigenous defense technologies.

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[100]"Israeli Missiles: First Report," 267.

This line of reasoning is particularly powerful for high-tech projects, bringing together effects on upstream industries, quality control, and the faith in technology described above.

2) Technology. The Israeli defense industries need to develop new systems or new technologies quickly, cheaply, and predictably in order to overcome the primary restraining force--the IDF's preference for foreign systems. By practicing a conservative development philosophy, the defense industries lower the technological resources needed for developing new systems. The Israeli emphasis on reducing technological inputs contrasts with the U.S. experience, where pushing the limits of capability and gold-plating are more important in winning the approval for new projects.[101]

When developing new systems, Israeli defense industries make maximum use of existing technologies and components. For example, according to a Ministry official with responsibility for missile development, a new missile project would not also develop a binder for the solid propellant. By the time of the feasibility demonstrations that mark the official beginning of most projects, the propellant would be "already developed, and tested, and shot, or you wouldn't put it" into the missile. For a preliminary study of a long-range version of the Gabriel, engineers at Ta'as used readily available components for the propellant and binder, nozzle, case, and liner, when the application was apparently quite demanding and could have benefited from new materials.[102] When Ta'as first

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[101]Unlike the Israeli system, in the United States "the intense rivalry for the few new programs is based on technological competition rather than real price competition." Jacques Gansler, *The Defense Industry* (Cambridge: MIT Press, 1980), 107.

[102]See the discussion of the Gabriel missile, below.

introduced fiberglass as a material for rocket motor cases, the managers insisted on using extremely conservative safety margins despite the results of stress analyses that had been completed at the Technion. In other words, while a conservative development philosophy may be optimized for the political environment of military technology in Israel, the resulting systems are not necessarily optimized for their intended military applications. A partial exception should be noted for Rafael, where Rafael's continued perceived stature as a national laboratory encourages a strategy of organizational differentiation, with Rafael emphasizing exotic technologies (especially for already well-defined systems or missions) as a way of competing with the other industries.

By using existing capabilities in developing new systems, each of the defense industries is also able to keep those development projects in-house. A project at one industry might not be aware of, or might choose to ignore, a particular materials processing technique available elsewhere in Israel--a phenomenon widespread in other countries as well, but probably more severe in Israel, especially given the small size of the defense establishment. Thus it is not just secrecy that accounts for discrete components being the only common form of internal technology transfer.

Israeli defense industries also tend to pursue incremental improvements to industrial capabilities. By keeping such improvements small, any given expenditure remains small, even though the total investment might need to be larger in the long run. By emphasizing infrastructure, they improve not only their industrial capacity but also their odds in the inter-industry rivalries. For example, when IAI began manufacturing the Kfir aircraft, they followed the existing French design, but replaced the jet engine with a more powerful (and more available) GE J79 engine. This single change prompted:

- A modified fuselage to accommodate the larger engine;
- More airscoops on the fuselage outer skirt to balance the higher engine surface temperature;
- A modified intake mobile plug for larger air mass flow; and
- Redesigned landing gear to bear the extra weight.[103]

This "incremental" modification was not straightforward, but could be represented as such. With the aid of such experiences, IAI's subsequent leap into airframe design and production was much easier.

Finally, developers can reduce the apparent technological demands of a new project by using an "existence proof." As one engineer defined it:

> What does it mean? You come with a new idea, to do this or that. "Anybody ever think it can be done?" You say, "No." [They answer you,] "Ah, c'mon. How come you can come with the first idea? Nobody got this idea anywhere?" So they have this kind of attitude. If somebody else has proven, and you can come and say, "I can do this and this, and even better"...it's a lot easier.

This phenomenon is particular marked with respect to the United States. According to one scientist:

> Many people, especially in engineering--though not necessarily in science, in academia--only see that the Americans do not adopt a concept, and say, "Well, if it's not good for them, why should we break our head and do it? They [the Americans] have better solutions; let's use their solutions--why do we need this?"

For example, scientists who worked on hybrid rocket technology in Israel continually felt the absence of any hybrid systems to point to in the rest of the world: "Israel is not isolated from the world....When the whole subject starting declining in the United States, people here lost interest." As a result, whatever

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[103] Rao and Ruina, *Disarmament and Development*, III-27 to III-28.

interest had existed in the late 1960s faded, until today. But now that a U.S. firm is again pursuing the technology aggressively, interest in Israel may revive.[104] Similarly, an innovative artillery design suggested by Gerald Bull was rejected because of a lack of an existence proof; shortly thereafter, the South Africans adopted the same design, with great success. Sometimes, an existence proof is not that useful as a decision rule, because both of the competing technologies may be in use. Thus, in choosing between a movable nozzle and secondary liquid injection for thrust vector control, "Because the world and all the other countries, they have both systems, so mainly the main contractor had the last word."

3) Time. The long development periods of most weapons systems is another disadvantage of indigenous weapons, from the perspective of the military services. The defense industries therefore attempt to minimize the time between the request for approval for a development program and the estimated deployment date. One primary technique is to let a project progress as far as possible before the feasibility demonstration (where the project is presented for approval). However, this technique is in conflict with the need to keep costs as low as possible before this point. The outcome is a pressure to do both at once, primarily by using existing technologies and components to put together the feasibility demonstration, and then using the same strategy when designing the system for production. For example, the unofficial feasibility demonstration for the first

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[104]See R. J. Kniffen and Kirk Flittie (both of the American Rocket Company), "The Development of a 200,000 lb(f) Thrust Hybrid Rocket Booster," *42nd Congress of the International Astronautical Federation*, Montreal, 5-11 October 1991, IAF Paper #91-265; Alon Gany, Y. M. Timnat, and M. Wolfstein, "Two-phase Flow Effects on Hybrid Combustion," *Acta Astronautica*, vol. 3 (New York: Pergamon, 1976), 241-63; and Alon Gany, "Theoretical Investigation of Hybrid Rocket Motor Employing Liquid Oxidizer," D.Sc. diss., Israel Institute of Technology, 1975.

Israeli RPV consisted of little more than a camera and some flight equipment from a hobby shop. Early production versions, while obviously using different hardware, echoed the same design philosophy.

A second technique for shortening the time horizons presented to the military is to make extremely optimistic estimates of the time remaining until deployment. Many of my interviewees were quite open about this "exaggeration factor":

> Look, in industry it's a well-known thing, the exaggeration factor. The aerospace industry: in Ta'asiya Avirit I would say it's about a factor of three; in Ta'as will be simply by two; and in Rafael about 1.5. So, that's my experience from the last forty years. I don't know what the position is today. In America, it's between about 1.3 and 2.5, depending what kind of project, how advanced the project is.[105]

Similarly, when IAI took over the Gabriel project from Rafael, "they promised to finish it in two years--I think it was maybe ten [years]. But this is the usual exaggeration."

4) Political authority. Developers also try to minimize the political authority required to carry out a development project. The more sponsors a project has, and the less ambitious the project appears to be, the less political authority or credibility needs to be expended. Thus, projects will often be multi-purpose systems that can satisfy a number of customers. The very first significant missile project in Israel, the Luz, began life as an experimental air-to-surface missile, was developed in surface-to-surface, sea-to-sea, and air-to-sea modes, and finally deployed as the Luz and the Gabriel. By contrast, Israel has never attempted to

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[105]As one could infer from these estimates, the speaker spent much of the past forty years working at Rafael.

develop a dedicated anti-aircraft missile (although the Air Force is also happy to claim all of the air defense missions for its own airplanes).

To make projects appear less ambitious developers can use two arguments. First, as mentioned above, Israeli development programs are far more likely than those in the United States to display satisficing behavior, rather than using the gold-plating or other advanced capabilities that a more user-driven innovation system would use as a draw (at least for the period under study). Second, if the defense industries request funding only for improving capability and potential, rather than production, then the customers can avoid having to commit to a particular system as being necessary or optimal. At the same time, the defense industries are then in prime position to either attract foreign funding or to further "intertwine" the Ministry and the IDF.

Other Bottom-up Forces: A number of other features of the Israeli system for defense technological innovation result in strong bottom-up forces. For example, we have already described how a concern about brain drain produces a follow-on imperative for centers of specialization in the technical labor pool. Given that the system will practically guarantee such people continued development projects, the character of those projects depends more on their objectives and desires than on those of their customers.

Similarly, the emphasis on people that follows from Zionist ideology results in a kind of default development strategy: put a good group of people to work on an important problem, and left to their own devices, they will come up with a good solution. Upper-level management in the defense industries, while generally aware of what development projects are under way, tend to take very little role in determining the technological trajectory of those projects. Especially in earlier periods, they could also frequently be overruled or circumvented, again placing more discretion directly with the developers.

V. Birthmarks: Deconstructing Artifacts and Technologies

Most of the analysis in this chapter has been devoted to understanding the overall system for the development of military technology in Israel. In this section, as in the chapters on Brazil and India, we finally focus on the details of particular technologies and weapons systems in order to analyze the process of their construction. To confirm the analysis given so far in this chapter, we should see the same social and political context reflected in the artifacts deconstructed here.

Long-range Artillery Rockets

Ta'as has developed and manufactured all Israeli long-range artillery rockets. Although the Luz guided missile artillery system was deployed by 1962,[106] Ta'as conducted no work on rocket systems until 1965, when they began development of a 290 mm system with a 25 to 30 km range. Following the 1967 Six Day War, Ta'as reproduced both rockets and launchers to match the large number of Soviet BM-24 systems captured from the opposing armies. Ta'as's successful development history since then has included work on 160 mm, 190 mm and 350 mm rockets, including sophisticated multiple launch systems.

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[106]Rafael undertook in August 1959 to transfer sixty Luz missiles to the Army, but the deployment process of the still-experimental missile took several years. Mardor, *Rafael*, 265.

Contrary to the accepted wisdom that "Israelis had little to do with rockets until they captured large numbers of Soviet rocket launchers from Egypt and Syria in 1967," the first work was on the 290 mm system, probably in 1965.[107] Before this time, Ta'as was already manufacturing advanced missile motors for systems including the Luz, Gabriel, and Shafrir missiles. However, to manufacture rocket motors Ta'as did have some hurdles to overcome. Lacking any means for trajectory correction or thrust termination, the quality control for the grains needed to be improved over what had been achieved for the missile motors.

The forces restraining innovation, as described above, prevailed against this technological development until approximately 1965. Even though Ta'as already had so much of the necessary infrastructure, the services and the Ministry solicited no proposals for such systems, and provided no funding for such development. The army in particular placed its faith in its soldiers and in low-tech mortars.[108] Furthermore, none of the other defense industries had any interest or capability in producing rocket motors, so inter-industry rivalry played no role.

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[107]Ian Hogg, *The Israeli War Machine*, (London: Hamlyn, 1983), 107. But according to Christopher Foss, ed., *Jane's Armour and Artillery, 1992-93* (Coulsdon: Jane's Information Group, 1992), 729, the Rocket Systems Division of Israeli Military Industries started work on the 290 mm artillery rocket in 1965; confirmed in interviews.

[108]Even the use of the mortars seemed at times to be more connected to their effect on *Israeli* soldiers than on enemy forces:

> When we crossed the channel [of the Suez Canal], we had artillery at our backs, firing with *red hot* tubes--which means, you never hit *anything*. All the soldiers down there think they're getting artillery support. They *get* artillery support--the artillery was no bloody good for nothing at all! But you don't need it. Apparently, in order for the soldiers to fight properly, you need for them to believe that it is being taken care of.

The IDF's neglect of artillery has been noted before, particular the damaging effects in the Golan during the Yom Kippur War. See for example, Chaim Herzog, *The War of Atonement: October 1973* (Boston: Little, Brown, 1975), 271.

This default position of no development continued until one of the forces promoting innovation appeared on the scene, in the form of a West German solicitation for a 290 mm long-range artillery rocket. Using internal funds and minimal resources (money, technology, and time), Ta'as responded within a few weeks with a rocket that was essentially two serial Gabriel rocket motors. Following this successful feasibility demonstration, Ta'as received a well-funded contract to develop its first fin-stabilized rocket motors.[109] However, the Germans only funded the development of the rocket itself; Ta'as itself took the initiative by "stealing budgets from here and there in order to make" the rest of the system over perhaps half a dozen years. Finally, with the block box already closed, the Israeli Army could be convinced to purchase the system. Although the technical details are not public, one would have to assume that the rocket purchased by the IDF is identical with that developed for the German army, and could even betray some minor but interesting contingencies of the German context transplanted to the Israeli system.

At approximately the same time, Ta'as developed a 240 mm rocket system. Again, a very specific spur was needed to propel this development. In the course of the 1967 Six Day War, Israeli forces captured the Soviet-supplied BM-24 240 mm rocket system--a large number of launchers and a smaller number of unexploded munitions. By reproducing an existing, functioning system, Ta'as could reduce the time, cost, and uncertainties of the development program, as well as providing a compelling existence proof for precisely that technology. The physical traces of this political context survive in a groove found at the base of the

[109] The innovative composite motors were free-standing grains reinforced by a fiberglass tube. With concurrent inner and outer burning surfaces, the constant surface provided a constant thrust.

rocket itself. Although Ta'as engineers could not determine a functional role for this groove, and suspected that it was an artifact of the particular Soviet casting process used to manufacture the rocket, they nonetheless made sure to reproduce it exactly.[110]

Despite this addition of incremental industrial capabilities at Ta'as, and despite the existence of successful rocket systems that could lower the disbelief threshold, further development continued to rely on outside forces that could overcome the dominant forces restraining new military technologies in Israel. Thus, the 160 mm system received crucial funding from Venezuela and Argentina. Ta'as undertook a more challenging rocket system with a 90 km range, the MAR-350, only with the spur of development funding from Argentina. When that funding was withdrawn, Ta'as counted on having lowered the needed development resources sufficiently to interest the IDF.[111] Yet even while Ta'as produces high-quality multiple rocket launch systems, its implicit competition with foreign-supplied systems still impedes its sales to the IDF, as the Israeli Army instead "lusts" after the U.S. MLRS.

Shafrir Air-to-air Missiles

[110]The story of the groove is an unconfirmed portrayal from a Ta'as engineer involved in that program.

[111]"The fin-stabilised system originated as a joint IMI project with Argentina [which] withdrew from the project because of the country's increasing financial difficulties. IMI hopes to sell the rocket on the export market as well as to the IDF." "IAI Short-range SSM Near Completion," *Jane's Defence Week* (10 June 1989): 1135. See also "Argentine and Israeli Firms Collaborate on VCLC Project," *Jane's Defence Week* (26 March 1988): 552; "Venezuela: Israeli LAR 160s Bought," *Defense & Foreign Affairs Daily* (22 March 1985): 1; and "Surprise Rocket from Israel," *Defence* (July 1989): 495. The rockets are also described in *Jane's Armour and Artillery, 1992-93*, 729-31, and in Evron, *Magen ve-Romah*, 256-57.

The Shafrir is one of a generation of missiles which all received their start at Rafael from about 1958 to 1962. This exceptional period eventually resulted in the Luz, Gabriel, Shafrir, and in some sense the Jericho families of missiles. Despite the lack of interest, the disbelief, and at times active the hostility of the military services and significant portions of the Ministry of Defense, this collection of projects could command the necessary resources to survive because of their powerful political sponsors of "great vision": David Ben-Gurion, Shimon Peres, and Ernst David Bergmann. Shortly after this gestational period, which was not particularly resource intensive, "the original dream was replaced by practical men. And still today." The missile projects then had again to contend with the usual inhibiting forces that we have described.[112]

Even with this initial boost, the Shafrir project was molded by needing to press its way through the forces restraining its development. First, an infrared homing air-to-air missile was a technology that no other nation was then willing to supply, eliminating one source of competition, at least for a time. Second, the development period for the Shafrir was predicted to be approximately two years, while the missile was not deployed for at least five years, and was not particularly successful when it was deployed.[113]

Most important, by assuming that the missile's kill mechanism would be through achieving a direct hit on the target aircraft, the warhead size could be reduced from the 9 kg charge on the U.S. Sidewinder missiles of the time, to the

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[112]Almost every one of my interviewees who was involved in these projects used the word "vision" in connection with these men, a term they seemed to reserve for this period.

[113]"Israeli Missiles," 268-69.

approximately 3.5 kg charge of the Shafrir 1 design. The overall missile weight was similarly reduced from 90 kg to approximately 30 or 40 kg.[114] Otherwise, the basic missile parameters were consciously based on publicly available data about the Sidewinder. In this way, the Shafrir could still take full advantage of the existence proof provided by the Sidewinder, while simultaneously reducing the economic and technological resources needed to develop the new missile.[115]

The assumption that a direct hit could be consistently achieved was definitely "on target" as far as securing support for the project (though it left much to be desired in combat during the 1967 Six Day War).[116] Although the Air Force "didn't believe in missiles" in a general sense, Air Force personnel at the time did not have sufficient resources to pry open the black box of the Shafrir design. In fact, no one did: "The only people who could look at the technically detailed parts of it--were internal people at Rafael!"

