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Evaluating The Military Potential Of A Developing Nation's Space Program: A Case Study Of Brazil

by

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Evaluating the Military Potential of a Developing Nation's Space Program: A Case Study of Brazil

by

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Submitted in partial fulfillment
of the requirements for the degree of

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ABSTRACT

This thesis examines how and why a developing nation may use its civilian space program to acquire ballistic missiles. Using a single case study of Brazil, this analysis looks for universal patterns in space program development and for how Third World nations use their civilian space programs for military purposes. This thesis analyzes the relationship between space and missile development, the Missile Technology Control Regime, reasons for building missiles (political, economic, national security, geopolitical, need for technology), Brazilian civil-military relations, and various technologies and space systems. It identifies the critical technologies required for a successful space program; identifies the critical industries that are missing in Brazil and the technologies that it must import; highlights indicators of military intentions of a civilian space program; and evaluates how the generalizations developed throughout the thesis may be applied to other nations.

EXECUTIVE SUMMARY

The issue of ballistic missile proliferation was given a new sense of urgency due to Desert Storm and Desert Shield. Of particular importance to the allies was the disposition of Iraq's Scud ballistic missiles and its weapons of mass destruction.

The purpose of this thesis is to examine the case of a developing nation (Brazil) that has active space and missile programs. The intent is to form generalizations based on this case study which can be applied to other developing nations in order to evaluate the progress and military potential of their space programs. This thesis addresses the following questions:

(1) What are the critical technologies, facilities, and processes required for a successful space program?

(2) What technologies must be imported and which can be indigenously produced? What critical industries are typically absent in Third World nations which inhibit progress in space?

(3) What indicators would be present to show military intentions and at what point would a military divergence take place?

(4) Based on this case study, can generalizations be formed that reliably predict the military potential of another developing nation's space program?

This thesis examines how and why a developing nation may use its civilian space program to acquire ballistic missiles. Using a single case study of Brazil, this analysis looks for universal patterns in space program development and for how Third World nations use their civilian space programs for military purposes. This thesis analyzes the relationship between space and missile development, the Missile Technology Control Regime, reasons for building missiles (political, economic, national security, geopolitical, need for technology), Brazilian civil-military relations, and various technologies and space systems. It identifies the critical technologies required for a successful space program; identifies the critical industries that are missing in Brazil and the technologies that it must import; highlights indicators of military intentions of a civilian space program; and evaluates how the generalizations developed throughout the thesis may be applied to other nations.

It concludes that:

(1) The critical technologies that Brazil needs include liquid fuel engine and TVC technologies. Solid fuel technology is applicable in some capacity for orbiting satellites, but liquid engines are needed to economically compete in the space launch market. Solid fuel missiles are easier to hide, transport, and fire than are liquid fuel systems like the Scud. These advantages make Brazil's solid fuel technology attractive to customers seeking ballistic missiles.

Additional technologies that are vital to both liquid and solid fuel systems include composite materials for heat shielding and reentry vehicles,

pyrotechnics for stage separation, heat treatment capability to strengthen motor casings, and computer technology to help design engineers and assist in on-board guidance.

(2) The lack of a sophisticated computer industry combined with restricted access to First World computer technology is one of the biggest inhibitors to progress in Brazil.

(3) Indicators of military intentions for a civilian space program include the strong presence of the military in both the space and missile programs, and its ongoing influence on the government.

(4) Brazil has determined to continue with its space and missile programs. A poor domestic economy combined with a resurgent demand for missiles may leave Brazil little choice but to build and sell missiles to keep its space program viable and to keep a positive trade balance. However, Brazil may conform to MTCR guidelines in order to modernize its VLS system and compete in the commercial launch market.

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But my deepest and most sincere thanks goes to my wife Bobbi for her love and support. Together with my son Patrick, they made even the toughest days a joy.

I. INTRODUCTION

A. BACKGROUND/PURPOSE OF THESIS

The issue of ballistic missile proliferation was given a new sense of urgency due to Desert Storm and Desert Shield. As the allied coalition assembled for battle against the forces of Saddam Hussein, they faced the stark reality that the weapons opposing them were their own. Of particular importance to the allies was the disposition of Iraq's Scud ballistic missiles and its weapons of mass destruction. Fortunately for the allied coalition, Iraq did not have, or did not use, atomic weapons, and did not use the chemical weapons it possessed. But as Scud missiles flew towards Riyadh, Dhahran, and Tel Aviv, one could not help but wonder if the ballistic missile genie was out of the bottle.

In the months before and after Desert Storm, the news media focussed on the debate surrounding the issue of ballistic missiles in the Third World. Part of the debate was centered on how a developing nation could have an active space program and how it could hide ballistic missile capability. This is an extremely important question which is at the very heart of the intelligence problem. It is important, therefore, to understand why developing nations want space and missile capabilities and how they are achieving their goals.

Ballistic missile proliferation commands the attention of the world's leaders. In 1982, then-president Ronald Reagan ordered the beginning of negotiations which brought about the 1987 signing of the Missile Technology Control Regime (MTCR). In 1991, president Bush put into effect the Enhanced Proliferation Control Initiative, which is designed to further reduce the flow of missile systems and technology to the Third World. In mid-1991, representatives of the United Nations Security Council were discussing measures to curb ballistic missile proliferation.

According to Dr. Janne Nolan of the Brookings Institute, there are three principal methods by which developing nations acquire ballistic missiles. They are:

(1) Modifying space-launch vehicles to create ballistic missiles.

(2) Producing missile prototypes in national defense industries.

(3) Acquiring foreign missile systems, components, and technical assistance.

(Nolan, 1991,p.39)

The first method is the most difficult to detect and analyze. Many of the technologies that go into space launch vehicles are identical to those involved in ballistic missiles. Legitimate national goals of exploiting space for peaceful purposes can cover covert missile production, whereas the second and third methods mentioned above are more traditional intelligence problems. It is relatively easy to observe defense industries and notice shifts in product lines or anomalies in supplies, facilities, operations, etc. Likewise, tracking known missile systems can be accomplished through traditional intelligence methods. The more difficult intelligence problem is trying to discern the intentions and capabilities of a nation that is pursuing ballistic missile production under the cover of a civilian space program.

The purpose of this thesis is to examine the case of a developing nation (Brazil) that has active space and missile programs. The intent is to form generalizations based on this case study which can be applied to other developing nations in order to evaluate the progress and military potential of their space programs. This thesis will attempt to answer the following questions:

(1) What are the critical technologies, facilities, and processes required for a successful space program?

(2) What technologies must be imported and which can be indigenously produced? What critical industries are typically absent in Third World nations which inhibit progress in space?