> So when of course Hillel Merrilyn in '58, '59 made the suggestion for an air-to-air missile, nobody could check on him. All the people were in

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[114]U.S. figures from the Sidewinder AIM-9D being developed at the time. "AIM-9 Sidewinder," in Duncan Lennox and Arthur Rees, eds., *Jane's Air-Launched Weapons (JALW)* (Coulsdon: Jane's Information Group, 1990), JALW-Issue 10, second page. Shafrir warhead weight based on Mardor, *Rafael*, 422; launch weight from interviews.

[115]The missile may have taken more advantage of the Sidewinder than an existence proof. "During that period [the early 1960s], Israel didn't have as yet any suitable goals for developing air-to-air missiles, and some of the experiments were made abroad." "Israeli Missiles: First Report," 268, partially confirmed in interviews.

[116]I do not believe that the engineers' assumptions about direct hits were intended to bamboozle the IDF into supporting the Shafrir. Rather, some engineers on the project criticized an excessive attraction to the latest, most advanced technologies--the "Aviation Week idea of the week" phenomenon. According to this perspective on the Shafrir's history, only when a new project manager finally stabilized the design (for what became the Shafrir 2) was there satisfactory progress.

Rafael itself. And of course we at the time were still quite young at the profession.

Did Peres have staff or technical advisors?

Well, he was dependent on Professor Bergmann. Professor Bergmann as you know was in chemistry. He could not...there was nobody you could ask.

Thus for example, the Air Force was reportedly quite enthusiastic about putting a proximity fuse on the Shafrir 2, given the difficulties of the original design. But when I asked an engineer who had been involved in the project at the time why the Air Force had not specifically required a proximity fuse before that time, he replied: "Because Rafael convinced them that it was not necessary. All simulations show that there will be straight [direct] hits--it's just a waste of money." Even later, when Dr. Yosef Shinar, the future chair of the Technion Aerospace Engineering department, was the Air Force's program officer for the Shafrir 2, "the Ministry's involvement...was really minor. [The] project officer, he made most of the decisions."

The fact that the Air Force could not actively participate in the social construction of this missile reinforced their tendency to treat it as a black box. Thus, the IAF's operational requirements for the Shafrir 2 (which they were not even asked to provide for the Shafrir 1) stated that the missile should not interfere in any way with a pilot's ability to engage in a then-traditional gun battle. Rafael was apparently happy to fortify this attitude, by suggesting that the Air Force adopt a "wooden-round" policy for the Shafrir, with Rafael performing all depot-level maintenance. Divorcing the design, use, and maintenance of the missile from Air Force operations assuredly found reflection in the details of this artifact, but unfortunately no details are publicly available.

One aspect over which the Air Force did exercise some control was the choice of IR detector technology for the Shafrir 2. The Shafrir 1 had used relatively simple uncooled lead sulfide (PbS) detectors. For the next generation, the Rafael design team offered two options to the Commander of the Air Force, Ezer Weizman: continuing to use uncooled detectors, or moving to a more complicated homing head with cryogenically cooled detectors. Weizman chose in accordance with the patterns we have described, opting for the cheaper and already proven PbS technology, despite its more limited operational capabilities (rear-aspect only). He reportedly concluded, "I want a missile fast."

A decision to use cooled detectors would not only have gone against the grain of the Israeli pattern of developing military technologies, it also would have probably doomed the Shafrir family to extinction.[117] As one manager described it,

> Now, of course, I know, that if he [Weizman] had decided the other way, it wouldn't have been good. Because we could never have finished on time. Because you must realize that in '69, the U.S. started to supply Sidewinders. And if we didn't get in there first, there would be no Israeli air-to-air missile today.

The U.S. decision to sell Sidewinder missiles to Israel, from the Israeli perspective, appears to have been based on the success of the Shafrir program. The offer came only after a set of highly successful engagements with Syrian aircraft in July 1969 in which the Shafrir design was finally validated.[118] Despite the

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[117] All-aspect cooled IR detectors were included on the next generation, known as the Python-3, which reportedly downed over 40 aircraft in the 1982 Lebanon War. "USAF Considers New Popeye Use," *Flight International* (5 March 1991): 12.

[118] "Israeli Missiles: First Report," 269. According to "Chronology," *The Middle East Journal* 23, no. 4 (Autumn 1969): 506, on 8 July 1969 "Israel reported downing 7 Syrian jets in a dogfight between Damascus an al-Qunaytirah." In interviews, I was told that this "was [the] date for finally getting the Shafrir to be an effective weapon....Then things changed."

relatively large investments in the Shafrir program, and despite its ultimate success, the U.S. offer almost derailed the program's future:

> So once we developed them [the Shafrir], and the Americans saw that we had missiles, they immediately offered to the Air Force, "OK, you get Sidewinders if you want them." So the reaction of the--and I think this letter must still somewhere be lying around--the head of the Air Force wrote to the head of Rafael, "Cancel the program. We don't need it anymore, we get Sidewinders." Finished! [Exclamation accented by thumping the table.]
>
> We had hundreds of people, maybe a hundred people, working on this. There was a big row in the government--"Oy, what do you mean?" Then, they decide something, OK, not produce so and such, maybe just fifty or something, half and half... Still today. We still get the American missiles.[119]

Gabriel Sea-to-sea Missiles

The Gabriel family of missiles descended from the sea-to-sea version of the Luz, part of the exceptional burst of missile activity around 1960 described above. While still in development, but with the propulsion system complete, IAI took over the project from Rafael (Ta'as remained the subcontractor for the missile motor). IAI developed a semi-active radar homing system, though the trouble-ridden development process continued until after the 1967 Six Day War. An improved version, the Gabriel II, was deployed in 1976. The Gabriel missile system consists of a shipboard launch system, a semi-active radar, and a missile

[119]Note how this thumbnail sketch portrays several of the patterns we have described. In addition to the competition with foreign-supplied systems, we also see the emphasis placed on *people* (as opposed to money or technology), and the probable role of the equivalence of military technology and economic development in the eventual acquiescence of the government in overruling the Air Force and permitting Rafael to continue manufacturing the Shafrir.

with booster and sustainer motors. Development work has continued on longer-range sea-to-sea missiles, while since the late 1970s the Israeli Navy has deployed U.S.-supplied Harpoon missiles.[120]

Although Rafael conducted much of the development work for the Gabriel, the missile project and a few key personnel were transferred to IAI in 1962. The reasons for the transfer have entered into Israeli mythology as the first incidence of inter-industry rivalry, with both Rafael and IAI fighting hard to win the largest possible portion of a project that could provide entree into the whole missile field. In addition, Al Schwimmer and others at IAI made successful use of the arguments equating military technology and economic development, claiming that "IAI's future depended on controlling the project."[121]

In attempting to complete the development effort successfully, the Rafael team steadfastly avoided the technically challenging option of radar homing. Sticking instead to the command-guided system used with moderate success in the land-based version of the Luz, Rafael tried to keep the missile within the usual confines for an Israeli development program:

> We're trying this, we're trying that. Of course the possibility of radar homing was in the background, but we still insisted on trying, perhaps believing that it could be done without the radar homing, and thus, a much

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120For a succinct description of the Gabriel and its development history, see "Gabriel," in Duncan Lennox, ed., *Jane's Strategic Weapon Systems* (Coulsdon: Jane's Information Group, 1991), JSWS-Issue 04.

121Reiser, *Israeli Arms Industry*, 63. However, other sources indicate that Rafael was more willing to give up the Luz/Gabriel project because of the addition of at least one other large, secret project to their work. A project to develop a long-range ballistic missile would certainly fit this description. "Israeli Missiles," 268; confirmed in multiple interviews.

simpler and cheaper missile.[122]

Rafael's failure to solve the guidance problem helped open the door for IAI to propose a much longer development program that included semi-active radar homing. IAI gave the "usual exaggeration" in their optimistic deployment date. But only the unusual combination of Rafael's failure and IAI's successful political appeal for the project enabled the development program to undertake the new radar technology.

By contrast, as a result of the transfer, the propulsion system which had been developed at Rafael was preserved unchanged through essentially all of the subsequent design work. At least as late as 1966, engineers on the project continued to place calls to Rafael to understand aspects of the design. Those changes that were adopted were not used to re-optimize the rest of the propulsion system. For example, when the propellant formulation was changed from composite to double-base, significantly increasing the motor operating pressure, the nozzle design was not adjusted to compensate. When this inconsistency was finally rediscovered and redressed years later, a range increase of nearly 4% resulted.

With the Gabriel II requirements, we finally see an example of a clearly external security motivation shaping a missile's design. The 40 km range of the Soviet Styx SS-N-2 missiles on the Egyptian boats vastly exceeded the 22 km range of the Gabriel I. While the Navy searched for tactics to enable its Reshef-class boats to maneuver to within missile range, it also welcomed the opportunity

[122]The major difficulty (among an apparently large number of snags) was deceptively simple. As a sea-skimming missile, the Gabriel flew its entire 22 km range at a height of approximately 3 meters above the sea. Anyone attempting to guide the missile to its target with an optical command guidance system rapidly lost the missile in its own contrail.

to acquire a longer-range missile that would match its strategic environment.[123] Note, however, that the Navy nonetheless had accepted deployment of the Gabriel I missile in the same strategic environment, and that the timing of the Gabriel II development program matched the follow-on needs of IAI's "centers of specialization," rather than the strategic needs of the Navy.

Furthermore, despite the Navy's strong support for a new generation, IAI could not solicit sufficient resources to escape from a conservative design philosophy. The most important question was whether to develop an active radar homing system. Time, among other resources, was in short supply:

> It took them [IAI] ten years to develop this type of technology [semi-active homing]. Now to start with a new technology, this would take them another ten years, to come with a fully active system, etc. They didn't want that.

This judgment appeared correct in hindsight, as at least some Israelis believed that, "Later on, we knew that we are very far from fully active homing system."

Even beyond the question of active homing, "one very important, very important decision which was taken for Gabriel 2 was to rely as much as possible on existing technology, and to improve by improving performance, not to start with new technology." Thus, IAI chose to extend the missile's range in the simplest possible way, even though it was not necessarily the most efficient:

> The whole point is, you don't open it, because you don't change the launchers--the launchers for the ship-to-ship are very small, and it's hard to change all the launchers. You can't say, "OK now, let's replace all the Gabriels with the new ones." [Instead you ask,] "What can we do with the existing thing?" That's how you go about it.

So IAI gave design parameters to Ta'as for developing a longer, rather than thicker, sustainer motor. This choice increased the weight fraction of the motor

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[123]Reiser, *Israeli Arms Industry*, 156, citing *Aviation Week & Space Technology* (10 March 1975): 19.

case, and required the addition of more insulator and inhibitor to the aft of the motor, again increasing the inert weight of the motor. In these sorts of ways, the development program could avoid trying new solutions or re-optimizing the system.

This strategy, by which the next generation "stayed with the existing Gabriel," also permitted IAI to maintain full control over the program and its technology: "Because the Aircraft Industry, who had the technology for the Gabriel, even when they proposed the Gabriel 2, they stayed more or less with their technology." In this instance, therefore, even inter-industry rivalry acted as a restraining force, working against the development of new technologies.

Since the deployment of the Gabriel II in 1976, the Israeli defense industries have periodically investigated longer range sea-to-sea missiles. The details of these programs are not publicly available, but in what little information is available, the expected patterns do appear. For example, Israel considered an extremely long-range missile (up to 200 km) in the mid-1970s. Even with foreign support for the development work, the project seemed to push beyond the constraints that govern Israel's conservative development philosophy, and the project was apparently canceled.[124] Similarly, the willingness of the United States to

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[124]Project Flower, and its support from Iran, is repeatedly mentioned in both National Security Archive, "Transcript of Weizman and Tufanian Meeting," and "Minutes from Meeting Held in Tel-Aviv Between H.E. General M. Dayan, Foreign Minister of Israel and H.E. General H. Toufanian, Vice Minister of War, Imperial Government of Iran," Tel Aviv, 18 July 1977, in National Security Archive, *Iran: The Making of U.S. Policy, 1977-1980* (Alexandria VA: Chadwyck-Healy, 1990). Weizman is quoted as saying, "on the next stage of the...[Gabriel], what we call the Flower, I am having a discussion with our Navy, and I am not sure that for our immediate future we need the 200 km. missile."

supply the long-range Harpoon missile was probably a significant blow to any indigenous programs:[125]

> Forget about the fully automatic [radar for a Gabriel III]. See, OK, this [development program] is not happening really. The Harpoon had the fully automatic, had very long range. The semi-active homing system could only give up to 40 kilometers. This is the Gabriel 2. For seventy kilometers, they [the Israeli Navy] have the Harpoon.

Inter-industry rivalry has also played a significant role in promoting technology development, as each of the three leading industries has conducted research on different propulsion technologies that could be used for such missiles: Rafael on the ramjet; IAI on the turbofan engine; and Ta'as on an extremely long-range long-burntime solid propellant motor. While the details are again sketchy, we can examine a pilot study done at Ta'as which was later published as a research article.[126]

From this paper and several discussions with Prof. Gany, we can see some of the lowest-level aspects of technology development in Israel (which of course are not that different from such development work in other advanced industrial countries). For example, the binder for the propellant selected for the pilot study's tests was HTPB (hydroxyl-terminated polybutadiene). However, most of the work done at Ta'as at that time was with PBAN (polybutadiene acrylonitrile), which is the standard for solid fuel applications around the world. Why use a new formulation for such a low profile, conservative project? Evidently, HTPB devel-

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[125]Harpoons were promised to Israel from at least 1976, and deployed beginning in 1979, according to International Institute for Strategic Studies, *Military Balance* (London: Brassey's, various years).

[126]Arie Midlik and Alon Gany, "Development of an Advanced Rocket Motor for Long Burning Time," in *28th Israel Annual Conference on Aviation and Astronautics*, Tel Aviv and Haifa, 19-20 February 1986, pp. 244-50.

opment was a separate, on-going development, which was strengthened by inclusion in this study, and which in turn made this study interesting to a larger number of supporters.[127]

The priority given to using this binder is evidenced by the study's unwillingness to find a propellant with a low enough flame temperature for using a tungsten nozzle, which would have made other aspects of the design much simpler.[128] The study did not follow the same strategy of hooking up with an on-going development effort for carbon-carbon materials, which were rejected for a nozzle material as being "unavailable."[129]

Finally, quite elaborate but essentially low-tech and conservative efforts were needed to protect the nozzle and the aft-end of the motor from the effects of

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[127]It is conceivable the work at Ta'as on binders was partially just reverse engineering from small quantities of smuggled compounds. For example, one report claims that "the representative in Israel of a major California-based U.S. defense corporation is said to have illegally sold to Israel a butyl rubber compound that was used in the Jericho's propellant. 'When mixed with powder and molded, the rubber compound acted as binder for the solid propellant fuel,' a source said." "Nuclear Efforts of Israel, Pakistan Prompt Meeting of U.S. Group," *Aerospace Daily*, 17 May 1985, p. 99. Such compounds may be restricted for export, but are in other ways readily available. Consider the nearly full-page advertisement for propellant stabilizers, next to the *Aviation Week* masthead, trumpeting the "key solid fuel propellant stabilizer used in the Trident, Peacekeeper, S-ICBM, TOW and Hellfire missiles to help preventing damaging effects caused by oxidative degeneration," followed by offerings of "a wide range of related propellant stabilizer and antioxidant products." *Aviation Week & Space Technology* (29 June 1992): 3.

[128]The researchers did in fact try to lower the flame temperature for a variety of reasons, but with the binder as a given, they could not lower it below the melting point of tungsten.

[129]"Carbon-carbon composite would be a good choice as a material exposed to the hot gases due to its high heat conductivity. However, as this material was not readily available, graphite-phenolic was selected instead during the initial design of the divergent section" (p. 245). Perhaps the project would have been more successful if it had allied itself with this additional ally, since Ta'as did subsequently move into carbon-carbon technologies.

exposure to a full five-minute burntime. It is quite possible that the extra structural weights needed for this protection would have justified using a staged design instead. But, shying away from the complexity of such a design, and especially the higher costs of getting to a feasibility demonstration, the researchers stuck to a straightforward extension of existing hardware. Had the IDF had enough interest in this study, or had Ta'as seen sufficient export potential, then these largely conservative choices would probably have been reified in the continuing development effort, again in an attempt to black box the project as quickly and with as few resources as possible. Instead, the study did not attract sufficient interest, probably in large part because of the willingness of the United States to supply Harpoon missiles. The only end product was a Master's thesis at the Technion.[130]

Jericho Long-range Surface-to-surface Missiles

Early Efforts: Developing strategic missiles is an immense task, especially for a state as small as Israel. But even the United States and the Soviet Union started with quite small investments in missile technology, gradually moving toward the ICBMs that became the international acme of missile technology. Similarly, Israeli investments in missile technology began with the schooling provided by the wooden-frame Malah, progressed to the various versions of the Luz by the

[130]The idea apparently lingers, but in IAI's preferred form. Jane's lists a long-range "Gabriel Mk 4LR" as "under early development," and "not expected to enter service until 1993." Using a turbojet engine and supposedly featuring a 200 km range and fully active homing radar, I suspect that "early development" is a permanent description for this project. "Gabriel," JSWS-Issue 04.

mid- to late-1950s, and then blossomed into the panoply of tactical missiles that we have just described.