(3) What indicators would be present to show military intentions and at what point would a military divergence take place?

(4) Based on this case study, can generalizations be

formed that reliably predict the military potential of another developing nation's space program?

B. METHODOLOGY

This thesis uses a single case study method. The advantage of the single case study is greater depth and analysis of the thesis questions as they pertain to the subject. The main disadvantage is that the ability to make generalizations is limited, owing to the dearth of comparative examples. In this thesis, the choice of the single case study method is sound due to the nature of the subject. Brazil is suitable for this approach for the following reasons:

(1) Brazil has an open press, a market economy, and a fairly open society, all of which facilitate the flow of information. This includes information about space and missile projects. Many developing nations have authoritarian regimes that inhibit openness, thereby limiting the availability and reliability of data.

(2) Brazil is on the leading edge of the Third World, or the trailing edge of the First World. Brazil is sometimes seen as a bridge between the First and Third Worlds. The paths that Brazil chooses may influence other developing nations. Brazil's success in space-related ventures is closely watched by many nations, especially those interested in breaking down First World technological "cartels."

(3) Brazil has a growing industrial base. Its industrial policies and current economic condition is in many ways representative of other developing nations, and can therefore be the basis of generalizations.

This thesis will follow the pattern in Figure 1:

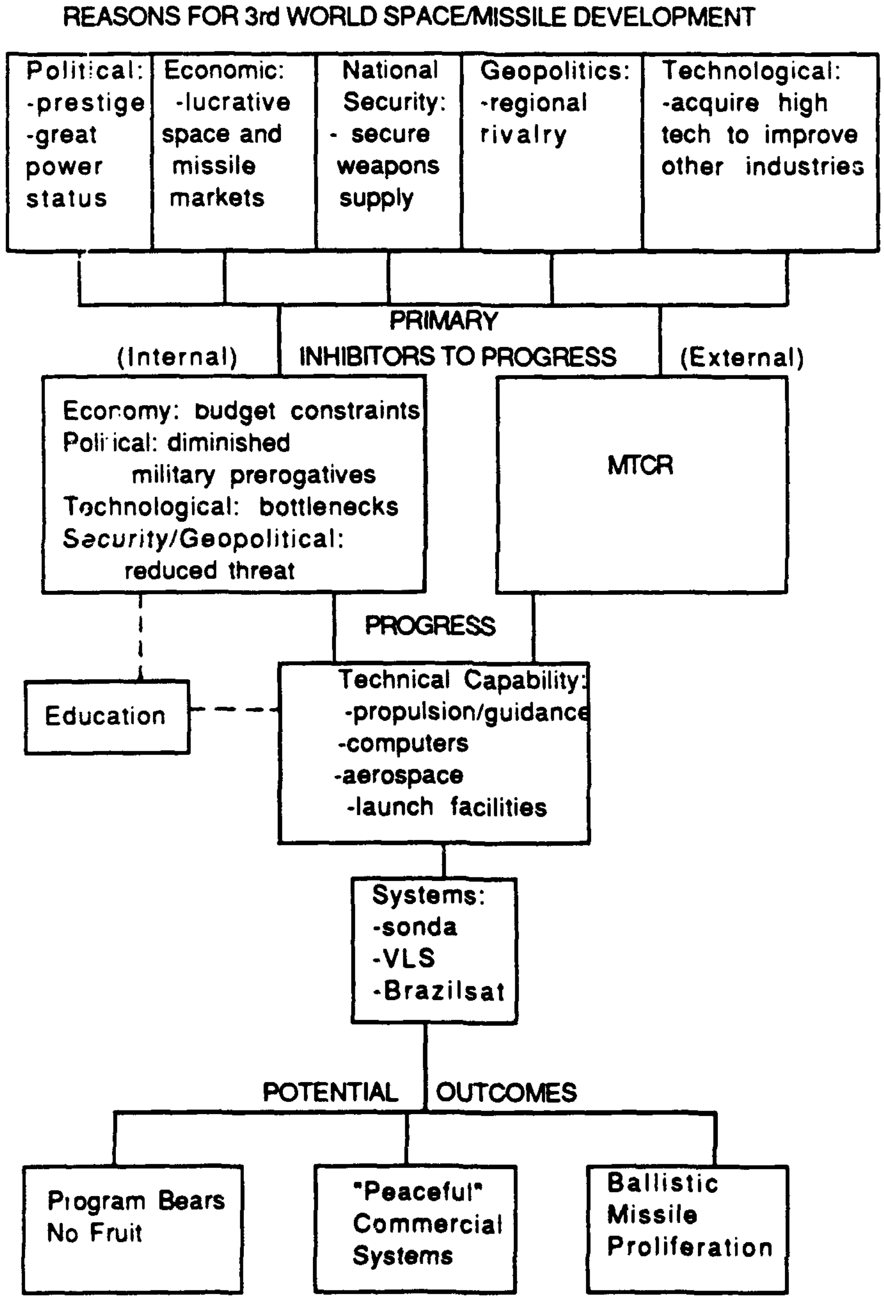

Figure 1: Thesis Design

This thesis is divided into two parts. Part one examines the process of space development and the issues of missiles in the Third World. It looks for macro patterns in space development and micro patterns in the reasoning behind Third World missile issues.

Part two examines space technologies, systems, fundamentals, and facilities involved in Brazil's space program. It searches for the level of development in Brazil's space program and identifies some of the inhibitors to Brazil's progress.

The patterns developed in part one and the level of progress derived from part two should create generalizations that may be applied to the original thesis questions.

PART I

Part one is comprised of chapters II and III. The intent of part one is to introduce the reader to non-technical issues surrounding Brazil's space and missile programs. Chapter II will show a reversal of space usage patterns between First World and Third World nations, specifically from military-civilian to civilian-military progress. Chapter III will examine some of the reasons for developing nations' desire for missiles, and U.S. reactions. Also, Brazilian civil-military relations will be studied and will show a pattern of military involvement in the space program from the genesis of the space program until today. The activities of General Hugo Olivera Piva are used as one example of this involvement.

II. PATTERNS OF SPACE DEVELOPMENT

A. INTRODUCTION

This chapter will introduce the reader to the process in which space and missile programs have traditionally begun and demonstrate a new pattern of development that emerging nations are exhibiting in their pursuit of space and missile technology. Brazil's space program typifies this new pattern and is paralleled by the Indian program. A brief discussion of how Germany, the United States, and the Soviet Union began their space programs will establish the First World baseline of military-to-civilian applications in space. The European/Japanese programs will show a shift to exclusively civilian applications in space, while an examination of India's program will show a shift towards civilian-to-military applications in space. The changing models in the use of space and Brazil's adherence to the last pattern will become evident throughout the chapter.

B. MILITARY-CIVILIAN MODEL

There is a near reversal in the pattern of space industry growth in the past 40 years. Whereas Germany, the United States, and the Soviet Union pursued space for military purposes and then branched into civilian applications, the European community, Japan, and various developing nations are pursuing civilian space programs before aspiring to achieve military capabilities.

The process in which nations have pursued space and missile programs has changed through the years and has done so relative to the nations' economic and technological infrastructure. Although space and rocket research had been going on since the 1920's with Dr. Robert Goddard's experiments, practical applications in rocketry were not realized until World War II with the advent of the German V-2. After World War II, both the United States and Soviet Union captured many German scientists and put them to work building weapons for their respective countries. The goal of both regimes was to build systems to deliver weapons, especially nuclear weapons, over long distances. The missile programs were kept in the realm of the military for the duration of the 1940's and most of the 1950's. In the United States the Scout rocket was transferred to NASA in May 1958. While the Soviet launch of Sputnik in 1957 alarmed the American public because it seemed to signal that the Soviets were ahead in space technology, the U.S. Air Force had already begun robust ICBM and satellite programs. The ballistic missile programs had begun in the late 1940's after the observation of German V-2 success. The satellite program was started in 1954 with a RAND report which urged that a satellite reconnaissance program be undertaken as soon as possible. The industry requirements took shape in 1955. (Burrows, 1986,pp.79-80)

The Thor program began in 1955 as an Intermediate Range Ballistic Missile (IRBM). It was later adopted as a booster for space exploration. (Hazard, 1977,p.5-49) Likewise, the Soviet Union began its space program with the intention of developing ballistic missiles and eventually satellite capability. It then turned towards "civilian" applications.

C. CIVILIAN-CIVILIAN MODEL

In more recent times, the European community and Japan have entered strictly commercial phases of space applications. Both are developing launchers and payloads that have commercial uses, such as communications satellites, imaging (eg: SPOT), and remote sensing satellites for scientific purposes. While there is potential for military uses for these technologies, there are public prohibitions to those uses. The Japanese constitution allows its armed forces to be used for defensive purposes only and renounces other than peaceful uses of nuclear power. In Europe, there is a strong Green movement that opposes nuclear weapons and missiles, and the many small countries that comprise the European Space Agency (ESA) are not inclined to expend resources for ballistic missile programs. As well, there may be a reluctance among

European nuclear powers (France and Britain) to share their nuclear and missile technologies with their neighbors.

D. CIVILIAN-MILITARY MODEL

There appears to be a slightly different pattern emerging in the Third World. Several developing nations are pursuing space programs under the pretext of exploiting the commercial uses of space and modernizing their industrial infrastructure to support contemporary applications. Brazil and India are two such cases and their programs are causing concern due to the close ties between their civilian and military space programs.

1. India

India established the National Committee for Space Research in 1962. It was a part of India's Department of Atomic Energy. In 1969 the Indian Space Research Organization was established to direct sounding-rocket experiments and in 1972, the cabinet-level Department of Space was created. The purpose of the Department of Space was "the transition of the space effort from a scientific undertaking of limited magnitude to a coordinated program with specific goals and time-bound projects in space applications and technology." (Nolan, 1991,p.41) In 1983, the 21-year-old Defense Research and Development Organization (whose mission is to oversee defense industrial investment) was explicitly linked to the space sector when missile production became a priority. (Nolan, 1991,p. 41)

India gained a great deal of its space-related knowledge through cooperative efforts with the Soviet Union. They began working on sounding rockets in the 1960's and satellite launch vehicles a few years later. The Soviets, typically conservative about controlling access to advanced military technology, offered an unusually high degree of assistance to India. In 1971 the Soviet Union and India agreed to jointly develop a satellite that was successfully launched in 1975. The Aryabhata (1975) and the Bhaskara (1979) were primarily made in India and launched from Soviet facilities. During the joint projects, the Soviets provided Indian scientist with ample expertise to build their own solid-fuel rocket by late 1979. (Nolan, 1991,p.42)

India had been working on an indigenously designed an advance space launch vehicle (ASLV), specifically the SLV-3, since 1968. It launched the Rhoni satellite into near-earth orbit in mid-1980. A follow-on to the SLV-3, the SLV-4 was tested in 1986 and in 1989. Indian officials announced that the first stage of the PSLV had been successfully tested. The PSLV (Polar Space Launch Vehicle) was scheduled for launch in 1991 and was designed to carry a 5000-lb payload into geostationary orbit. Even now, a follow-on to the PSLV, the GSLV is being built. The new system will use a cryogenic engine and liquid oxygen/hydrogen fuel. (Nolan, 1991,p.43)

The technology and expertise being displayed in India's space launch vehicle production is being carried over into its military space program. In May 1989, India successfully test fired the Agni (fire) missile. The Agni reportedly flew 625 miles. It is designed to carry a one-ton payload 1,500 miles, but could carry a half-ton payload about 2,200 miles. That would allow India to drop a nuclear warhead on Beijing if it was so inclined. (Milhollin, 1989,p.31)

Dr. Gary Milhollin, director of the Wisconsin Project on Nuclear Disarmament, suggests that India's successful development of its missile and space program was accomplished not only with Soviet aid, but with the aid of Western firms and governments. Specifically, he notes that Agni's chief designer, A.P.J. Abdul Kalam, spent four months in the United States training in 1963-64. Kalam did most of his training at NASA's Langley research center and the Wallop's island facility where the Scout was conceived and launched. The Scout designs were sent to the head of the Indian Atomic Energy Commission. Between the Scout designs that were sent to India and the knowledge and training that Kalam received, the United States in effect gave India the Scout. A comparison of the Scout and the ASLV shows distinct similarities between the two. The SLV's first stage was eventually became the first stage of the AGNI. (Milhollin, 1989,p.32)

Milhollin states that France gave liquid fuel technology to India and in the mid-1970's helped Indian engineers develop a version of the Viking engine. That engine was used in the Indian Prithvi (Earth) missile and was modified to become Agni's second stage. German assistance came in the form of guidance, composite materials, and testing technologies. The guidance and composite technologies delivered for the civilian space program also assist in the guidance and survivability of re-entry vehicles. (Milhollin, 1989,pp.33-34)

India has developed its missile program ostensibly under the cover of its civilian space program. Through cooperative efforts with the West and Soviet Union, Indian engineers have received valuable training and expertise. Through outright purchases, they have obtained advanced technologies and assistance in manufacturing, quality control, and other areas critical to producing high technology components for its space program. Once the ASLV program was well underway, the Agni and Prithvi programs used India's corporate knowledge of space to develop ballistic missiles.