The key question is whether such efforts were also intended to contribute to the ultimate achievement of a strategic missile capability. Apart from appeals to the logic of history, some clues do exist. For example, Shimon Peres was recently quoted as saying "that [Ernst David] Bergmann, even in 1948, was constantly speaking about a missile capability for Israel."[131] Professor Bergmann is universally hailed as the visionary responsible for Israeli investments in technological and industrial infrastructure, particularly for military applications. He was a leader of the Weizmann Institute after independence, a founding figure for Rafael, and a close advisor to Peres and Ben-Gurion throughout this period. He is also known as the "father of the Israeli atomic bomb," the development effort for which was in high gear by the early 1960s.[132]

It is frankly hard to imagine that scarce financial and technological resources would be poured into missile programs, over the objections and occasional ridicule of the military, without serious consideration being given to eventual strategic applications. Particularly as the tactical programs progressed in the late 1950s and early 1960s, providing both lower threshold costs and greater credibility for strategically-oriented programs, it seems likely that Bergmann, Peres, Ne'eman, and others would have supported directing resources into long-

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[131] Hersh, *Samson Option*, 26, citing Hadar, "Who Forgot the Father of the Israeli Atom."

[132] Numerous interviewees recalled Bergmann's pivotal role in various missile programs. See also James Feron, "Israelis Honor Atom Scientist. Expert Who Quit in Dispute on Policy Gets Award," *New York Times*, 14 May 1966, p. 3; Hersh, *The Samson Option*, 19-32; and Shimon Peres, "Ernst David Bergmann," ch. 5 in Peres, *From These Men: Seven Founders of the State of Israel*, trans. Philip Simpson (New York: Wyndham Books, 1979), 185-212.

range missiles.[133] However, based on our analysis of the forces restraining the indigenous development of military technology in Israel, we would expect that such resources would have been small, and would have been devoted to incremental, cautious projects generated bottom-up by the engineers involved.

These efforts presumably had already begun by 1961, when reports of German-assisted Egyptian rocket development emerged from the Israeli intelligence establishment.[134] Of particular concern to the ruling Mapai Party leaders was a report "that the United Arab Republic was planning to fire United State-made [sic] rockets on July 23, the anniversary of the 1952 coup" that had eventually brought Nasser to power, a date just a few weeks before the next Israeli election.[135] To avoid a domestic political disaster, a primitive two-stage sounding rocket was hurriedly assembled after incomplete ground testing.[136] To

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[133]One scientist at Rafael recalled a visit of Prime Minister Ben-Gurion to inspect the Shafrir program not long after the first Sputnik launch. On that visit, the Prime Minister reportedly asked how long it would take for Israel to launch its own satellite. The answer was "twenty-one years: twenty for you to decide, one for us to build." Other sources for this same story referred it to the Shafrir program rather than satellites.

[134]Contrary to the current mythology, it seems that the Israeli government was not aware of the Egyptian programs before this date. See Ian Black and Benny Morris, *Israel's Secret Wars: The Untold History of Israeli Intelligence* (London: Hamish Hamilton, 1991), 192-95; and Isser Harel, *Mashber ha-Madanim ha-Germanim, 1962-1963* (Tel Aviv: Sifriyat Ma'ariv, 1982), 11-18. Military intelligence's belated discovery of these programs seems to have provoked quite a bit of finger-pointing and overreaction in the aftermath.

[135]"Publicity on Rocket Explained in Israel," *New York Times*, 10 July 1961, p. 3.

[136]Only a handful of static tests took place, seven for the first stage and eight for the second. Of these, all but the last and the last two, respectively, were failures (mostly case burnthrough). Mardor, *Rafael*, 325. On the Shavit launcher in general, see pp. 324-46.

great public fanfare, the Shavit 2 rocket was launched on 5 July 1961.[137] In many ways, the Shavit 2 is reminiscent of the desperate attempts by the United States to orbit a satellite as soon as possible after the Soviet Sputnik launch of October 1957. The U.S. response to Sputnik was to accelerate existing programs beyond the point of likely failure, to initiate a large number of additional programs that were subsequently canceled, and to attach as much publicity as possible to both of those courses of action.[138] Similarly, the Israeli response took pieces of existing programs, often pieces that were inappropriate for their newly-intended application, to put together the Shavit 2.[139] The publicity surrounding the launch was counter to usual Israeli policies (note that the one photograph of the rocket before the launch is posed in such a way as to exaggerate the apparent size of the rocket--see Fig. 2). The only remaining question is what new programs the Israeli government initiated, and whether they too

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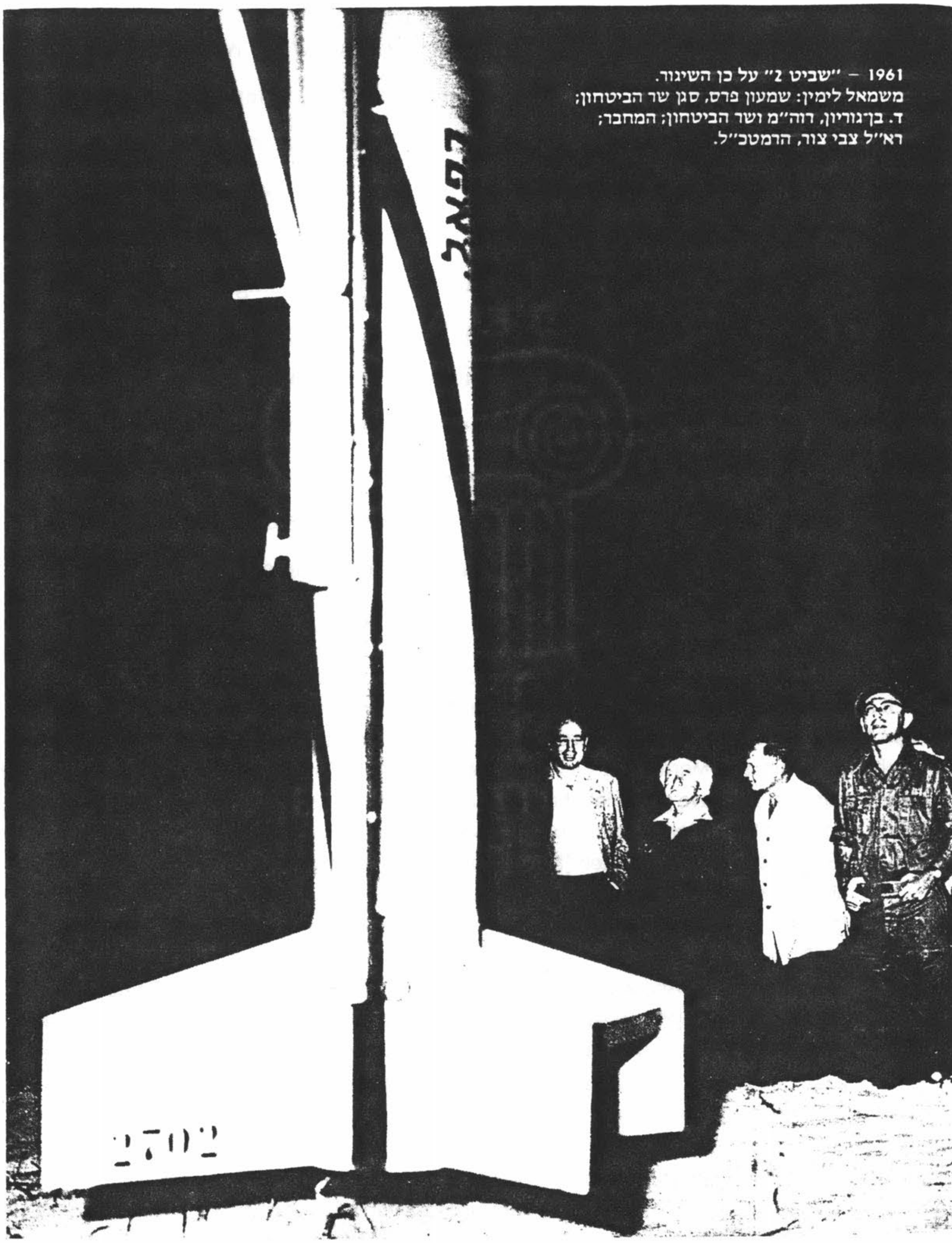
[137]The appellation Shavit "2" was apparently selected because the "aleph" of Shavit "1" was the Mapai electoral symbol, and the party did not wish to "be accused of making propaganda." Hersh, *Samson Option*, 104. Others claim that the number 2 was selected in order to make Nasser wonder how he had missed the Shavit 1. Sylvia Crosbie, *A Tacit Alliance: France and Israel from Suez to the Six Day War* (Princeton: Princeton University Press, 1974), 160n. See also the discussion on names in Mardor, *Rafael*, 328-29.

[138]For an unforgiving critique, see Herbert York, *Race to Oblivion: A Participant's View of the Arms Race* (New York: Simon and Schuster, 1970), 132-33. York concludes that "virtually all the new programs that came into being in the burst of inventive activity inspired by Sputnik and the 'missile gap' all came to a dead end sooner or later....To put it simply, large amounts of money and human effort were wasted in a wild pursuit of the exotic."

[139]For example, the propellant for the Shavit 2 was too rigid to be useful for manufacturing large rocket motors. Similarly, the guidance system and thrust vector control system were practically nonexistent, and certainly inappropriate for any military applications. Mardor, *Rafael*, 325ff. Further emphasizing the extent to which Shavit 2 was a reaction, not a program, there are reliable reports that the launch was programmatically a failure, exploding in mid-air. Sources for all figures are given in the List of Figures, pp. 8-9.



Shavit 2 Launch, 1961

Figure 2

were subsequently canceled or dramatically scaled back.[140] What the Shavit 2 launch unarguably succeeded in doing was to reassure its intended audience of Israeli technological prowess and commitment to military strength. As one participant put it, "The point was: Look around the world--*we* have the Shavit 2."

Afterwards, those working in the missile field evidently found the Shavit 2 launch to be a useful ally in promoting a full-fledged sounding rocket program. Mostly under the rubric of space research, Rafael developed and launched progressively larger sounding rockets, culminating in 1965 with a launch of a "very large payload" to a 70 km altitude. Further proposals shortly thereafter, formulated cooperatively by Rafael and several Israeli universities for the launch of a small demonstration satellite, were never seriously considered, and were withdrawn on the advice of Prof. Bergmann, who was then the chair of the Israeli Academy of Science committee on space research.[141]

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[140]It is known that the intelligence reports on the Egyptian rockets returned to calm "almost overnight," with a special analysis by future General Aharon Yariv concluding that the threat had been overblown. Black and Morris, *Israel's Secret Wars*, 199-200. But just as with the U.S. missile gap, other forces seem to have propelled the program forward, despite the fading of the original justification. Consider the historical mythology at work in the following exchange:

> [Gen. Weizman:] We started [the Jericho missile development] when Abdul Nasser fired his Zephyr...
>
> [Mr. Ben Yosef, interrupting:] He didn't fire it. He demonstrated it but with no firing, in July 1962.
>
> [Gen. Weizman:] And we convened a meeting at 12 midnight. I was Air Force Commander, Shimon [Peres] was Deputy Defense Minister, and everyone got into a panic.
>
> [Gen. Tufanian:] I don't think those Egyptian missiles ever flew.
>
> [Gen. Weizman:] No, but this helped develop the missile you are going to see tomorrow.

From "Transcript of Weizman-Tufanian Meeting," 16.

[141]When Prof. Bergmann was "asked if Israel was continuing to develop rockets like the meteorological rocket it fired in 1961[, he answered,] 'There is a national committee for space research that deals with atmospheric testing...and it's impossible to study this without rockets.'" Feron, "Israelis Honor Atom Scientist," 3. See also Mardor, *Rafael*, 346-48.

It is not clear how much concerted effort Israel devoted to ballistic missiles until 1962 or 1963. There are indications, however, that a large program was being contemplated. For example, the project or projects that replaced the Gabriel missile at Rafael may well have included ballistic missile development.[142] Similarly, rumored objections from the Israeli elite when a ballistic missile contract was signed with France include advocating the continuation of then-ongoing projects in Israel.[143] Since no information is publicly available, any deconstruction is impossible. But we can note that a large research program for a radical innovation like strategic missiles would be quite exceptional for all the organizations concerned; if such an effort were made, it would likely be sustainable only for a short period.

Cooperation with France: Sometime between 1960 and 1963, Israel negotiated a major contract with the Marcel Dassault company of France for the development of an intermediate-range ballistic missile (IRBM).[144] With payments amounting

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[142]A semi-official source claims that "since RAFAL [sic] was then assigned to a project of high security, further pursuit of this project [the Gabriel] was vested with a subsidiary of the Aircraft Industry" when "development hit a serious snag." "Israeli Missiles: First Report," 268. Confirmed in multiple interviews.

[143]"Israelis Warned on Arms Lag," *New York Times*, 13 April 1963, 5.

[144]Press reports give contradictory dates. The most likely sequence is growing collaboration beginning from the late 1950s, culminating in a contract in 1962. The latest date given is 1963, in an otherwise reliable article, "Israel's Jericho IRBM Completes Long Range Test," *International Defence Review* (July 1987): 857. Cordesman offers the earliest date, claiming that by mid-1957 Israel "had evidently begun a cooperation in missile technology that eventually led to Israel building the Jericho I." Anthony Cordesman, *Weapons of Mass Destruction in the Middle East* (London: Brassey's, 1991), 119. 1962 is my best guess. Many reports refer to the MD620 or MD660 program, which probably signifies a Marcel Dassault 1962 contract which was extended or renegotiated in 1966. See "Fifty Tests for Israel's Rocket," *The Economist* (4 May 1968): 67-68. Referring to the strategic missile whose firing they would observe the next day, Ezer Weizman mentions unambiguously that "We started working on it in 1962." However, it is conceivable that he could be referring to the start of an Israeli program which was ubsequently transferred to

to perhaps $100 million, the Dassault effort appeared to take longer than planned, ultimately resulting in 400 to 500 km range missiles with a 450 to 750 kg payload that were due to be delivered in 1968 or 1969.[145] The French embargo imposed on Israel by President De Gaulle immediately before the 1967 Six Day War interfered with the completion of the contract, leaving the Israeli defense industries to continue alone on what became known as the Jericho I.

The fact that Israel negotiated a contract with the French for one of its most important strategic military projects for technology development is not at all surprising. We have already discussed how the centrality of security in Israeli politics guarantees funding for military projects, as long as they are broadly enough accepted as being necessary, and as long as there are no less costly alternatives.[146] We have also discussed the military's preference for foreign-supplied systems, and its disbelief and lack of interest in indigenous Israeli capabilities, particularly during this time period. In addition, Dassault apparently claimed

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France. "Transcript of Weizman-Tufanian Meeting," 14.

[145]The cost estimate is given in Crosbie, *Tacit Alliance*, 158-59. Contradictory range and payload estimates are given in various editions of *Jane's Strategic Weapons Systems*; in "Israel's Jericho IRBM," 857; and in Hedrick Smith, "U.S. Assumes the Israelis have A-Bomb or Its Parts," *New York Times*, 18 July 1970, pp. 1, 8. Other sources, including a leaked CIA report, are summarized in Leonard S. Spector, with Jacqueline Smith, *Nuclear Ambitions: The Spread of Nuclear Weapons 1989-1990* (Boulder, Colo.: Westview Press, 1990), 362n (though Spector incorrectly cites the 1974 CIA report as giving a 400 mile range instead of 400 kilometers). A 750 kg maximum payload is assumed correct on the basis of the payload of the later Israeli version. "Transcript of Weizman-Tufanian Meeting," 15; and "Minutes of Dayan-Toufanian Meeting," 5.

[146]Note the strong evidence of similar Israeli-French cooperation in the nuclear sphere, with the French receiving a contract for building a plutonium separation plant in Israel. Pierre Pean, *Les Deux Bombes: Comment la France a 'Donne' la Bombe a Israel et a l'Irak* (Paris: Fayard, 1982); and Hersh, *Samson Option*.

that he could complete the development in 18 months.[147] Finally, Israeli development of such a system at that time would have gone against the prevailing incremental, conservative practices that we have already documented.