2. Brazil

The path to modernization that Brazil's space and missile programs are following is similar to that which India has chosen. Both India and Brazil have pursued civilian space programs which have branched off into military missile programs.

Brazil has used its space program to gain technology and manufacturing modernization in a number of different ways. It has used joint/cooperative efforts, offset agreements, purchases of equipment, reverse engineering, and indigenous designs. Brazil's space program had the cooperation of the United States nearly from its beginning. In 1965, The Brazilian Air Force Ministry created the Space Activities Institute (IAE-Instituto de Atividades Espaciais). In 1966, the United States began supplying sounding rockets, financial, and technical support to the Brazilian space program. The governments of Brazil and the United States already had a military assistance agreement dating back to 1952, so this seemed another way to strengthen bilateral ties. (Tollefson, 1990,pp.28-30)

The Brazilian program continued with the development of the Sonda I, Sonda II, and Sonda III. Those projects are described more completely in chapter IV. The projects became more ambitious and cooperation between the governments of the United States and Brazilian remained close. That cooperation ended in 1977 when Brazil's

President Ernesto Geisel ended the 1952 military assistance agreement with the United States. The agreement was ended in protest of the Carter administration's pressure on Brazil's human rights record. In March of 1977, the Carter administration issued a report on Brazil's human rights record that was extremely critical. The Carter administration also tried to intervene in Brazil's nuclear power plant agreement with West Germany and introduced a more restrictive arms export policy towards Brazil. (Schmidt, 1988,p.5) Brazil did not end all relations with the United States. However, many cooperative efforts were canceled and Brazil sought to diversify its foreign contacts, especially among western European nations. (Wesson, 1986,p.89)

In 1978 the "All-Brazilian Space Program" the MECB, was approved. In 1983 the plan to design, build and launch 4 satellites of indigenous origin was unveiled. Two of the satellites, the 115 kilogram SCD (Satelites de Coleta de Dados) were designed to relay environmental data. They were to go into a 750-kilometer orbit. The 150-175 kilogram SSR (Satelites de Sensotiamento Remoto) was an Earth Resources Imaging satellite. It was designed to occupy a 650 kilometer orbit and have the capability of imaging objects on the Earth with a 40 meter resolution. (Interavia, 1991,p.3)

The initial plan was to cost $1 billion, which included $280 million for the satellites. The satellites were to be launched on the VLS. By mid-1989, Brazil had spent $100 million on the space segment and $700 million on the launcher, and they were not near completion. (Interavia, 1990,p.3)

The MECB has intermittently stalled due to lack of funding and restrictions placed on technology transfers by the Missile technology Control Regime (MTCR-see discussion below). The funding shortage is a result of changing government priorities, a difficult economic situation, and a shortage of orders for military hardware from Third World customers. The MTCR has blocked sales of supercomputers, liquid fuel engines, heat treatment capabilities, and other technologies that are critical to Brazil's space program.

E. MISSILE TECHNOLOGY CONTROL REGIME (MTCR)

The purpose of the MTCR is ideally to halt, but practically slow the proliferation of ballistic missiles by limiting sales or transfers of systems or technologies that might make possible the manufacture of missiles. This includes dual-use technologies, which are items that can be used in both military and civilian space programs

The MTCR was initiated in 1982 by President Ronald Reagan. He instructed executive agencies to implement U.S. export restrictions on ballistic missiles and their associated components. He also directed that multilateral talks on missile proliferation control be initiated. From 1983-87 representatives from the United States, Great Britain, Canada, France, Italy, Japan, and West Germany met in secret and worked out the MTCR. The MTCR was announced on April 16, 1987 as the first multilateral agreement to control the proliferation of delivery systems for weapons of mass destruction. (Schmidt, 1990,p.17) Since then, nine more countries have signed the MTCR, bringing the total to 16 countries that are signatories. Brazil and India are notably absent among signatories.

The MTCR applies to all unmanned delivery systems that can carry a warhead weighing more than 500 kilograms over distances greater than 300 kilometers. It applies to ballistic missiles, cruise missiles, drones, space launch vehicles, and any other unmanned delivery system regardless of its designation. (Schmidt, 1990,p.17)

The MTCR controls items that fall under two broad categories, complete missile systems and component parts. Category I items include whole systems, major subcomponents, and missile production facilities. Major subcomponents are items like reentry vehicles, solid or liquid fuel engines, warhead components, guidance sets with CEP's (circular error of probability) of 10 kilometers or less, etc. Category I items are normally not exported except if end-use/no retransfer agreements are signed by the purchaser. (Schmidt, 1990,p.18)

Category II items include smaller components and missile-related technclogies such as production technologies and equipment for propellants, composite materials, flight control systems, avionics, missile computers and software, etc. Category II items must be reviewed on a case-by-case basis and also must have signed end-use clauses if the item could contribute to nuclear capable missiles. (Schmidt,1990,p.18)

The MTCR is specifically credited with delaying component and technology transfers to Brazil and Argentina, among other nations, as Mr. Henry Sokolski, Deputy for Non-Proliferation Policy, testified before Congress. He specifically pointed to the "success" in stopping the Argentine "Condor II" program. According to Mr. Sokolski, the U.S. administration blocked exports relating to the Condor despite claims that it was a peaceful space launch vehicle designed for civilian, scientific, applications. Then, critical technologies such as guidance, propellant mixing equipment, etc. were blocked. Although Mr. Sokolski believes that not all technologies could be blocked, he felt that stopping key items would bring the entire project to a halt. (U.S., Congress, 1991,p.10-11)

In fact, the Condor II, which was being developed by Argentina, Egypt, and Iraq, was supposed to be in production prior to Desert Storm. The delays caused by the MTCR meant that U.S. troops were faced with the threat of modified (extended range) Scud-B's rather than Condor II's. Whereas the Scud has a CEP of 1 kilometer, the Condor would have had a CEP of a few hundred meters. The liquid-fueled Scud takes longer to prepare and fire, and is harder to find than the highly mobile, solid-fuel Condor. (U.S.,Congress, 1991,p.9) The potential threat faced by U.S. troops in Desert Storm due to more accurate and mobile Condor, and the added difficulty in prosecuting the mobile missile threat might have changed the complexion of the battlefield.

In Brazil's case, the MTCR has been used to block the transfer of the Viking liquid-fuel rocket motor, supercomputers, furnaces, and other materials critical to their space programs. In August 1990, Dr. Gary Milhollin Director of the Wisconsin Project on Nuclear Arms Control publicly exposed the proposed transfer to Brazil of the Viking engine along with extensive training packages in on-board computer, guidance systems, and launching techniques for multi-stage rockets. This deal was supposed to be concluded between the government of Brazil and a consortium of firms from at least four European nations. This transfer was primarily worked out in an offset agreement in which Brazil would hire Arianespace for some of Brazil's space needs if Arianespace would transfer technology in return for the contract. (Milhollin, 1990b, pp.10-11) But quiet government-to-government talks between the United States and France halted the transfer even before Dr. Milhollin's article. The United States felt, and the French reluctantly agreed, that the transfer would violate both the letter and spirit of the MTCR. (Anonymous, interview)

One week prior to his "Brazilian Bomb" article, Dr. Milhollin exposed the proposed sale of I.B.M. supercomputers to Brazil. He stated that the supercomputers can help missile designers simulate rocket engine thrust, calculate heat and pressure on reentry vehicles, and every other aspect of flight from launch to impact. Supercomputers can drastically cut development time and costs for flight tests. This proposed sale came at a time when Brazilian engineers were in Iraq working on various space projects including Iraq's December 1989 launch of a rocket large enough to orbit a satellite. Within the U.S. government, there was a debate about the sale. While the Commerce and State Departments wanted the sale approved, the Energy Department and the Arms Control and Disarmament Agency disapproved of the sale. (Milhollin, 1990a,p.19) The sale was eventually disapproved.

Another transfer battle with Brazil occurred over the heat treatment of rocket motor casings. Rocket motor casings are heat treated to improve their strength, but Brazil lacks the facilities to heat treat the casings for their space launch vehicle (VLS), and does not yet have the capability to build the necessary heat treatment facility. In October 1989, a State Department licensing officer granted a U.S. Munitions License that allowed the heat treatment of 18 motor casings. Seven motor casings had been shipped to the United States for heat treatment when the case came to the attention of the nonproliferation community. The license was reviewed and for various reasons, the seven previously treated motor casings were re-exported to Brazil, and the license was revoked for the remaining 11 motor casings. (State Department, 1990,p.1)

F. CONCLUSIONS

Reviewing chapter two, one can see how the pattern of space related projects has *changed over* the decades. The First World model showed a pattern of military space use branching off into civilian space use. The next generation of space technology powers, the European community, concentrated primarily on civilian uses of space. Now, some of the developing nations that are attempting to use space technology are beginning with civilian programs and are branching off into military projects.

The Missile Technology Control Regime is designed to prevent the proliferation of ballistic missile technology by restricting both overt missile system sales and transfers of "dual-use" technologies. The existence of the MTCR and its efforts to control dual-use technologies indicates that there is a threat of ballistic missile proliferation and that developing nations with a civilian space program may be diverting dual-use technologies into covert ballistic missile programs. Reasons for shifting civilian space resources to military projects will be discussed in the next chapter.

III. MISSILES AND THE MILITARY

A. INTRODUCTION

Recognizing that emerging nations are pursuing missile technology through their space programs leaves several questions to be answered: (1) Why do developing nations desire ballistic missiles? (2) Why is the United States concerned about developing nations' space programs? (3) How does the military affect "civilian" space programs?

The first two questions have universal qualities, that is, they may be applied to any developing nation. The third question may or may not apply to most nations and is more indicative of a particular nation's character. All three questions will be answered with respect to Brazil.

B. REASONS FOR BUILDING MISSILES

1. Political

There are several reasons why Brazil might want to indigenously build and launch satellites or even missiles. Those reasons could be political, economic, security, or technical in nature. Politically, missile and space technology represent the consummate symbols of national prestige in the same way that dreadnoughts were a mark of national power and prestige in the early 1900's. In the today's global arena, only great powers have missiles or space programs, so the ability to produce such items would put Brazil in a very exclusive club. As well, missile exports can be used to further foreign policy aims. They can be used to improve ties with Third World nations through co-production and licensing agreements, and they can be used to engender the perception of self-reliance, and independence from other First World powers. (Tollefson, 1991,p.425)

2. Economic

The economic argument contends that a new product line could be very profitable. Some estimates assert that a missile with a range of 300-1,000 km would cost between $2 million and $5 million while a satellite launching vehicle would cost $10 million on the international market. In 1988 the operations director at Orbita estimated there was sufficient global demand for missiles that Brazil could export over a half-billion dollars worth per year. (Tollefson, 1991,p.426)

There have been ups and downs in the arms and missile markets. At the end of the Iran-Iraq war in 1988, there was a marked decline in the demand for weapons, though Iraq continued to seek missile technology and hardware. In the aftermath of the Desert Storm and the demise of the Soviet bloc, both the supply and demand of weapons is in doubt.

3. National Security

National security is a third potential reason for Brazil's missile program. While Brazil faces no regional threats which would require ballistic missiles or nuclear weapons to deter it, a case can be made that it needs indigenous weapons production to hedge against a cutoff of critical technology from the First World. An example of this is the development of the Piranha missile. This was an air-to-air missile patterned on the US Sidewinder. It was to be put on Brazil's fighter jets. When the program was canceled, it called into question the integrity of Brazil's armaments pipeline. (Tollefson, 1991,p.426) But more importantly, a case can be made that the Malvinas War between Britain and Argentina profoundly affected Brazil. In that war, Brazil saw parallels between itself and Argentina. Both were better equipped to handle internal threats than external ones. Argentina was unable to sustain logistical support for the war near their shores while the British came from thousands of miles away. As well, Brazilian military leaders felt that Argentina's inability to conduct joint operations reflected some of Brazil's own military shortcomings. (Stepan,1988,p.87)

Brazil has worried about the need to defend against a in the South Atlantic. There have been discussions about forming the South Atlantic Treaty Organization (SATO), a Latin American version of NATO. Considering the lessons learned from the Malvinas war and the proposed formation of SATO, one might accept the plausibility of the need for an advanced defence industry, even regarding missile production, as the national security justification for Brazil's space and missile programs.

On the other hand, it is difficult to envision any conflict where Brazil would be isolated against a powerful regional enemy. These realities make the national security argument for Brazil's space and missile programs questionable.