However, the timing of the contract raises a number of interesting questions. If it were as early as 1960, then it would have preceded the "panic" caused in 1961 by the Egyptian missile program. If it were as late as 1963, then it would have coincided with the change of government from David Ben-Gurion to Levi Eshkol, which would manifest an importance for high politics that we have not yet seen in this analysis.[148] However, the most likely date remains 1962, on the basis of the evidence cited above. In this case, the timing would indicate a post-Sputnik-like spurt followed by a reassertion of the dominant pattern of technology development, with the willingness of a foreign state to supply the needed technology outweighing the meager forces promoting indigenous development.[149]

147"In the early 1960s, when the program was in its infancy, the French armaments concern of Marcel Dassault reportedly suggested that if the project was moved to France to make joint development possible, an operational missile could be produced in about 18 months. After a major debate, Israeli leaders decided to accept the Dassault offer." William Beecher, "Israel Believed Producing Missile of Atom Capability," *New York Times*, 5 October 1971, pp. 1,15. The delay from this original schedule may account for the existence of a second (MD660) contract.

148The issue is laid out in Michael Barnett, "High Politics is Low Politics: The Domestic and Systemic Sources of Israeli Security Policy, 1967-1977," *World Politics* 42, no. 4 (July 1990): 529-62.

149The question of why France was interested in such cooperation is also interesting. Dassault was left out of the French missile development program, and may have been looking for either a consolation prize or a way back in. See Crosbie, *Tacit Alliance*, 158; and the description in Judith Young, "The French Strategic Missile Program," Adelphi Paper #38 (July 1967). According to an interview with David Bergmann, Israel may have had good enough solid fuel technology to interest the French (cited in Crosbie, *Tacit Alliance*, 160). Finally, Israeli and French personnel had forged a close cooperation at lower levels, to the extent that De Gaulle not even informed of the joint missile project until 1967, at which point he ordered its termination. According to Pean, "General de Gaulle was told of the existence of the Jericho program in 1967, at the time of the first full flight test of the missiles at the large islands in the East [sic?]. The old Chief of State, when again confronted with this fact [of Israeli-French collaboration], flew into a rage. Those responsible for French avia-

The accepted hypothesis is that the change to an Eshkol government in 1963 was decisive in ending indigenous Israeli development and shifting the work to France. Yuval Ne'eman, probably a participant at the time, committed this version to print in 1976. Aronson claims that this decision was made "over the protests of some of the heads of Israeli security, who wanted the work done at home."[150] Similarly, "Shmuel Segev, veteran political journalist of *Ma'ariv*, said that after his retirement, Ben Gurion had told him that the Eshkol government had made a decision in terms of cutbacks of investments in an (unnamed) project that will 'make Israel cry for generations.' Segev believed that Ben Gurion was referring to the Jericho program."[151]

There is no question that Eshkol had a markedly different attitude toward "visionary" technology from Ben-Gurion (consider his reaction to the possibility of Israeli satellites, as recounted above). However, other members of the Israeli elite did not change positions in 1963. Eshkol specifically asked Peres to remain as Deputy Defense Minister, where he remained until leaving the government to join Ben-Gurion in the Rafi faction in 1965.[152] David Bergmann did not submit

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tion during those seven years kept a thick curtain between the government and the activities of the intrepid Marcel" [my translation]. *Les Deux Bombes*, 141.

[150]Ne'eman, "Why I Resigned from the Defense Ministry," *Ha'aretz*, 6 February 1976, cited in Shlomo Aronson with Oded Brosh, *The Politics and Strategy of Nuclear Weapons in the Middle East: Opacity, Theory, and Reality, 1960-1991. An Israeli Perspective* (Albany, N.Y.: State University of New York Press, 1992), 86; and Aronson, *Conflict and Bargaining in the Middle East: An Israeli Perspective* (Baltimore: Johns Hopkins University Press, 1978), 51.

[151]Reiser, *Israeli Arms Industry*, 63n, from a July 1984 interview with Shmuel Segev.

[152]Schiff and Haber, *Leksikon*, 435.

his resignation to Eshkol until 24 June 1964,[153] and at Rafael at least, "the philosophy was dominated by [Bergmann]" until he left over a year later. Furthermore, some evidence from the history of the nuclear program leads to the conclusion that the new Eshkol government had less effect than is usually believed. Finally, as argued above, the mostly likely contract date is 1962. Overall, the usual political dynamics of technology development in Israel are sufficient to account for the change without appealing to the deus ex machina of a change of government.

Although technical information is scant, the impact of the social and political context on the details of the MD620 or MD660 design is obvious. The missile was designed, developed, and produced in France, and bears all of the traces of that history. For example, all large solid propellant grains in France were manufactured at the Poudrerie de St. Medard.[154] Until at least 1965, only 550 mm and 800 mm grains could be made. With a reported outer diameter of one meter, it seems highly probable that an 800 mm grain from St. Medard propelled the Dassault missile. Similarly, most French missiles of that era used CD6 steel for motor cases, while Israeli missiles soon switched from CD6 to maraging steel, and then to fiberglass.[155] The French-supplied Israeli IRBM thus presumably bore its French pedigree in its motor case material as well.

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[153]Mardor, *Rafael*, 389.

[154]Young, "French Strategic Missile Programme," 3.

[155]Le Groupement des Industries Francaises Aeronautiques et Spatiales (GIFAS), *L'Industrie Aeronautique et Spatiale Francaise: 1947-1982: Programmes et Materiels*, vol. 3 (n.p.: Publi Real, 1985), 182-83, 402-5; and interviews.

After the end of French collaboration, the Israeli government made one later attempt to acquire foreign-supplied IRBMs. In that case, the foreign government was not willing to supply such missiles, and high politics did appear to play a significant role in the episode. In 1974 or 1975, Israel officially requested Pershing I ballistic missiles as part of an arms supply agreement. After a decent interval for consideration, the United States rejected that portion of the request, offering instead the shorter-range Lance missile, which the Israelis accepted.[156]

This episode appears to have little to do with any internal disputes about the indigenous development of Israeli missile technology. Indeed, the Lance missiles themselves were reportedly ignored and poorly maintained, to the point where they became unusable. Instead, feuding between Defense Minister Shimon Peres and Prime Minister Yithak Rabin may account for the incident. According to an unconfirmed story circulating on the Israeli "grapevine," Peres had wanted to put missiles, specifically the Pershing I, on a list of requested military aid that was being prepared for Rabin's upcoming trip to the United States. Rabin had removed them, but when Rabin presented the list in Washington, the Pershings had miraculously reappeared. Besides embarrassing Rabin, Peres had succeeded in implementing a "start high, settle low" strategy which netted the Lance missiles for Israel. The incident also highlighted Israel's nuclear policies, which Peres supported over Rabin's objections.[157]

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[156]"Journal Discusses Spread of Missile Technology," *Guoji Wenti Yanjiu* (Beijing), no. 3, 13 July 1990, pp. 29-36, in JPRS-TND-90-019, 25 October 1990, pp. 4-11, 5; George Wilson, "U.S. Pershings for Israel?" *Washington Post*, 17 September 1975, p. A2 (my thanks to Seymour Hersh for this citation); and Pollock, *Politics of Pressure*, 185. On the deployment and characteristics of the 218 Lance missiles that the United States supplied, see Hogg, *Israeli War Machine*, 104-7.

[157]For a published account that reinforces the general outlines of this story, see Yitzhak Rabin, *The Rabin Memoirs* (Boston: Little, Brown, 1979), 277-78. Rabin claims that "Peres delivered the list to the United States as it stood--exaggerated and pretentious. In the course of his talks, he agreed to sift out its superfluous elements and present a modified list, but the members of Congress had yet to receive the revision. I was therefore subjected to some very embarrassing questions by various congressional committees." Thus a different sort of low politics also enters into

The Jericho I: After the French embargo, the strategic missile program required a new round of decisions. The Dassault contract had supplied some few missiles to Israel, and it seems likely that more equipment flowed to Israel even after the official imposition of the embargo: "American officials also report that despite an embargo, the French arms manufacturer, Marcel Dassault, is proceeding with development for Israel of a 280-mile [sic] ground-to-ground missile known as the MD-620, which can carry a 1,000 to 1,200 pound warhead....Because of reported difficulties with the guidance system, however, delivery has been delayed until next year."[158] Nonetheless, the embargo did prevent the completion of the contract (which seemed to have suffered from constant delays in any event). One course for Israel would be to undertake indigenous manufacture of the missiles, an option which they had forsworn in 1962. But now, in the late 1960s, indigenous production was much more attractive, because of the patterns of Israeli technology development that we have been describing in this chapter.

First, by working with a successfully completed missile design, the Israeli defense industries could offer a convincing existence proof, lowering the

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Israeli missile programs.

[158]Hedrick Smith, "Nasser Reported to Be Getting Ground Missiles From Soviet [sic]," *New York Times*, 24 April 1968, p. 6. Approximately 25 missiles had been completed by 1967, with perhaps 11 of them having been used for flight testing and the remainder delivered to Israel. Crosbie, *Tacit Alliance*, 205-6. These totals are consistent with press reports of Israel putting 13 IRBMs on alert during the 1973 Yom Kippur War. "How Israel Got the Bomb," *Time*, 12 April 1976, pp. 39-40. Components that were to have been included in additional missiles presumably existed in France. As with some other well-known incidents (such as the missile boats at Cherbourg or the Mirage V aircraft), at least some of those components probably found their way to Israel. Crosbie concludes that by the end of 1967, the embargo was effectively vitiated for existing contracts (p. 197).

uncertainties and the time and money required. Second, the cooperation with France had included incremental additions to Israeli industrial capabilities, from maintenance facilities to pilot production lines for the missile motors by the time of the embargo--again, lowering the threshold costs for indigenous production. Lastly, all the competition for an indigenous program had evaporated, while the fears of perpetual embargoes were at their all time high.[159]

Yet even with all those consistently supportive factors, it seems that an indigenous IRBM was not a foregone conclusion, or at least not an immediate priority. The nation also faced unprecedented security challenges in attempting to control vast new territories, to rebuild its military forces and its economy from the destruction of the war, and to counter the massive infusions of Soviet weaponry that quickly restocked the Arabs' arsenals--all without the aid of its long-time primary arms supplier, France. Confirming the cumulative effects of these competing pressures, there is some evidence that work on the Israeli version of the Jericho I started only in late 1969.[160]

At a lower level of technical detail, we can see that even strategic programs are subject to the same contesting forces as any other Israeli technology develop-

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[159] In addition, the logical candidate for managing the program from a technological point of view was Rafael, but Rafael was only just starting to enter into the production business at that time. According to a Rafael manager at the time:

> So the policy [prohibiting weapons production at Rafael] was changed, formally, after '67. Actually, it was not changed as one big policy directive. It was actually changed by three big decisions ["between '67 and 1970"]: to produce in Rafael three major systems. One was the Shafrir 2; two others which I cannot discuss.

[160] In July 1977, Ezer Weizman refers to the start of the program: "we have been at it in Israel now, in the country itself, for about 7 or 8 years." "Transcript of Weizman and Tufanian Meeting," 16. Also, the initial contacts with the eventual U.S. supplier for the motor cases (obviously a crucial component) did not take place until approximately November 1969.

ment effort. The clearest example is the material used for the motor cases. Even though the Israeli defense industries were manufacturing motor cases for tactical missiles, and despite the impact of world-wide military embargoes and boycotts against Israel, the hurdle of jumping to one-meter diameter cases was too great to clear as long as a foreign supplier could be found. Thus, at the beginning of the Israeli phase of Jericho I production, the missile still had a U.S.-supplied motor case.[161]

However, in the usual bottom-up fashion, this motor case was eventually replaced by an indigenous fiberglass case. An engineer who had been working with fiberglass windings in manufacturing such items as the Gabriel launch tubes proposed the incremental advance of using the same machines and winding techniques to produce the missile cases. Using only resources that could be garnished "under the table," demonstration tubes were assembled (using highly conservative safety margins, as would be expected for a conservative development philosophy). Upper management was only informed after enough of the black box had been closed to perform feasibility testing. Nonetheless, the management of this defense industry, which had the subcontract for the motor cases, was not interested in moving into full production for the fiberglass cases. However, the lower level engineers were able to convince the prime contractor to request specifically a fiberglass replacement for the existing metal case.

Similarly, it seems likely that the inertial components in the Jericho's guidance system followed a similar path. The missile obviously used French suppliers

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161"Nuclear Efforts of Israel, Pakistan Prompt Meeting of U.S. Group," *Aerospace Daily*, 17 May 1985, p. 99, may also be referring to the Jericho I in claiming that "Israel obtained 'aluminum extrusions' or 'basic rocket shells' [from a U.S. company] through such [surreptitious] sales. The extrusions were two-foot wide pieces of aluminum pipe made of a special hardened compound."

initially, possibly continuing after the embargo (since such small components are easily smuggled), and possibly supplemented by some U.S.-supplied components. In typically incremental fashion, Rafael and then IAI were moving into the inertial components business. A large team of researchers (by Rafael standards) had been investigating development of gyroscopes and accelerometers since the early 1960s. Although this effort did not come close to producing useful hardware, it was possible to sustain because of the long time-horizons that were part of Rafael's philosophy at the time (under the influence of Prof. Bergmann), and because of Rafael's status as a national laboratory, uniquely tasked to pursue more fundamental, academic-style research.[162]

With this foundation, the transition to the indigenous development of missile guidance systems had a much lower threshold. As described above, in perhaps 1968 (after the French embargo), the Director-General of the Ministry of Defense ordered the entire inertial components research team transferred to IAI, where it became the nucleus for a new division, Tamam. Today, Tamam "has long term experience in the field of inertial components, and is Israel's leading

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[162]The Rafael and IAI research is described above. The French guidance systems may in turn have been based on U.S. components. The U.S. firm Kearfott gave a production license to SAGEM, "the French firm responsible for SSBS and MSBS guidance[, to produce] inertial guidance instrumentation such as floated integrating miniaturized gyroscopes and stabilized platforms." Young, "French Strategic Missile Programme," 9. Also, "Israel is said to have obtained elements of the Jericho's inertial guidance system" through mislabeled exports from the United States. "Nuclear Efforts of Israel," 99. The transition from French to U.S. to indigenous technology is hinted at in Rao and Ruina, *Disarmament and Development*, III-1/3: Tamam "is a licensee of a major U.S. producer, but was initially guided by a European manufacturer of inertial and navigation equipment. The experience of producing navigational equipment permitted the development of inertial sensors, gyroscopes and accelerometers of high inertial navigational capability."

producer of high precision electro-mechanical components."[163] The transfer to IAI demonstrates some of the enduring features of Israeli development patterns: even a large, long-term effort could not receive orders for developing specific hardware until foreign suppliers became unavailable; inter-industry rivalry certainly spurred IAI's interest in this sector; and future exports were probably a factor, since export potential has always been perceived as being better realized at IAI than Rafael. In the end, the forces promoting indigenous development prevailed, and Tamam has by now certainly taken over the production of inertial components for the Jericho missiles.

In sum, we still reach the usual conclusions that Israel started producing its own Jericho missiles in early 1970s.[164] But looking at the details helps us to understand both the contingent nature of this outcome, which is built on numerous smaller battles, and the extent to which even strategic programs fit consistently into the broader patterns of indigenous technology development in Israel.

The Jericho II Missile and the Shavit Satellite Launch Vehicle: Details of the

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[163]For a sample of Tamam's current capabilities, see I. Aloni, Y. Sarig, and U. Shimoni, "Tamam Minitune Gyro," *Symposium Gyro Technology*, Stuttgart, 1983, pp. 11-0 to 11-33; R. Kariv, "Development of TM-74 TAMAM Low Cost High Performance Accelerometer," *Symposium Gyro Technology*, Stuttgart, 23-24 September 1986, pp. 5.0 to 5.42; I. Millo, "Some Design Criteria of Dynamically Tuned Gyro for Space Applications," *Symposium Gyro Technology*, Stuttgart, 19-20 September 1989, pp. 6.0 to 6.22. Even today, however, Israel relies on foreign suppliers for some gyroscopes. Ta'as recently awarded a contract for more than $1 million for RPV gyros. "Israel Military Industries," *Jane's Defence Weekly* (27 October 1990): 850.

[164]Beecher, "Israel Believed Producing Missile," 1, estimates a production rate of three to six missiles per month, though he also asserts that deployment had not begun at the time of writing (October 1971).

next stages of the Israeli missile program are hidden behind thick walls of secrecy and taboo. The programs are also beyond the focus period of this study. Nonetheless, some speculative conclusions are possible.