4. Geopolitical

Interwoven with the political and national security arguments is the concept of geopolitics. Within the southern cone, Brazil and Argentina have a rivalry that goes back nearly 400 years to their colonial days of Spanish/Portuguese rivalry. Brazil and Argentina have vied for dominance in the southern hemisphere in all areas, and geopolitical theories account for many of their actions. To some extent, Brazil seems to be quietly pursuing a vision of manifest destiny. It is trying to develop its frontier lands and in some instances (Paraguay and Bolivia), a large number of Brazilians have settled across the border. Argentina on the other hand, has seen its position in the Southern Cone slip from first to second since World War II. Other tensions exist in their rivalry for dominance in the buffer states. One argument is that Argentina is pursuing nuclear and missile technology as an equalizer against Brazil while Brazil, confident in its dominance, is pursuing the same capabilities so as not to be taken by surprise by Argentina. (Child, 1985,p.102)

The arguments that Brazil was trying to maintain parity with Argentina's Condor and nuclear programs appear moot in light of the Condor's lack of success and the joint agreement between those two countries not to pursue a nuclear device. ("Collor, Argentina...", 1990, p.31) But given the nature of their longstanding rivalry, the contentions cannot be ruled out entirely.

The geopolitical argument carries weight in another aspect; specifically, north-south rivalry. The geopolitical competition between Argentina and Brazil centers as much around dependence on and independence from first world influences, particularly the United States, as it does on the Portuguese/Spanish rivalry. In the period of the 1940's through the 1960's, Brazilian geopolitical writers freely acknowledged that the path they followed towards their vision of manifest destiny was as a junior partner of the United States. There was a good faith agreement between the United States and Brazil (barganha leal) that the United States would help Brazil along its path to greatness. This was at a time when Brazil was the United States' principal ally in Latin America. The Argentines responded to this "deal" by accusing Brazil of being lackeys of the United

States and by asserting that Argentina would never subordinate itself to a foreign power in that way. By way of abrogating the Brazil-U.S. military assistance agreement in 1977, Brazil renounced its dependence on the United States. (Child, 1985,p.35) In this light, Brazil's space and missile programs make a case for the sovereignty and independence of Brazil.

5. Need for Technology

A final argument is that Brazil's desire for advanced technology is driving its space and missile program. The space program is a high priority project because it requires educated and well trained workers, high technology manufacturing, improved quality assurance techniques, improved computer industry, and much more. It is thought that the demands of the space program would spur the supply and proliferation of the supporting components that it needs. In this way, Brazil's space program, with income gained through missile sales, would partially finance and drive the modernization of the national industrial infrastructure.

C. REASONS FOR U.S. CAUTION

The second question asks why the United States is concerned about Brazil's space and missile programs. The reasons for concern include:

(1) The connection between ballistic missiles and

weapons of mass destruction.

(2) The destabilizing effect of ballistic missiles in regional situations.

(3) The ability of ballistic missiles to threaten U.S. allies and vital interests, and the United States itself.

(4) Economic competition in the commercial space industry.

1. Physical Threat

The first three reasons are obvious, especially in light of events related to Desert Storm. The presence of modified Scud-B missiles in the Iraqi arsenal during the Gulf War changed the character of that conflict. The potential that Iraq might mount chemical warheads on its Scuds made those missiles a higher priority target of allied forces. The ability for Iraq to threaten Israel, a non-belligerent, non-bordering nation, with a chemical attack, gave the world reason to examine the issue of missile proliferation more closely. An issue that has drawn a considerable amount of attention is the number of Western companies that assisted Iraq in building up its arsenal. Brazil's (and General Piva's) role in helping the Iraqi missile program will be examined more closely in the following section regarding the military effect on "civilian" space programs.

2. Commercial Competition

The effect of Brazil's space program on competition in the commercial space launch industry is a very real, yet not publicly discussed issue. In many non-attributable interviews with government officials in Washington, a recurring theme is that Brazil's success in space might threaten the U.S. market share in the commercial space launch industry. This point was not made directly, but rather, was implied discretely. When the question of the legitimacy of Brazil's space program was discussed, the surplus of world, and particularly U.S. launch vehicles and facilities was pointed to as a reason that Brazil does not need a space program. The follow-up conclusion is that since Brazil does not really need a space program, then the facilities can only be intended for one thing -- ballistic missile production and testing. And since Brazil has no credible regional enemies, their ballistic missiles can only be intended for the Third World arms market, thereby leading to increased missile proliferation.

When examining the advantages of a launch facility near the equator with range clearance to the north and east, one can see the commercial potential of the Brazilian Alcantara Launch Center. Only one other commercial launch facility in the world can boast the geographic advantages of Alcantara and that is Kourou. These launch facilities and their advantages will be studied later. Arianespace estimates sales of over 5 billion francs per year at Kourou and claims that they have secured half of the entire satellite launch market. (Arianespace, 1991,p.6) If these figures are accurate, there appears to be a great deal of hard currency profit to be gained through a successful space program. The potential savings in fuel per launch, labor, and production costs for space industries make Brazil a viable competitor in the commercial space industry. These competitive advantages can threaten U.S. commercial launch industries.

D. CIVIL-MILITARY RELATIONS

The third question of this chapter is how does the military affect "civilian" space programs. As stated earlier, this question is more dependent on the character of the country involved and is less prone to universality than the previous two questions. In order to best answer this question vis-a-vis Brazil, Brazil's civil-military relations will be examined and tied into her military-industrial complex. Specifically, the politicization of the Brazil's military, its constitutional "prerogatives", and its role in twentieth century society and politics must be understood in order to comprehend the level of military control and influence in the defense and space industries.

1. Political Moderator

Brazil's military has an explicit political role. In addition to its mission of defending the nation against external threats, the army has the constitutional responsibility of ensuring domestic tranquility, and an historical role of moderating the political system.

In 1889 Benjamin Constant, a proponent of "Republican Positivism" spoke at the Military College. In that speech he said "the undeniable right of the armed forces to depose the legitimate powers constituted by the nation when the military understands that its honor required this to be done, or judges it necessary and convenient for the good of the country." This was the beginning of the "moderating pattern" in Brazilian civil-military relations. (Wesson, 1986,pp.186-187)

The notion that the military must play a moderating role in the government was first formally established in the constituent assembly of 1891. It was reaffirmed in the constituent assemblies of 1934 and 1946. Those assemblies specifically wrote two critical clauses into the Brazilian constitution. One clause states that the military should obey the president "within the limits of the law." The other says that the military is a permanent national institution specifically charged with maintaining internal law and order in the country and guaranteeing the normal functioning of the three constitutional branches of government. (Stepan, 1988,p.112) These clauses were seen by some as giving the military discretionary power to obey presidential orders. More importantly, they were seen as justification for the military to topple the government when it felt that either the president was acting illegally or that governmental policies threatened the integrity of national law and order.

The need for order has been a recurring theme in Brazilian history as is the desire for economic development. Nineteenth century republican positivism ended the empire under the banner of "Order and Progress." These values were intensified during the 1930's and the "New State" (Estado Novo) and were codified in the 1950-60 military ideology of "Security and Development." (Wesson, 1986,p.142) This last slogan became the banner of the 1964 military government.