We have argued throughout for the dominance of the forces restraining technology development in Israel, so that programs which do finally receive support show the traces of having passed through those barriers. In most of the cases examined in this chapter, programs which feature incremental advances and resource-cheap development have the greatest chance of success. In long-range ballistic missiles, however, no developments are truly resource-cheap, with the exception of the replacement of foreign-supplied components described above.

I would argue that since the Jericho I program of the early 1970s, the Israeli defense industries have had great difficulty promoting new development programs for strategic missiles. Although newer, longer-range missiles have certainly been under constant consideration, it seems unlikely that they would have commanded sufficient resources. In one of the few quotable comments on such programs, then-Defense Minister Weizman referred in 1977 to the next version of the Jericho as being possible, but not yet "serious."[165] Furthermore, no tests beyond the range of the Jericho I are reliably reported until 1987.[166]

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[165] "When it is serious, I will tell you and I will say: General, let's go together on it. But first I want to be one hundred per cent sure. I am not sure yet." "Transcript of Weizman-Tufanian Meeting," 17.

[166] "Israel's Jericho IRBM," 857. However, a Soviet press report in 1990 refers to a possible longer range test, with a nine minute flight time, in 1982. "Missile-Attack Warning System Described," *Krasnaya Zvezda*, 27 September 1990, in FBIS-SOV-90-194, 5 October 1990, pp. 57-60, 59 (my thanks to Martin Navias for this citation). Leonard Spector reports an unreferenced claim that ten tests had been completed by May 1987. Spector, *Nuclear Ambitions*, 362. Ten is a surprisingly small number of tests for a full development program, unless the program had started flight testing only a few years before that date. Compare to the historical data for U.S. SLBMs given in U.S. Congress. Senate. Committee on Armed Services, *Hearings on Defense Appropriations for Fiscal Year 1981* (Washington, D.C.: Government Printing Office, 1981), 3511; and the statistical discussion in Jeffrey Merkeley, "Trident II Missile Test Program," Congressional Budget Office Staff Working Paper, February 1986.

Cooperation with the Iranians certainly ended by the 1979 revolution, too short a time after the Weizman-Tufanian meetings for Israel to have pursued any significant joint developments. Reports of Israeli-South African cooperation do not indicate major development work prior to the 1980s.[167]

I would speculate that industry proposals for the Jericho II missile and Shavit launcher won narrow approval in the early 1980s after hard-fought but extremely closely-held bureaucratic battles. Under the tight cover of secrecy, an historically-contingent but powerful alliance recruited the necessary resources to go ahead. Specifically, the military, deterrent, and prestige values of ballistic missiles were not sufficient. Advocates needed to add the appeal of a civilian space program (with significant export potential); the possibility of Israeli-held photo reconnaissance assets; and an expansion of industrial and technological capability that would have been presented as a key to future economic development and growth. Only in combination were these four elements strong enough to overcome the otherwise prevailing forces inhibiting such a large development effort.

In the most dramatic manifestation of this alliance, I believe that the same physical hardware is used for both missile and space launch applications, buttressed by concurrent development of auxiliary systems for both applications. What little evidence is available supports this interpretation. Since the existing Jericho design was only of intermediate size, and therefore inappropriate for space applications, the next generation of missile would have to go well beyond the Jericho I if it was to double as a satellite launcher. Press reports of Jericho II ranges over 1500 km with payloads over 1000 kg still seem too small to match

[167]Based on an examination of the sources in National Security Archive, *South Africa: The Making of U.S. Policy, 1962-1989* (Alexandria VA: Chadwyck-Healy, 1991).

with a satellite launching capability. However, Israel has had no opportunity to test the Jericho II to its full range, and the weight of the payload in the observed tests would be very difficult to determine.[168] Furthermore, the various open-source estimates of the size of the Shavit launcher rely on assumptions about the weight of the navigation package for the satellite that contain a large margin of error (see below). My argument is that the range of uncertainty for both the Jericho II and the Shavit launcher leaves room for the possibility that they are the same basic vehicle.

More specifically, I would propose that the first two stages of the Shavit launcher are, by original design, the Jericho II missile.[169] The only possible difference would be if the Israelis used a segmented design for either of the motors,

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[168]The longest-range test to date was 1500 km, to a point a few hundred kilometers north of the Libyan coast. S. Filatov, "Pravda Comments on Israeli Missile," *Pravda*, 3 November 1989, p. 5, in JPRS-TND-89-022, 29 November 1989, p. 31. The South African test that may have been conducted with Israeli cooperation was reported as 900 miles (or 1440 km), according to an NBC reporter's reference to a classified CIA report. U.S. Department of Defense, "Transcription of October 26, 1990, *NBC Today Show*," 27 October 1990, reproduced as part of National Security Archive, *South Africa*, Document #2575.

[169]Janne Nolan and Albert Wheelon similarly conclude that the Jericho II "rocket was used with a third stage to launch the first Israeli satellite." Their calculations for the two-stage version give a range of 2400 km for an 1100 kg payload. Nolan and Wheelon, "Ballistic Missiles in the Third World," Appendix 3 in Aspen Strategy Group, *New Threats: Responding to the Proliferation of Nuclear, Chemical, and Delivery Capabilities in the Third World* (Lanham, Md.: University Press of America, 1990), 96, and note 10 (published erroneously as note 17), pp. 125-27. However, Steven Gray's calculations for the probable capabilities of the Shavit launcher give a range of 4500 km for a two-stage version with an 1100 kg payload. Gray, "Israeli Missile Capabilities: A Few Numbers To Think About," Lawrence Livermore National Laboratory, unpublished paper, 7 October 1988. Steve Fetter's calculations yield an approximate range of 3600 km for an 1100 kg payload. Fetter, "Israeli Ballistic Missile Capabilities," School of Public Affairs, University of Maryland at College Park, unpublished paper, 10 April 1990. I have not done the calculations needed to resolve these estimates. Nonetheless, they demonstrate the basic plausibility of the conclusions presented here.

in which case an additional segment could easily be added.[170] For the Shavit launches, a small highly-efficient third stage is added to boost the payload into low-earth orbit. This apogee kick motor, marketed under the name Marble, is manufactured by Rafael, while the first two stages are manufactured by Ta'as, both under an IAI prime contract for the overall system.[171]

This development strategy would also match some of the observed testing history. Reports of tests at dramatically different ranges are reconciled if one assumes that the Israelis continued to follow French testing philosophy and conducted some tests with a dummy second stage.[172] The third stage presumably completed development later, since Rafael only belatedly won the disputed contract from Ta'as, and because in order to win the contract, Rafael needed to propose as sophisticated a design as it could.[173] These assumptions accord with the

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[170]The Indian space program uses such designs, but I have no evidence that the Israelis do. See R. Nagappa and M. R. Kurup, "Development of HTPB Propellant System for ISRO's Motors," *26th AIAA, SAE, ASME, and ASEE Joint Propulsion Conference*, Orlando, Fla., 16-18 July 1990, AIAA Paper #90-2331.

[171]See "Rafael Technology Goes to Market," *Flight International* (19 - 25 June 1991): 23; "IAI to Boost Civil Shavit," *Flight International* (19 December 1990 - 1 January 1991): 11; and "Israeli Satellite is 'Threat' Say Arabs," *Jane's Defence Weekly* (1 October 1988): 753. Many reports mingle reliable and unreliable information, as in Anthony Cordesman, *Weapons of Mass Destruction in the Middle East* (London: Brassey's, 1991).

[172]The Financial Times cites Yuval Ne'eman in reporting four tests (ostensibly of the Shavit) before the first space launch, two of them with dummy second stages. Andrew Whitley, "Israel Presses on With Its Spy-in-Space Satellite Program," *Financial Times*, 18 October 1988, p. 4. For a description of French testing during missile development, see Young, "French Strategic Missile Programme," 13.

[173]The motor case for the apogee kick motor is thin-walled titanium, a material in which Ta'as has little experience. An extremely high mass fraction would also lead to a difficult development. As we have seen in some previous examples, Rafael is the one defense industry which is able to use high-tech sophistication as an argument in its favor.

timing of the first Shavit launch in September 1988, after what may have been a fairly large number of tests of the two-stage missile version.

There is some evidence that most of the elements of this alliance had independently attempted to secure support for developing a large boost vehicle, each without success. As discussed above, it seems that the defense industries could not garner support for longer range missiles after the completion of the Jericho I development in the early 1970s. Also mentioned previously is the unsuccessful plan for a Sputnik-like Israeli satellite launch that was promoted in the mid- to late-1960s. Other such plans may well have existed, but have not been made public.[174] In what may have been the most important factor, IAI appears to have promoted space technology as an important future market since the late 1970s, investing ever-greater funds in an area that has yet to produce large returns.[175]

The third ally for large boost vehicles was the Israeli desire for photoreconnaissance. While also a defense need, this goal attracted different supporters than the long-range missiles, probably including army officials who, while dismissing the effects of conventional or nuclear-armed missiles, would be extremely interested in learning details of strategic developments and deployments in Israel's neighbors. The Pollard affair and other recent incidents demonstrate the interest of at least some Israelis in satellite intelligence.[176] Today, some Israelis

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[174]Some low-level technology development probably continued through this period. For example, in the mid-1970s, Rafael studied hydrazine monopropellant thrusters with 500 N thrust, an effort which would make the most sense as part of a satellite or post-boost vehicle program.

[175]See note 93, above.

[176]According to Seymour Hersh, the Israelis were so focused on acquiring intelligence from the U.S. KH-11 that "'they did everything except task the bird,' one disturbed military man acknowledges." Hersh, *Samson Option*, 13. Nor is the interest or the potential for conflict new. Mordehai Gur, then a minister without portfolio, "said that Israel had begun work to develop a reconnaissance satellite after it decided that it could not rely on the United States to provide full intelligence information. During the 1973 war, 'the United States did not give us enough information,' he said after a Cabinet meeting Sunday [18 September 1988]. 'When I say not enough, I mean less than

are unabashed in their pursuit of a reconnaissance satellite, with public statements broadcasting their ultimate intent.[177] Some of the debate of the wisdom of various levels of capabilities is even taking place in public.[178] But this interest, taking the form of technological development, appears to have been present for decades, especially among the technical elite. Plans at Rafael in the late 1960s gave way to low-level funding at IAI in the early 1970s to developed

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what we got before the war.'" John Kifner, "Israel Launches Space Program and a Satellite. Spy Craft Are Expected to Be Main Emphasis," *New York Times* (20 September 1988), pp. A1, A12. In 1984, Israeli officials expressed their desire for their own reconnaissance satellites to Defence Secretary Weinberger. "What's Ahead in Aerospace: Strategic Cooperation," *Aerospace Daily*, 9 October 1984, p. 193.

[177]According to "U.S. Ambassador Probes Israeli Space Project," *Flight International* (10-16 June 1992): 32, "Israel has admitted it is developing a reconnaissance satellite." See also "Iraqi Missile Attacks Spur Backing for Israeli Military Satellites," *Armed Forces Journal International* (April 1991): 29. Within Israel, then-Defense Minister Moshe Arens declared to a full session of parliament, "I suppose that I will not suprise anyone if I mention that we have already launched two satellites into space. Therefore, don't be amazed if one of these days we launch another satellite into space, one with intelligence capabilities." Gideon Alon, "Arens Hints that Israel Will Launch a Spy Satellite," *Ha-Aretz*, 7 March 1991, p. A3.

[178]Foreign sources, such as those cited above, can be quoted in Israeli publications despite military censorship, as in "Is Israel Building Its Own Reconnaissance Satellite," *Innovation* (June 1991): 8. Within Israel, the debate has spilled over into the daily newspapers. See the ongoing exchange of opinion and analyses: Reuven Pedatzur, "Decisions Pending," *Ha-Aretz*, 30 June 1992, p. B1; the letter by Prof. Giora Shaviv to Defense Minister Moshe Arens, published as "Affordable Satellites," *Ha-Aretz*, 23 July 1992, p. B4; and the response by former ISA head Prof. Dror Sadeh, "Not a Vital Necessity," *Ha-Aretz*, 30 July 1992, p. B4. See also Dror Sadeh, "Israel, Satellites, and the Trouble to Come," *Ha-Aretz*, 7 March 1991, p. B3; and Reuven Pedatzur, "Spying Over the Horizon [Ofek]," *Ha-Aretz*, 28 February 1991, p. B1.

Reports about operational reconnaissance equipment being launched on an Ofek-3 (or even the Ofek-2) appear exaggerated. Compare the claims in "Israel Launches Ofeq-2 Satellite," *Defense & Foreign Affairs Weekly* (9-15 April 1990): 5, with the detailed system descriptions given in the operational reports for Ofek 1 and 2 cited below.

selected hardware. IAI gradually devoted more of its own internal funding to space programs, including cleanroom and vacuum testing facilities. Respected engineers became recognized as the "pushers" for an Israeli space reconnaissance capability, and surely played a role in the decisions that eventually led to the Shavit satellite launch vehicle.

Conflated with all of these arguments--missiles, civilian space technology, and satellite photoreconnaissance--is the idea that "Space is the technology of the future, if there...[is] to be technology in this country." Advocates draw on the types of reasoning described before as "faith in technology":

- The needs of space technology can influence many fields in engineering, science, and industry, such as minitiarization, quality control, or computers;
- For a small country, the fallout of space activity is so tremendous that Israel *has* to go into space technology and industry, or it will "pay through the ears."
- If Israel does not become an "advanced country," it is poor in resources, has only small agricultural areas that have already reached their peak of production, and has no other means of securing its economic (and therefore military) survival.

Furthermore, a national demonstration of space technology like the Ofek, while merely garnering "prestige" in one sense, also demonstrates a scientific and industrial prestige that is directly convertible into other kinds of currency, including export sales. No space industry can win significant sales unless it can demonstrate that its products are "space-worthy." A complete satellite system is the best demonstration of such a capability, but no satellite contracts would be awarded to an industry unless it had already demonstrated its capabilities. The way to bootstrap out of this dilemma is through a nationally-funded demonstration launch, precisely the role of the Ofek program.[179]

Thus, the Jericho II missile and Shavit satellite launch vehicle can be many things to all people, as weapon, deterrent, symbol of technological prowess, harbinger of future export earnings, promoter of technological and economic development, or vehicle for vital intelligence data. Only by piecing together an alliance of all these incarnations could the rocket itself come into physical being. Having crossed the threshold of existence, it can now reproduce into different forms in order to serve better its various masters.

Ascribing the development of long-range strategic missiles in Israel only to security-driven motivations falls far short of this complex truth. While it may be possible to point to external justifications for the Jericho II missile, this analysis demonstrates that such justifications cannot explain the existence or timing of the missile program. We need to ask what happened to turn the long-standing arguments of particular advocates into an actual missile. Particularly in the Israeli case, enough resources could have generated the necessary capabilities earlier; but those resources would not have been committed without the multi-faceted alliance just described. Even in other cases where weapons programs appear to follow immediately in the footsteps of technical capability, the sociology of technology reminds us to ask why that technical capability has come to exist.

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[179]This point is reinforced by the extremely detailed reports released after both satellite launches on the performance, capabilities, operations, and qualification procedures for the space vehicles themselves, while the same reports somehow avoided mentioning a single word about the boosters that placed those satellites in orbit. Jerry Wittenstein and Moshe Barlev, "Offeq-1: Preliminary Flight Evaluation Results," *30th Israel Annual Conference on Aviation and Astronautics* (Haifa: Israel Institute of Technology, 1989), 288-300; and Jerry Wittenstein, et al., "Offeq-2: Orbit and Attitude Flight Evaluation Report," *4th Annual AIAA/USU Conference on Small Satellites*, Logan, Utah, 28-30 August 1990, 1-42.

VI. Conclusions

This analysis has emphasized the difficulties involved in constructing new missile technologies in Israel through the late 1970s, and how the resulting systems show the traces of those pressures. Using the methods of the sociology of technology reveals the span of allies that had to be recruited in those cases where technology development did occur. Understanding such dynamics also permits better policy formulation.

This chapter would have been stronger had I acquired enough data for a complete deconstruction of some artifacts. In moving to a higher level of generalization than in the Brazilian and Indian cases, my descriptions may apply to patterns of R&D in other countries as well. A truly comparative study would highlight what features are unique to the Israeli case, and perhaps better identify their origins.

Since the aftermath of the Yom Kippur War, the thesis and antithesis structure described in this chapter has faded but remains relevant. This analysis suggests a key role for technical expertise in the MoD and the IDF, permitting the emergence of whole new agendas and political battles over military technology. The bottom-up processes that gave such a prominent role to the industries have been tempered by a new ability and willingness of the users to open black boxes to lower levels. The IDF's reserve policies have continued to strengthen such intimate working contacts, now with an organizational infrastructure for support.

While Israel seems to have averted the opposite danger of weapons policies completely controlled by military services, the resulting policies bear more resemblance to the synthesis described above (especially virtual autonomy) than they do to an ideal reconciliation of competing visions of Israeli security needs. In other words, the increasing power of other voices in the process of developing military technology has merely increased the compromises needed for the still-difficult task of satisficing all parties. Often those compromises are sheltered from scrutiny, outside the interested parties, by the cover of military secrecy. Disasters such as the Lavi then follow easily.

In comparison to the analysis of the Brazilian and Indian missile programs, the system-wide analysis pursued here reveals patterns in the development of military technology that cut across a wide swathe of the weapons field. From tactical air-to-air missiles to satellite launch vehicles, we see some of the same forces and counter forces, the same actors and roles, shaping the evolution of particular artifacts and the overall system. Examining the details of a missile motor reveals different aspects of the same information revealed by examining the relationship between defense industries and the Ministry of Defense. While an analysis that roams across so many levels of analysis may be extremely difficult to carry out, it can also prove to be versatile and revealing.

CHAPTER FIVE

Summary and Conclusions

I. Introduction

This thesis has examined the missile development programs in Brazil, India, and Israel. The analysis has attempted to probe more deeply than traditional security-centered or bureaucratic politics analyses by examining the technologies themselves. The case studies have demonstrated the richness of the politics of developing military technologies. This concluding chapter first summarizes the conclusions from each of the cases. Based on the results of the case studies, I then draw some overall conclusions about the utility and applicability of the history and sociology of technology. Despite a sample of only three countries, I describe some of the clearest patterns applicable to missile proliferation. Finally, from a U.S. perspective, I lay out a series of policy implications for dealing with the Brazilian, Indian, and Israeli programs, concluding with a more general policy assessment.

II. Case Summaries and Conclusions

Brazil: The Brazil chapter argues that a traditional security analysis, looking at threats, rivals, security dilemmas, and military capability, is insufficient to explain this case. As one of the main figures in the research effort, an Air Force colonel, said, "After all, whom will we attack?" For Brazil, a realist perspective cannot explain even the existence of missiles, much less their specific history or characteristics.

My analysis instead examines how the detailed construction of Brazilian missiles reflects the empire-building tactics of important engineers, the competition between the leading missile and space research organizations, the prevailing ideas about military technology's role in development, and the place of the military in the Brazilian polity. I conclude that the Brazilian space launch vehicle and ballistic missile programs are a result of a temporary convergence of a diverse set of personal, organizational, and ideological interests, a convergence that is now mostly in the past.

India: While there may be little technical difference between the Indian missile and space programs, they are politically quite distinct. The space program is supported by a stable, national consensus based on broad themes that are found throughout Indian politics, such as nation-building, self-reliance or technological autonomy, and international position. The missile program is an historically contingent alliance of particular interests, such as concerns about brain drain, a small cadre of missile engineers, India's nuclear "option strategy", and Army-Air Force rivalry. The analysis again examines the detailed construction of the artifacts of the missile programs, especially the intermediate-range Agni and short-range Prithvi missiles.

The Agni missile, although it did travel a thousand kilometers in its first test, is not a ballistic missile in the usual sense. So far, it has been just two specimens of a hybrid, RV technology test bed, a weak political alliance that is only as strong as the interstage holding together rockets from the space and Prithvi programs. The Prithvi missile, which is far more likely to become a deployed, mass-produced system, has had its political essence defined by its relationships to the Army, to long-range artillery, and by necessity, to conventional (non-nuclear) warheads. This analysis helps us to understand why the Prithvi contributes negligibly to the capabilities of their already-purchased fleet of bombers and ground-attack aircraft, or why the Agni does not add any significant targets that their shorter-range systems could not reach, while failing to cover important more distant strategic targets, such as Beijing.

Compare these conclusions to a standard realist picture, which would hold that Indian missiles are a response to strategic threats that India faces from Pakistan and China. A traditional analysis would not be able to explain, for example, why Indian missile programs throughout the 1960s and 1970s did not succeed, while the 1980s saw a successful program based almost entirely on those earlier development programs. My analysis demonstrates that the Indian space and missile programs are far less problematic (from the perspective of risks of war or of U.S. policy). Many traditional political analyses, because they ignore so much of the politics of developing military technologies, are not able to reach these same conclusions.

Israel: Four forces in the Israeli political system promote the development of new weapons systems and new military technology: self-reliance, inter-industry rivalry, faith in technology, and secrecy. The primary inhibiting forces are economic limitations, the availability of alternatives to indigenous development, and again secrecy. These forces are structural, in the sense that their power spans more than the single issue of security, and in the sense that they are not likely to change quickly as a result of events only in the security arena.

The characteristics of Israeli missiles are determined largely by a synthesis of these conflicting forces, rather than any specific military requirements. The resulting patterns include virtual autonomy, export dependence, and bottom-up technological development. Each is functionally adapted to meeting simultaneously the demands of both the promoting and constraining forces. Even strategic systems such as Jericho missiles fit consistently into these broader patterns of indigenous technology development in Israel.

A security-centered analysis of Israeli missile programs could not explain much beyond the basic fact that Israel will have missiles--not how many, what kind, or whether or not they will be indigenous. So the realist perspective can do something in the Israeli case, but its power is limited. Balance of power theorists would miss the conclusions that the Jericho II owes its existence an alliance among civilian space applications, photo reconnaissance missions, and so on. It is true that without the Jericho II, Israel would still have had the Jericho I and Lance missiles. But if the development of the new longer-range missile system matters, then realists cannot explain it.

Since the mid-1970s, some of the structural factors enforcing the dialectical pattern in Israel have changed. For example, the alliance with the United States has become closer, and the Army's perception of the immediacy of potential conflict has eased somewhat. But we also need to take into account that technology is itself an actor. Each test, each use of indigenous technology in combat, increases the acceptance, desirability, and ease of recruiting for new indigenous technologies. The process feeds on itself. Since the mid-1970s, it has become progressively harder to challenge the idea that Israel can and should develop its own weapons systems.

Nonetheless, even now the internal contradictions highlighted by this analysis continue to plague Israeli military industry. The Lavi disaster was merely the most acute and visible symptom of the dangers of a long term strategy of "virtual autonomy." The negative consequences of this strategy, as well as changing circumstances in Israel, has weakened the hold of the old philosophies, but no new consensus has yet emerged to replace them.

Future Applications: This thesis could be extended to examine missile programs in other countries as well. Where imported technology plays a larger role, as in the Iraqi case, the idea of a large technological system would have to be modified substantially. For Brazil, India, and Israel, I have accepted the artificial analytic boundaries of the nation in defining the relevant systems. In studying Iraqi missile development, the analysis would have to include an international network of arms traders, multinational corporations, banks, export regulations, and other actors. These same actors do have an impact in the three cases I examined. While it seemed an acceptable simplification to treat them as lying outside the system, the analysis becomes more complex for weapons that are not developed indigenously,

Extending this approach to other cases offers its greatest rewards for heterogeneous systems. The more heterogeneous a missile LTS is, the more a systemic approach is necessary to encompass all of the relevant actors. Similarly, the more communities are involved, with their distinctive norms and agendas, the more an interpretive approach is necessary to recognize competing meanings for the same artifacts or actions.

Analyses of nuclear weapons development programs would look very similar to the cases presented here. A preliminary investigation of the Indian and South African programs reveals powerful allies and contingencies that have escaped the attention of traditional analysts.[1] An Indian system-builder, the physicist Homi

[1] Steven Flank, "Exploding the Black Box: The Historical Sociology of Nuclear Proliferation," *Security Studies* 3, no. 1 (Fall 1993), forthcoming.

Bhabha, succeeded in establishing an independent, insulated research establishment, governed largely by Western scientific norms. This nuclear establishment could shop for whichever allies were best able to support its agenda. During a period in the late 1960s and early 1970s, one of the system's leading allies was the burgeoning agro-industrial complex. Had that trajectory continued, India might now have indigenous natural uranium nuclear reactors powering fertilizer factories, whose gas streams would feed heavy water plants. These sites were also to include desalinization plants and irrigations pumps (powered by the nuclear stations) that would water fields of nuclear "mutant" breeds whose harvest would be protected against spoilage by massive irradiation from radioisotopes. Instead, agribusiness proved an unreliable ally, and the Indian nuclear system remains awkwardly suspended, with tentative ties to both military and civilian applications.

With South Africa's uranium and mining industry as the nucleus of its nuclear system, we can understand the evolution of the nuclear LTS in South Africa as the gradual addition of value-added processes to the resource-based foundation of uranium ore. This frame established the reverse salients that governed the system's evolution. Later crises, imposed by the anti-apartheid campaign and the collapse of uranium prices at the end of the 1970s, forged a new industrial-scientific-military alliance which had nuclear weapons as its product.

In sum, the approach used here has provided significant conclusions in the cases of Brazil, India, and Israel. It has the potential to do the same for other important cases in the future.

III. Evaluating the Methodology

One of the major goals of this thesis has been to probe the utility of new methods in the history and sociology of technology for understanding the development of military technology. According to some intuitive criteria for evaluating a methodology, the systems perspective used here has performed quite well.[2]

First, in each of the three cases, it has been possible to reach some conclusions about the evolution of missile technology. Enough information was publicly available so that determined research could lay out a detailed picture of the artifacts and large technological systems involved. I was then able to use that information to explain the causes, contingencies, and possible future evolution of each system. However, my case selection was also biased toward systems with stronger civilian ties (and therefore with more public information). A study of the North Korean missile program might uncover different patterns in the web, but probably would not be feasible to perform in the open literature. Furthermore, because information about civilian applications is easier to find, I probably emphasized the more dual-use categories of military technologies.

Second, some of the conclusions that I have reached differ from the results of other analyses. The unfamiliar and sometimes counter-intuitive principles of a constructivist methodology would hardly be worth the trouble unless they offered something other than the usual fare. I believe that many of the conclusions are also interesting in an academic or aesthetic sense. The approach used here can spin a good story and capture the attention of the analyst and the reader. Not

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[2]These criteria are partially drawn from Stephen Van Evera, "Hypothesis, Laws, and Theories: A User's Guide," Version 2.4, Revised April 1991.

only are some conclusions new or different, they can also be useful in a policy sense, as explored below.

Finally, this methodology meets some requirements for widespread adoption. It is parsimonious--that is, it uses a small number of methodological principles in order to examine a diverse range of phenomena. While those principles may take some effort to understand or apply, the results of such an analysis can be presented to an uninitiated reader, one who is outside the constructivist idiom. Each of the cases presented here has been developed using the methods of the history and sociology of technology; yet I would take it as a compliment if readers can understand my analysis without knowing any of the theory.

In sum, this thesis demonstrates the merits of looking at missiles and other military technology as large technological systems. However, the methodology does have some weaknesses, and will need to continue to develop.

The greatest weakness of the social construction of technology is how it addresses interests. The theory spans the panoply of human motivations: greed, altruism, organizational interests, national prestige, or aesthetic pleasure. The theory tells us about the *process* by which technological systems evolve; but it does not tell us anything about which interests determine those outcomes.[3] In the future, the history and sociology of technology may seek to recover the specific political struggles and economic forces found in other sociological and

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[3]The SCOT literature shows some signs of a conceptual dead-end. Some recent articles have moved into endlessly self-referential refinements of the theory; others have attempted to tie constructivist terminology back into earlier theories; only a few have concentrated on seeking the patterns in the seamless web. My apologies to Trevor Pinch, but his "Turn, Turn, and Turn Again: The Woolgar Formula," represents the field's recent navel-contemplating tendencies (presented at the Society for Social Studies of Science Annual Meeting, Cambridge, Mass., November 1991). For recent articles attempting to integrate patterns, see Thomas Misa, "Theories of Technological Change: Parameters and Purposes," *Science, Technology & Human Values* 17, no. 1 (Winter 1992), 3-12; Alex Roland, "Theories and Models of Technological Change: Semantics and Substance," *Science, Technology, & Human Values* 17, no. 1 (Winter 1992): 79-100; Law and Bijker, "Postscript: Technology, Stability, and Social Theory"; and Ronald Giere, "Science and Technology Studies: Prospects for an Enlightened Postmodern Synthesis," *Science, Technology, & Human*

political theories.[4] For example, the theory may incorporate Marxist perspectives and examine how class interests shape technology development strategies in the third world (including its impact on military technologies). Already, some organizational sociologists are incorporating SCOT into theories that identify the most important organizational forces.[5]

As the sociology of technology joins with other theories, the offspring will hopefully retain insights into the simultaneous and interactive ways in which interests come to be defined and reject linear means-ends explanations of how interests translate into actions or artifacts. The history and sociology of technology may thus come to rest as a school of historical and anthropological

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Value 18, no. 1 (Winter 1993): 102-112. As described Chapter 1, bureaucratic politics theories suffer the same drawbacks.

[4]Earlier discussions in the sociology of science addressed the question of interests more directly, but did not transfer successfully to the sociology of technology and have now dropped out of the mainstream. See Barry Barnes, *Interests and the Growth of Knowledge* (Boston: Routledge and Kegan Paul, 1977); Latour and Woolgar, "Cycles of Credit," ch. 5 in *Laboratory Life*; and the criticism of interests theory in Steve Woolgar, "Interests and Explanation in the Social Studies of Science," *Social Studies of Science* 11, no. 3 (August 1981): 365-94.

[5]P. Anderson and M. L. Tushman, "Technological Discontinuities and Dominant Designs - A Cyclical Model of Technological-Change," *Administrative Science Quarterly* 35, no. 4 (December 1990): 604-33; and M. Tushman and L. Rosenkopf, "Organizational Determinants of Technological-Change - Toward a Sociology of Technological Evolution," *Research in Organizational Behavior*, vol. 14 (1992): 311-47; see also Robert Joseph Thomas, "What Machines Can't Do," MIT Sloan School of Management Working Paper, forthcoming; and Wanda Orlikowski, "The Duality of Technology: Rethinking the Concept of Technology in Organizations," MIT Sloan School of Management Working Paper no. 3141-91, January 1991. For an application of SCOT to information technology and organizational change, see Wanda Orlikowski and Debra Carol Gash, "Changing Frames--Understanding Technological Change in Organizations," MIT Sloan School of Management Working Paper no. 3369-92, April 1992, to be published in *Organization Science*.

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interpretation--a method for telling better stories--without any pretensions of generalizability.

In the case histories, we can see the power of this approach for telling better stories. For example, I claim that the Indian missile and space programs are separate entities. My primary basis for that claim is the detailed analysis of the DRDO's missile technologies, and how they shows few signs of originating in the space program. It so happens that I can adduce support for the same claim from other sources: elite statements, government documents, the movement of personnel, and so on. Those other sources corroborate my original interpretation, so that the lack of transferred technology is confirmed as a good indication of what is going on in the Indian missile and space programs. In general, I can then feel more confident that in other areas as well, technological artifacts accurately reflect and embody the same phenomena as political processes. The consonance of the technological deconstruction and the partial bureaucratic histories in each of the three cases lets us conclude that this methodology is looking at the right variables.

A constructivist perspective also improves our stories by giving us more data to play with. By treating technology seriously, we can reveal the histories, alliances, and contested interpretations that should be at the core of any good history. For example, our deconstruction of the Prithvi's propellant reveals the gap between the Indian defense and space research organizations, the weakness of the missile project's claim on resources, and the lack of ties to development programs or agricultural interests. Analysts concerned with an issue as important as missile proliferation cannot afford to ignore the wealth of relevant information embodied in the diverse artifacts of a missile LTS.

The methodology's focus on technology also demonstrates its comparative advantage over standard analyses of bureaucratic politics. While bureaucratic politics and other organizationally-centered analyses could reach conclusions similar to the ones in this thesis, they usually do not. Researchers focusing on bureaucracies do not bother to look at the technology. In the Brazilian case, for example, they might examine the strained relationship between the IAE and INPE. But they would stop at that level, not asking about what motor case materials were used or why the VLS has so many large strap-ons--questions that supply important answers in our study. In essence, the history and sociology of technology applies bureaucratic politics more consistently than its practitioners usually do, adding technology as yet another variable that needs to be addressed.

The final lesson we learn from our methodology's performance in this thesis is the importance of interdisciplinary work. In order to unravel the strands of the web, we have needed to pull together detailed knowledge of missile propellants and guidance systems; of development theory and nation building; of economics and ethnic conflict. Research on large technological systems requires as much heterogeneity from the analyst as from the system-builders themselves.

IV. Patterns in the Web

So far in this chapter, we have discussed sub-conclusions, that is, specific stories from the cases about what happened in the missile programs and why; and meta-conclusions, that is, whether it is feasible and useful to apply the thesis's methodology for other cases. We now arrive at the kind of conclusions that one would normally expect in a dissertation, that is, generalizations about findings that apply across the cases. Such conclusions are always difficult, more so when one is using a narrative approach, and especially when the sample consists of only three cases.