This moderating pattern was summarized by Alfred Stepan as follows:

"1. All major actors attempt to co-opt the military. A politicized military is the norm.
2. The military is politically heterogeneous but also seeks to maintain a degree of institutional unity.
3. The relevant political actors grant legitimacy to the military under certain circumstances to act as moderators of the political process to check or overthrow the executive, especially one involving massive mobilization of new groups previously excluded from political participation.
4. Approval given by civilian elites to the politically heterogenous military to overthrow the executive greatly facilitates the construction of a winning coup coalition. Denial by civilians that the overthrow of the executive

by the military is a legitimate act conversely hinders the formation of such a coalition.

5. While it is generally held legitimate for the military to exercise temporary political power, it is not considered legitimate for the military to assume direction of the government for long periods of time.
6. A rough value congruence is the result of civilian and military socialization via schools and literature. The military doctrine of development is also roughly congruent with that of paramilitary groups. The military officers' social and intellectual deference facilitates military co-optation and continued civilian leadership."

(Wesson, 1986,p. 187)

2. Economic Development

Economic development has been a common rationale for the military intrusion into government affairs. A faltering economy and the military's institutional belief in the need for economic and industrial modernization contributed to military involvement in the end of the Empire in 1889. This was in part due to belief among members of the military that the republican goals of economic modernization represented the correct path for Brazil to follow. This theme recurred in the 1930 insurrection. Although the violation of an electoral agreement (one that selected presidential candidates from Sao Paulo and Minais Gerais) was the primary cause of the insurrection, the inability of the government to effectively deal with the depression caused a major loss of confidence among major economic players in Brazil. As well, the military was disturbed by the government's failure to accelerate the economic modernization of the country. (Wynia, 1990,pp.218-220)

Preceding the 1964 coup, an impressive economic recovery (1955-60) faltered in 1961. The economy continued to deteriorate rapidly in 1962 and 1963. Although there were many factors which contributed to the coup, the one that seemed to have the greatest impact was the economy. Other factors such as land reform and redistribution of wealth, as well as the government siding with the enlisted in a protest over their treatment by commanding officers, etc. seemed to be reactions to a deteriorating economic situation. (Wynia, 1990,p.226)

3. 1964 Coup

In 1964 the military assumed direct control of government functions with no immediate intention of relinquishing power. The military felt that the nation's security had been seriously damaged by weakening political institutions and needed strong authority to regain its strength. The movement from the coup to dictatorship took place in two stages. The first stage came in 1965-1966. At that time, hard-liners feared that direct elections would simply return the same politicians to office that the military had removed. President Castelo Branco extended his own term and renewed his extraconstitutional powers. During this time, he lost control of his succession, and the Army chose General Artur Costa e Silva as Castelo Branco's replacement. The second stage gave the president dictatorial power and adjourned Congress through the Fifth Institutional Act (AI-5) in 1968. (Wesson, 1986,p.190)

The stated purpose of the military take-over in 1964 was economic rather than political. Politics was seen as the primary means of economic modernization. The approach that the new government took closely resembled conservative-modernization strategies except that there was extraordinary state intrusion into the national development plan. (Wynia, 1990,p.235) The typical conservative approach would have minimal government involvement, except to provide incentives to entrepreneurs. Economic growth and development would then be guided by market forces. (Wynia, 1990,p.121)

4. "Security and Development"

One of the important decisions of the new government was to establish a heavy arms industry. This was a derivative of the "Security and Development" doctrine. It was felt that self-sufficiency in weapons would insulate Brazil's military supplies from the changing priorities of international politics. The arms industry was dominated by the military. The military coordinated civilian-owned and operated armaments companies with state owned and military directed plants. The arms industry rapidly grew to not only supply Brazil's armaments needs, but it became a major exporting sector of the economy. This industry also furnished the armed forces with a new role in the national's political economy. (Wesson, 1986,p.193)

It was during this period that the aerospace industries and the space/missile programs began to flourish. As has been mentioned earlier, the Space Activities Institute (IAE) was created by the Air Force Ministry in 1965 and was subordinated to the Aerospace Technical Center (CTA). In 1971 the Brazilian Commission of Space Activities (COBAE) was established and subordinated to the National Security Council. COBAE is chaired by head of the General Staff of the Armed Forces (EMFA) and directs the MECB. (Tollefson, 1990,p.29)

a. Aerospace Industry

In the 1960's and 1970's, the Brazilian government invested heavily in the aerospace industry. In 1964, the government decided to create Empresa Brasileira de Aeronautica (EMBRAER). EMBRAER was a mixed public/private sector aircraft company. The government was given 51% of the voting shares. EMBRAER's market strategy was to produce aircraft for Brazil's Air Force and to create commercial aircraft that would replace the DC-3 in Third World areas for use in remote areas and unfinished airstrips. (Menezes, 1989,pp.101-104) Other defense industries that received impressive government support were Helicopteros do Brazil S.A. (HELIBRAS) for the production of helicopters and CELMA for the production of aircraft engines. (Menezes, 1989,pp.112-115)

b. Space Industry

In the realm of space systems, Avibras Aerospacial S.A. was created in 1964 by a group of former CTA engineers. It was given the initial Sonda I project and has been a major contributor to the Sonda II, III, and IV. (Tollefson, 1990,p.52) Although Avibras has primarily concentrated in short-range barrage rocket systems like the Astros II, it was also developing the SS-150, SS-300, and SS-1000, which are ballistic missiles with ranges of 150,300, and 1000 kilometers respectively. These missiles were based on the Sonda IV design. (Menezes, 1989,p.125) As of 1991, these systems were still in either the concept or research and development stages. (Nolan, 1991,p.38)

The Orbita Sistemas Aerospaciais S.A. (Orbita) company was created in 1987 to coordinate Brazil's missile program. It is owned by a consortium of ENGESA, EMBRAER, ESCA, IMBEL, and PARCON. It was initially intended to develop guided missiles, rockets, and satellite launchers. However, the military took control of some of those programs. (Menezes, 1989,p.126) Probably the two most well-known projects in Orbita's inventory were the Piranha air-to-air missile (canceled in 1988) and the MB/EE-150. The Piranha was essentially a clone of the U.S. Sidewinder missile while the MB/EE-150 is a ballistic missile capable of carrying a 500 kilogram warhead over 150 kilometers. Follow-on projects include the MB/EE-350,600, and 1000. (Menezes, 1989,p.127) These systems were also in either the concept or research and development phases as of early 1991. (Nolan, 1991,p.38)

c. General Piva

Hugo Olivera Piva, a retired Brazilian brigadier general, was the president of Orbita and has been an active player both in government and in private industry. While in uniform he headed the CTA and was in charge of both Brazil's missile and nuclear programs.