The first pattern that emerges is the answer to our original question: What is the balance between internal and external factors in leading to missile development programs? In the three cases examined here, the neorealist emphasis on security threats and the structure of the international system seems misplaced. In the most benign of the security environments studied, Brazil, a security-centered analysis captures almost nothing of interest. In the most severe environment, Israel, security motivations do account for the some of the important structural conditions, such as the level of effort that Israelis are willing to devote to defense. Yet even for Israel, security arguments did not enter into our explanations of how much of that effort would be directed toward weapons such as missiles, what the capabilities of such systems would be, or whether they would be developed indigenously.

This strong conclusion needs to be tempered. Much of this thesis has tried to broaden the study of military technology beyond the traditional focus on security. The other half of this project--redefining and reconstructing the concept of security itself--has been entirely ignored. External security threats clearly *are* useful allies in building technological and other kinds of systems, though we have shown they are not the only useful allies. But what do people mean by "security concerns," and how do those concerns really translate from abstractions to artifacts?

For some artifacts, the translation may be fairly easy. In some diplomatic negotiations, for example, a relatively homogeneous system needs mostly human allies, and at that, from within a rather restricted elite. For larger and more heterogeneous systems however, the interpretation, manipulation, and relevance of the idea of security are ripe for a constructivist analysis. All this thesis has done is to show that we need to expand our thinking, our conceptual grasp, to include all of the strands of the seamless web. We have not really elucidated that strand which we call security, which surely must have some substance to its intuitive meaning. I hope, however, that this thesis will help to remove the privileged status of security as "explaining" military technology.

What other patterns emerge to supplement or take the place of security in explaining the development of missile technology? In each of our three cases, we see key roles for the overlapping agendas of security and development, for the quest for technological autonomy, and for the goals and norms of the scientists, engineers, or industrial researchers who carry out the development programs.

Security and development: Much of the development literature treats military spending primarily as a drain on national resources, and thus as an impediment to effective development policies. Instead, we have seen military technology firmly embedded as part of national technology development programs. For governments in developing countries, military industries are often an attractive target for investment, since both producers and consumers are already under government control. As we saw most powerfully in the case of Brazil, a government may actively promote the structural unity of military and civilian development in order to satisfy multiple constituencies, claiming that programs which fulfill military wish-lists will also meet development goals. Technologies which are dual-use in the usual terminology can also achieve the single use of sustaining a government's legitimacy throughout the polity.

Technological Autonomy: Starting with import-substitution industrialization after the Second World War, many developing countries have stressed indigenous capabilities for innovating and adapting technologies. Broad political, economic, and industrial interests support programs (such as promoting self-reliance or fighting brain drain) which enhance the technological and advanced industrial capabilities of the state.[6]

The quest for autonomy tends to come in two flavors. The first, following structural dependency theory, asserts that the current core/periphery structure of the international political economy prevents any developing nation from achieving economic equality with the advanced industrialized states--unless the developing nation is willing to forego the apparent benefits of operating within that internationalized economy and instead undertakes its own autonomous development programs.[7] The second approach to the quest for autonomy is what some have labelled a "pragmatic anti-dependency" theory, where cooperation with multinational corporations, international lending authorities and industrialized nations can all have a positive impact on a developing nation's progress, as long as the cooperation and interaction are effectively managed by the state.[8]

The Brazilian missile program seems to fit reasonably well with this pragmatic anti-dependency approach. Indian programs emphasize more of the go-it-

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[6]Support for such programs is not unique to the developing world. See for example Harvey Brooks, "National Science Policy and Technological Innovation," in R. Landau and Nathan Rosenbarg, eds., *The Positive Sum Strategy* (Washington, D.C.: National Academy Press, 1986), 119-67.

[7]Peter Evans, *The Alliance of Multinaticnal, State, and Local Capital in Brazil* (Princeton: Princeton University Press, 1979).

[8]Emanuel Adler, *The Power of Ideology: The Quest for Technological Autonomy in Argentina and Brazil* (Berkeley: University of California Press, 1987).

alone strategy, with only occasional successes. Israel practices an odd hybrid in its pursuit of virtual autonomy. This variety of approaches shows the possibility of changing the meaning and requirements of autonomy in a given situation, even while the basic drive remains constant across all of our cases. The flexibility of the practice of autonomy is confirmed by the shift that the new civilian government in Brazil has carried out, welcoming more international cooperation in pursuit of the same goal of indigenous technology development.

Scientific communities: The last pattern we have observed is the role of scientific communities and norms. In all three cases, scientists and engineers do much of the work of constructing missile technology and often hold high-level decision-making positions. While sharing ideological principles with the rest of their society (nationalism, militarism, self-reliance), they also follow their own community norms. For example, some researchers want to pursue exciting, advanced projects that can lead to recognition from the international scientific community. Others want to practice their trade, to move a single technological vision closer to reality and perfection. In both cases, meeting these goals requires progressively more sophisticated technologies, more resources, and more allies.[9]

Development strategies in both North and South grant scientists and engineers strong claims on the resources and independence they want. In

[9]Those norms are themselves the product of an historical evolution and are obviously culturally specific. For a careful examination of the Brazilian case, see Antonio Jose Junqueira Botelho, "The Professionalization of Brazilian Scientists, the Brazilian Society for the Progress of Science (SBPC), and the State, 1948-1960," *Social Studies of Science* 20, no. 3 (August 1990): 473-502. The generalizations described here still apply reasonably well across cultures, in part because of the many opportunities for international socialization, such as studying abroad, visiting scholarships, international conferences, and immersion in a common literature.

advanced industrialized countries, one of the prime roles of science and technology policy is buttressing such claims. In developing countries, meeting the technologists' priorities is ammunition in the fight against brain drain. Throughout, military technology has been the frequent beneficiary.

V. Policy conclusions:

We still need to point toward the last step of reconstructing rockets, namely better policy for missile proliferation (from the U.S. perspective). The main thrust of U.S. policy has been to define proliferation as a bad thing, and then to search for policy options in order to limit it. This thesis does not attempt to analyze the wisdom of this basic assumption, taking the current policy orientation as given and exploring how to improve it. The following section describes how this thesis can be applied to U.S. policy on three levels. First, by simply understanding specific cases, we can spot counter-productive policies, two examples of which we consider here. Second, we can identify what motivations and factors have helped produce indigenous missile programs. Better policy will presumably follow from that identification, regardless of what analytic techniques brought us to that point. Third, we can simultaneously adapt policies to fit the peculiarities of each case better and integrate proliferation policy back into the broader scope of U.S. policy, improving overall policy effectiveness in the process.

Improving Nonproliferation Policies

Avoiding counter-productive policies: In the Brazilian case, the United States has aggressively pursued its enforcement of export controls under the Missile Technology Control Regime.[10] U.S. policy appears to have been based on the assumption that Brazilian missile development was necessarily motivated by a nuclear weapons program, or by Brazil's presumed intention to threaten Latin American or U.S. security, or by an intention to cooperate with Middle Eastern nations in building strategic missiles. In other words, in reacting to the Brazilian missile programs, "U.S. policy-makers are generally concerned most with security."[11]

In implementing its missile nonproliferation policy, the United States has refused to permit the repair of control packages for the Sonda IV which a U.S. firm had already been selling to Brazil; confiscated and held motor casings undergoing an annealment process for which Brazil had already received a license; withheld stage separation charges; and in general "has restricted most of the requested technology for the space and missile programs, since the signing of the MTCR in 1987."[12]

This policy has almost certainly had the effect of delaying or increasing the costs of certain parts of the Brazilian programs. At the same time however, "U.S. policy has:

1) further strained Brazilian security relations with the United States;
2) weakened U.S. influence over Brazil's rocket and missile programs;

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[10]Most of this discussion follows Scott Tollefson, "Brazil, the United States, and the Missile Technology Control Regime," ch. 11 in "Brazilian Arms Transfers, Ballistic Missiles, and Foreign Policy: The Search for Autonomy," Ph.D. diss., Johns Hopkins University, 1991, pp. 382-518.

[11]Tollefson, "Brazil, the United States, and the MTCR," 406.

[12]Tollefson, "Brazil, the United States, and the MTCR," 462-66, 462.

3) strengthened Brazilian ties with European suppliers (especially France) of space and missile technology; and

4) driven Brazil into closer technological cooperation with Iraq, the PRC, and the [former] Soviet Union."[13]

Our analysis clearly demonstrates why U.S. policy has been so counterproductive. By incorrectly assuming that security motivations are central to the Brazilian missile programs, the United States has instead exacerbated some factors that do support the programs, primarily the drive for technological autonomy.

The United States recently followed a similar course for India. For over ten years, the ISRO has intended to replace the two upper stages of its PSLV launcher with a high-energy cryogenic upper stage to construct a Geosynchronous Satellite Launch Vehicle (GSLV).[14] Specific plans for a 12-ton class indigenous engine were approved in 1986, with testing to proceed at the Liquid Propulsion Systems Unit in Mahendragiri.[15] At the same time, India was negotiating with France to buy or license-produce third stage engines from the Ariane 4, but could not reach agreement on an acceptable price.[16] Finally, in 1991 and 1992, ISRO

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[13]Tollefson, "Brazil, the United States, and the MTCR," 511. Tollefson makes the same points in *Brazil, the United States, and the Missile Technology Control Regime*, U.S. Naval Postgraduate School Report #56-90-006, 19 March 1990.

[14]Jerrold Elkin and Brian Fredericks, "Military Implications of India's Space Program," *Air University Review* (May-June 1983): 56-63, 58, citing "Reusable Boosters for Indian Rockets by 1986," *The Hindu* (Madras), 1 September 1981, p. 1.

[15]"India Develops Cryogenic Engine," *Spaceflight* 30, no. 2 (February 1988): 54.

[16]"Space: Price of French Space Technology Too High for India," *Interavia Air Letter* (12 December 1989): 4. Rumors abound that one or more American firms were also involved in the bidding, but at too high a price for India to be interested.

found a seller with the right price, and agreed with the Soviet organization Glavkosmos to purchase hardware and production technology for the Energia (SL-17) cryogenic upper stage engine.[17] This LOX/LOH 75 to 100 kN engine with multiple restart capabilities is a close match to the capabilities called for by ISRO's plans for the GSLV.[18]

On the other hand, a cryogenic engine would not be the usual choice for military applications. It is extremely difficult to make mobile or to keep prepared for launch on short notice, and it is extremely expensive. No nation has ever deployed an LOX/LOH engine for military purposes, and we have seen that India already has other indigenous technologies that do regularly find missile applications.

The United States chose to see the ISRO-Glavkosmos agreement through the lens of ballistic missile proliferation, and imposed "strict sanctions" on both the ISRO and Glavkosmos.[19] Although the MTCR guidelines "are not designed to impede national space programs or international cooperation in such programs,"[20] and although the Indian and Russian governments agreed to

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[17]For data on the SL-17 engine, see *Interavia Space Directory*, Andrew Wilson, ed. (Coulsdon: Jane's Information Group, 1991), 350-51.

[18]Indian plans had originally called for a 120 kN engine, but with a specific impulse of 490 seconds, the Russian engine should be efficient enough to meet the same mission profile. "Official Briefs on Polar Satellite Launch Plans," *Indian Express*, 21 April 1990, p. 5, in JPRS-TTP-90-006, 28 June 1990, p. 11; and A. E. Muthunayagam with assistance from K. Ramamurthi, "Development of Liquid Propulsion Systems in ISRO," *39th Congress of the International Aeronautics Federation*, Bangalore, 8-15 October 1988, IAF Paper #88-224.

[19]Andrew Lawler, "U.S. Sanctions Imposed; India Deal With Russia Still On," *Defense News*, 18-24 May 1992, p. 14.

[20]"Missile Technology Control Regime: Fact Sheet to Accompany Public Announcement," U.S. Department of Defense, 16 April 1987.

undergo end-use certification and inspection, the United States insisted that the connection between the Indian missile and space programs was too strong to permit sanctioning the transfer.[21] Even with the new Administration, U.S. policy remains unchanged.[22]

As in the case of policy toward Brazil, U.S. actions seem likely to reinforce portions of the original Indian motivations, without having any long-term negative effect on the Indian programs. The U.S. sanctions increase the prominence and immediacy of the Indian drive for technological autonomy. To a more limited extent, the sanctions play into some of the existing themes in Indian politics that also support the missile program, such as international prestige and the need for development through defense. Finally, they also reduce incentives to keep the space and missile programs separate--if the U.S. accuses even this transaction of having evil intent, why bother taking measures to demonstrate otherwise?[23] U.S. policy makers could have avoided these counterproductive outcomes if they had followed the analysis in Chapter 3, which clearly demonstrates the divide between the Indian missile and space programs, a divide that is mirrored in the programs' politics and technology.

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[21]U.S. Department of State, "Russian Sale of Rocket Engine to India," *Dispatch* 3, no. 20 (18 May 1992): 386; Daniel Revelle, "U.S. Muscle Misses Mark," *Bulletin of Atomic Scientists* 48, no. 9 (November 1992): 10-11, 44; Barbara Crossette, "U.S. Imposes a Ban Over Rocket Sale," *New York Times*, 12 May 1992, p. A8.

[22]Sanjoy Hazarika, "Despite U.S., Yeltsin Backs Rocket Deal With India," *New York Times*, 30 January 1993, p. 2.

[23]This analysis ignores the effect of the sanctions on Russian military space organizations. The United States has been urging Russia to expand civilian-based sales, fearing that without sufficient export earnings, those organizations might turn to missile sales to avowed U.S. adversaries.

Identifying motivations: In each of the three cases examined, we have been able to identify motivations and drivers for the missile programs. SCOT's methods permit the policy analyst to read out social and political contexts from the details of an artifact's construction. For example, our deconstruction of the Prithvi's propellant reveals policy relevant information: the gap between the Indian defense and space research organizations, the weakness of the missile project's claim on resources, and the lack of ties to development programs or agricultural interests. In other words, one can infer motivations from the technical details. Stripped of the complexities and subtleties of the full analysis, these motivations are quite recognizable even from a traditional, realist perspective. Regardless of the analysis that got us to this point, such conclusions should be helpful in policy formation.

For Brazil, we see system-building motivations for individuals and organizations--Jayme Boscov and the IAE, Hugo Piva and the CTA, and so on. Brazilian engineers at the IAE place a high value on practicing their trade and continuing the sequential development of a set of core technologies. At the same time, INPE engineers used the IAE's VLS as a temporary ally to build up their own space-based technological systems. On a broader level, the military regime supported these system-building endeavors because they sought legitimacy through development programs. Through the rocket programs, the regime could satisfy multiple constituencies such as engineers, the military as an institution, and the leaders of private industries. Finally, the quest for technological autonomy meshed with all of these other motivations, providing a society-wide measure of support, support that eventually weakened with the emergence of a more interdependent development philosophy.

In India, we have less detailed knowledge about individual system-builders. Nonetheless, we see clearly the attempt to build an integrated large technological system within the DRDO devoted to missile technologies. Yet DRDL, BDL, and RCI remain relatively isolated, and are still trying to build stronger links to other allies such as high-tech industry. The rest of the defense research establishment supports missile programs, because and as long as those programs provide fodder and justification for pursuing their own research agendas.

For the Prithvi missile, we also see the support of the Army, treating the missile as an extension of artillery and trying to pry missions away from the Air Force. On a broader level, the missile programs play into a number of larger themes, including India's international position, the role of defense technology in development strategies, the fight against brain drain, and the long-standing nuclear "option strategy." Finally, the missile programs have only succeeded in making tentative links to stronger well-springs of public support, such as self-reliance or nation-building.

In the case of the Israeli military R&D establishment, we again see the crucial role of system-builders, this time within the three competing government defense industries, as well as the importance of the norms and goals of researchers within the engineering community. Their programs and objectives win broader support because of self-reliance, faith in technology, and the unavailability of foreign suppliers. In the particular case of strategic missiles, the motivating factors include these broad societal forces, the particular military capabilities of the missiles, and also the indispensable allies of a civilian space program, photoreconnaissance capability, and the promise of further high-tech economic development.

Adapting policies: We can use these understandings of missile development programs to fashion more effective non-proliferation policies by, for example, helping to target development assistance.[24] With missile technology at the confluence of many other systems, outside assistance to selected actors and potential allies can inhibit or channel the evolution of a country's missile program. At an early enough stage, a SCOT analysis could identify competitors able to block the evolution of a stable missile system. For well-entrenched systems, a nonproliferation strategy could tie the system to non-military allies. The same sorts of targeted strategies could apply to all of a missile system's allies: organizations, ideologies, laboratories, community norms, reputations, and so on. Current non-proliferation policies attack a mere handful of allies--foreign technology suppliers and external security threats. A more complete technological systems analysis gives us a broader range of policy options for combating missile proliferation.

For Brazil, for example, the U.S. could encourage the INPE to work with the Brazilian telecommunications monopoly, Telebras, to integrate satellite communications into the national system. The more independent the INPE becomes, and the stronger its other allies, the less it will need to rely on the CTA and the launch vehicle programs. The United States does have the opportunity for policy leverage here, for example by easing export restrictions, creating cooperative

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[24]This analysis is certainly not the first to suggest the security benefits of international efforts to promote development. See for example Umberto Colombo, "Co-operation in Science and Technology as a Contribution to International Security," *Science and Public Policy* 19, no. 1 (February 1992): 2-6. SCOT's contribution would be in determining the strategic intervention points for such assistance.

programs with NASA or other government agencies, or working with U.S.-based multinational corporations to foster their involvement.[25]

The CTA itself is already involved in and ideologically committed to non-military technology development. As a strong institution that is likely to survive regardless of outside intervention, the best option for the U.S. would be to work with CTA, perhaps directly or perhaps through FINEP or other development agencies. A research organization that helps to develop technologies such as the CTA's alcohol engines is no threat to U.S. security interests, whether or not it resides organizationally within the military. With some of Brazil's best facilities and concentrations of expertise, the whole Sao Jose dos Campos complex could contribute impressively to the economic, environmental, and social welfare of the Brazilian people.

In India, reorienting U.S. policies away from traditional security concerns could be helpful in trying to re-direct Indian motivations. For example, the United States might consciously promote existing paths such as the Indian space program in place of missiles. Instead of imposing sanctions on the ISRO, the United States could aim to tie that program more firmly to the mass public and to civilian users. Similarly, the United States could try to provide some of the missing pieces that would be needed to apply missile technology to other applications. The Indian missile program has constructed a new research facility to develop carbon-carbon composite materials in cooperation with Indian industry.

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[25]For example, after a change in government, Argentina has terminated its ballistic missile program to the extent of physically destroying some production equipment. But the politicians now administering the remnants of the program also need and expect to forge new links, for example through expanding existing research contracts from NASA. Interview with Felix Clementino Menicocci, Third Secretary in the Argentine Foreign Ministry, Directorate for International Security, Nuclear and Space Affairs, 14 January 1992.

Targeted assistance could conceivably incorporate those new materials into important Indian industries so that the technology's promoters would not have to rely on the missile programs in order to expand.[26] In other words, the United States could help prevent missiles from becoming an obligatory point of passage and try to dislodge portions of the research establishment from the missile program's orbit.[27]

The United States can also help, possibly significantly, to satisfy those Indian drives which are, for the moment, part of the alliance that supports the missile programs. Cooperation and aid in technological development programs could reduce the effectiveness of the claims of defense programs that they are vehicles for development. India's pursuit of a more prominent international position could be satisfied by substantive roles in international forums, rather than by long-range ballistic missiles.[28]

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[26]Applications might include high-temperature industrial processes in refining, or perhaps ceramics for high-efficiency internal combustion engines. According to AVCO engineers, such materials are already finding widespread application in the civilian aerospace sector, for example in brake linings and in components for the turbines of jet engines.

[27]These strategies will of course be in frequent conflict with other development or political priorities, both for funders and for recipients. But missile proliferation policies have always suffered from competition with other policy priorities. A different analytic perspective will not remove the tensions among competing policy goals.

[28]Consider recent statements by Kavel Ratna Malkani, a leader of the Hindu fundamentalist Bharatiya Janata Party, that "an Indian will talk straight and walk straight when" India has nuclear weapons and ballistic missiles. As a smart and increasingly successful politician, Mr. Malkani evidently believes that he is responding to a popular perception of the minor role and lack of respect accorded to India in international affairs. Edward Gargan, "Hindus Now Demanding the Leadership of India," *New York Times*, 24 January 1993, p. 3.

More traditional, security-oriented measures would not be correlated strongly with altering the trajectory of the Indian missile programs. For example, trying to help settle the disputes over Jammu and Kashmir would help. But why? Not only because it would lessen the force of one of the justifications for military programs; but also because it would ease the task of unifying the nation.[29] Trying to arrange for conventional arms control, on the other hand, would probably be irrelevant to the missile program, since the presumed security dilemma mechanisms are not really the driving force. Finally technology denial, which seems to be a primary tool for U.S. nonproliferation policy, is likely to be counter-productive, at least in the long run, because it reinforces many of the motivations that are driving the program.[30]

In the Israeli case, the United States has already been a strong influence on Israeli policy, though not intentionally. For more than two decades, U.S. policy has fostered greater capability and self-reliance in the Israeli MIT by permitting technology transfer but refusing to supply advanced weapons systems--until the

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[29]The conflict over Kashmir is not a simple security dilemma. Both countries' identities as nations are tied up in the dispute--Pakistan owes its very existence and definition to its inclusion of the subcontinent's Muslim population, while India maintains its fragile cohesiveness only through successful integration of diverse populations into the secular Indian Union. But as Pakistan has become more oriented toward the Middle East (so that incorporating all Muslims into the state is less relevant), and as explicitly Hindu politics and culture gain ascendancy in India, Jammu and Kashmir may fade in importance. On the idea of the Hindu basis of Indian nationhood, see Gyanendra Pandey, "Hindus and Others: The Militant Hindu Construction," *Economic and Political Weekly* (28 December 1991): 2997-3009.

[30]As one editorial notes, "every one of the success stories in self-reliance [in India] has come in the teeth of foreign pressure." Cecil Victor, "Agni as Strategic Currency," *Patriot* (Delhi), 2 June 1989, p. 4. Dr. Kalam asserted that "India is the main target of the [MTCR]," while pledging that "we will survive and, in fact, will prove that we can do a better job." Man Mohan, "Paper Details Missile Production Plans," *Hindustan Times*, 27 February 1988, pp. 1, 5, in FBIS-NES-88-044, 7 March 1988, p. 55.

Israelis gave evidence of having achieved the capability to produce such weapons themselves. Conversely, joint production and research agreements might have tempered the drive for technological autonomy by strengthening the significant minority who supported a more interdependent vision of Israeli military technology.

Conscious U.S. policy could also have strong effects. For example, suppose that U.S. policy makers were steadfastly opposed to the development of an Israeli ICBM and space launch capability. In that case, using this analysis, the United States could have pursued different policies on supplying photoreconnaissance, whether particular intelligence, procedures for routine access, or actual satellites. Deprived of a key ally, it is at least conceivable that the Shavit and Jericho II would not have gathered enough support to become a reality.

Each of these suggestions for fine-tuning U.S. policies attempts to take advantage of existing or potential alliances in order to re-direct missile programs in other directions. Is the U.S. security bureaucracy smart enough to formulate and implement such sophisticated and sometimes subtle policies? Probably not--but the probability is at least higher when the process is supported by the kind of analysis provided here. A stronger objection might be that if a frequent part of the recommended strategy involves helping to build up technological capabilities, then what of the possibility of those very capabilities being used to further the development of indigenous weapons systems? In other words, how high is the risk that these sorts of adaptive policies would backfire?

I would argue that the risks are not especially great. I do believe that missile programs can be a criminal waste of resources, especially in countries such as Brazil or India where millions suffer under crushing poverty. Yet an ill-considered policy is not necessarily a dangerous one, and the security threats from such programs seem minimal, both on a global scale and from the U.S. perspective.

The more robust prescription for adapting U.S. policies that may emerge out of this research follows from the recognition that missiles are not detached from the rest of politics in most countries, that they should not be treated as a "special" category of problem. Just as my analysis required looking beyond security to see how missile programs fit into a broader political scene, so U.S. policy needs to widen its focus and integrate proliferation into a broader spectrum of policy.

It should be possible to integrate proliferation policy effectively with policies promoting democratization, economic and technological development, expanded trade, and so on. Those policy areas need increased emphasis in any event, and I believe would largely take care of missile proliferation problems in the process. Cooperation, corporate investment, aid, and better trade relations would all benefit both the United States and other countries economically. At the same time, they would weaken the hold of what my analyses show are some of the strongest forces promoting missile development, particularly in Brazil and India, but also in Israel: the quest for technological autonomy; scientists and engineers trying to meet their own agendas; and development, self-reliance, international position, and all of those fuzzy but potent forces that could yet be a part of an interdependent North-South model of technology development and sharing.

Thus, on a broader level, U.S. policy should be trying to enhance each country's moves toward technological interdependence. Such a policy may entail a willingness to transfer advanced technologies or the loss of monopoly markets for U.S.-based multinationals. The intent would be to increase the pay-offs for domestic actors to invest in non-defense technologies, and to burnish the image of those strategies for technological autonomy which involve cooperation rather than autarky and confrontation.[31]

It is true that such policies would include technology transfer and other measures that would improve the general technological capabilities of developing countries. But I think that such improvements probably reduce the security threat from those countries, rather than increasing it. The United States does not fret about increasing the technological capability of Italy or Australia. More to the point, consider the U.S. strategy for re-directing South Korea away from nuclear weapons and ballistic missile projects. In addition to their concerns about maintaining U.S. ground troops and nuclear weapons, the South Koreans placed a high value on continued technology transfer and close, cooperative trade relations with the United States, to the extent that they were unwilling to put those relations at risk by continuing their nuclear program in the 1970s.[32] Today, U.S. officials are probably more worried about South Korea dumping D-RAM chips than they are about Korean weapons programs. I suspect that outcome is replicable.

In sum, the finely-targeted strategies described above do fit into this overall strategy. But the broader and more important point is how missile proliferation policy needs to fit into the big picture of North-South technological relations.

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[31]A recent critique of U.S. policies regarding the Brazilian computer industry makes many of the same points. See Peter Evans, "Declining Hegemony and Assertive Industrialization: U.S.-Brazil Conflicts in the Computer Industry," *International Organization* 43, no. 2 (Spring 1989): 207-38. Evans recommends important strategies that range from seemingly trivial aspects (such as not announcing trade sanctions on Brazil's independence day) to serious trade issues.

[32]Mitchell Reiss, *Without the Bomb: The Politics of Nuclear Nonproliferation* (New York: Columbia University Press, 1988), 78-108.

Focusing on that global problem, I believe, has the potential to resolve or temper many cases of missile proliferation.[33]

Applications in Other Fields

Beyond the specific cases examined in this thesis, our analysis has policy implications for areas including arms trade, development, and of course proliferation. The arms trade literature, for example, recognizes autonomy as a primary goal for indigenous arms production programs, but often views autonomy as being a security concern, rather than an economic or technological goal. Similarly, the traditional arms trade literature looks to import substitution, economies of scale, and civilian spin-offs to account for third world export strategies. Yet export patterns vary widely among our three cases, and seem not to be correlated with these variables. A broader systems-style analysis that spanned the components of the international arms market might reveal the relevant patterns.

A military's desire for autarky is not new, and accompanies most empire-building ambitions. But what we see in all three of our cases is a military pursuing autonomy not as a radical solution to either a security or an economic dependency problem, but rather as part of a pragmatic, incremental modern-

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[33]In some ways, this position reflects a traditional liberal understanding of power, economics, and the international system. But it is also mediated by a detailed, politicized understanding of how technological development occurs. See, for example, Richard Rosecrance, *The Rise of the Trading State: Commerce and Conquest in the Modern World* (New York: Basic Books, 1986); and Paul Kennedy, *The Rise and Fall of the Great Powers* (New York: Random House, 1987). For the role of economically-oriented sub-state actors in determining the shape of a potential proliferant's weapons programs, see Etel Solingen, "Economic Liberalization, International Institutions, and the Fate of Regional Nuclear Regimes" [working title], *Security Studies* 3, no. 2 (Winter 1994), forthcoming.

ization effort, though admittedly of the trickle-down variety. In the Brazilian case, the advent of civilian regimes that were progressively less dependent on the military has reduced the emphasis on autonomy and the emphasis on military programs. This dynamic is worth further study. Nonetheless, even the Brazilian military government's program to develop military technology looks surprisingly similar to an ordinary civilian development program.[34]

If military programs are often pursued for development goals, then the development literature has a whole new set of questions that need to be addressed. How do civilian and military technology programs differ? How well does defense as a leading sector work, and what kind of a technological infrastructure results? Are military governments more likely to pursue military technology than civilian governments? Although some work has been done on these questions, this thesis demonstrates that they are deserving of more emphasis.

Despite some overall appearance as development programs, we should not lose sight of the impressive complexity that these cases have detailed. It is precisely that complexity that bears the most important lessons for understanding development. Modernization itself needs to be seen as an interplay of competing motivations, organizations, ideologies, and interests. The technology that is the explicit goal of many national development programs will be constructed when and if a particular technology has some role in that complex interplay. Even

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[34]For example, the emphasis on defense industries is similar to Rostow's venerable "leading sector" approach, where a given industrial sector is promoted in order to generate upstream and downstream benefits that enhance economic development throughout a society. W. W. Rostow, *The Stages of Economic Growth: A Non-Communist Manifesto* (London: Cambridge University Press, 1960), 52-57. For a more general discussion, see Albert O. Hirschman, "A Generalized Linkage Approach to Development, with Special Reference to Staples," *Essays in Trespassing: Economics to Politics and Beyond* (Cambridge: Cambridge University Press, 1981), 59-97.

when already in use in other parts of the world, technology is still not waiting off-stage, ready to be introduced unproblematically. It must grow out of the plot, with its own role in the drama, or it will never appear.

The undercurrent for all of these policy implications is quite basic. The case studies in this dissertation help us to understand the story of how societies go about developing missile technologies. The same methods can be used to develop a better understanding of how system-builders assemble other military technologies. Throughout, my hope has been that by reconstructing these rockets I will provide additional resources for ultimately disassembling them.

APPENDIX:

List of Acronyms

AEC	Atomic Energy Commission (India)
ASLV	Augmented Satellite Launch Vehicle (India)
BARC	Bhabha Atomic Research Centre
BDL	Bharat Dynamics Limited (India)
COBAE	Brazilian Comission of Space Activities (Comissao Brasileira de Atividades Espaciais)
CTA	Aerospace Technical Center (Centro Tecnico Aerospacial) (Brazil)
CTEX	Army Technological Center (Brazil)
DAE	Department of Atomic Energy (India)
DOS	Department of Space (India)
DRDL	Defense Research and Development Laboratory (India)
DRDO	Defense Research and Development Organization (India)
ERDL	Explosives Research and Development Laboratory (India)
FBIS	Foreign Broadcast Information Service (U.S.)
FINEP	Studies and projects Financing Agency (Brazil)
FOUO	For Official Use Only (U.S.)
GSLV	Geosynchronous Satellite Launch Vehicle (India)
H2N4	Hydrazine
HAL	Hindustan Aeronautics Limited (India)
HTPB	Hydroxy-terminated polybutadiene
IAE	Space Activities Institute (Instituto de Atividades Espaciais) (Brazil)
IAF	Israel Air Force
IAI	Israel Aircraft Industries (Ta'asiyah Avirit)
ICBM	Intercontinental-range ballistic missile
IDF	Israel Defense Forces (see Zahal)
IGMDP	Integrated Guided Missile Development Program (India)
IFI	Industrial Coordination and Promotion Institute
IMI	Israel Military Industries (Ta'asiyah Tzvi'it, or Ta'as)
INPE	National Institute of Space Research (Instituto Nacional de Pesquisas Espaciais) (Brazil)
IR	Infrared
IR	International relations
IRBM	Intermediate-range ballistic missile

ISA	Israel Space Agency
ISRO	Indian Space Research Organization
ITA	Institute of Aeronautics Technology (Brazil)
JPRS	Joint Publications Research Service (U.S.)
LPSC	Liquid Propulsion Systems Center (India)
LTS	Large technological system
MECB	Brazilian Complete Space Mission (Missao Espacial Completa Brasileira)
MIT	Massachusetts Institute of Technology
MIT	Military-industrial-technological complex
MLRS	Multiple launch rocket system (specific U.S. Army system, and a generic term)
MoD	Ministry of Defense (India, Israel)
NASA	National Aeronautics and Space Administration (U.S.)
N2	Nitrogen
PBAN	Polybutadiene acrylonitrile
psi	Pounds per square inch
PSLV	Polar satellite launch vehicle (India)
R&D	Research and development
RCI	Research Center at Immarat (India)
RCS	Reaction control system
RFNA	Red-fuming nitric acid
Rs.	Rupees
RV	Re-entry vehicle
SCOT	Social construction of technology
SLV-3	Satellite launch vehicle (India)
SBPC	Brazilian Society for the Advancement of Science
VLS	Satellite launch vehicle (Brazil)
VSSC	Vikram Sarabhai Space Centre
Zahal	Israel Defense Forces