Brazil's nuclear weapons projects began in 1977 and were included in a larger program within the president's Military Household (cabinet) in 1979. The military expected to develop and initially test the technologies needed to build a bomb and then get the president's approval to actually build it. It has been alleged that the civilian satellite launching vehicle (VLS) was to be the basis for a missile capable of delivering a nuclear device over distances up to 3,000 kilometers. ("Development of Solimoes Nuclear Project Detailed", 1991,p.15) The Brazilian atomic bomb was designed at the CTA's Laboratory for Advanced Studies by a team coordinated by Piva. In addition to his work on Brazil's atomic bomb and ballistic missile projects, then-Colonel Piva cultivated international contacts associated with his projects. In 1981 he arranged for the shipment of eight tons of uranium oxide and enriched uranium to Iraq. In 1983 he tried to get the government's approval to build a nuclear device and later that year work began on the boreholes in Serra do Cachimbo. ("Development of Solimoes Nuclear Project Detailed", 1991,p.15)

When Piva left the military, he became the president of Orbita and his previous work continued. While he was at Orbita in 1988, word broke that the government of Libya offered to provide $400 million annually for at least five years to help finance the MB/EE series of missiles. ("Libya Offers...", 1988,p.201) But international attention to Avibras' potential sale of Astros 2 and SS-300 made Orbita's deal with Libya impossible.

Piva's stay at Orbita was short-lived in part due to the collapse of Brazil's Third World arms market. The crisis caused the Brazilian government to cancel production plans for the Piranha air-to-air missile. The arms market collapsed for three main reasons. First, many of the nations that ordered weapons in the late 1970's were taking delivery of them in the 1980's. The demand for weapons tapered off from fewer orders of new systems to more orders of spare parts. Secondly, the debt burden of many Third World nations rose even higher, making it harder for emerging nations to afford more weapons. Finally, and most importantly for Brazil, the Iran-Iraq war ended in 1988, drying up a constant stream of weapons orders that had flourished throughout the decade. In the 1980's, Iraq had been one of the world's leading arms importers and was Brazil's largest customer (Tollefson, 1990,p.82) By late 1989, Orbita had no manufacturing, products, or sales. It was essentially a skeletal organization whose main hope for salvation is a regeneration of Engesa. This leaves Avibras as the only company in Brazil capable of filling Brazil's missile and space launch vehicle needs. (Tollefson, 1990,p.49)

With the impending demise of Orbita, Piva started his own aerospace consulting firm, HOP (Hugo Olivera Piva). He retained many of the engineers that had worked for him at CTA and Orbita on both Brazil's missile and nuclear projects. He has recently drawn a great deal of attention to himself and his country by his work in Baghdad during the most recent Gulf crisis. Piva went to Baghdad ostensibly to build the Piranha missile for the Iraqis, which had been canceled by the Brazilian government at the end of 1988. But he took along the engineering team that worked on the Brazilian Air Force's "Big Piranha" project, which was supposed to be capable of delivering a nuclear warhead over 1,000 kilometers. ("Brazilian Engineers Aid in Manufacture of Missile", 1990,p.20) It was subsequently reported that the HOP engineering team may have helped modify Iraq's Scud-B missile to give them greater range and accuracy. This is a charge that Piva vehemently denies. ("Extending Missile Range", 1991,p.17)

In addition to his dealing with Iraq, Piva has sought consulting work with the government of Iran. It has been reported that Piva proposed assisting the Iranian Ministry of Military Industrialization with two of their missile projects: a 600 kilometer missile and a 1,000 kilometer missile. He offered the services of the same engineering team that was in Iraq. ("Retired Officer Proposes Missile Deal With Iran", 1991, p.17) This was the same team whose work in Iraq was supposedly on an air-to-air missile for fighter aircraft, not ballistic missiles.

In the non-proliferation world, General Piva's activities have caused a great deal of concern. The civilian government has said that they are unable to control Piva's extranational affairs because Brazil has no laws prohibiting them. At the same time, they claim that Piva is a loose cannon who is acting alone without the consent or knowledge of the government. But both statements are difficult to believe. In examining the role that the military traditionally has played in Brazilian society, one sees that the officer corps often forms its cliques at the age of 12, when the boys are in military school. General Piva rose through the ranks while the military was forming and implementing its "Security and Development" program and he gained stature during the 20 years that the military controlled the government. This was the time that the defense industry flourished and the nuclear and space programs gained prominence. So it is fairly clear that Piva's activities were beyond those of a strictly commercial firm. As has been shown in this thesis, the line between private and public is often blurred in Brazil. General Piva is reported as stating that his Piranha deals with Iraq were broached only after consulting with and getting "the green light" from then Brazilian Aeronautics Minister Octavio Moriera Lima. ("Brazilian Engineers Aid in Manufacture of Missile", 1990,20) It appears that Piva's activities are designed to keep alive the industries and projects that were of the highest priority to the military government when he was in uniform. He seems determined to get financial support for the projects that his government is no longer willing or able to fund. The motivation for his actions remains a mystery. Whether his motive is greed, ego, or patriotism, General Piva is determined to keep Brazil's missile programs alive.

E. CONCLUSION

In conclusion, the three questions that began this chapter should have been adequately answered. (1) Developing nations desire ballistic missiles for political, economic, security, technical, and geopolitical reasons. While this list may not be all-inclusive, these broad categories and their justifications can be considered universal reasons why developing nations might invest exorbitant amounts of their national treasure in a seemingly irrational pursuit of space technology. (2) For security reasons such as direct or indirect threats to U.S. territory, allies, and national interests, the United States is concerned about developing nations' space programs. For the reason of protection of domestic commercial space launch industries, the United States is concerned that developing nations like Brazil might become viable competitors. (3) In Brazil's case, the military still wields tremendous influence in government policymaking. The space and missile programs were major priorities of the military government from 1964 through 1985 and are still of vital importance to the military leadership. There is pressure in Brasilia to keep these programs alive and progressing in spite of a $120 billion external debt. This has led to some creative and controversial efforts to work around small budgets and MTCR restrictions. These efforts include greater reliance on offset agreements and attempts to garner more foreign funding for Brazilian missile projects. The latter method is the most controversial and illustrates the shift in space-use patterns mentioned previously.

To the extent that General Piva's role in Brazil's national space and missile program is concerned, some experts are convinced that he is a maverick, beyond the control of his government. Others think that General Piva is still connected with the government and that his international actions, while nationally embarrassing, fulfill the military's desire for continued funding of a vital segment of the arms industry. Still other think that he is little more than a mercenary, selling his services to the highest bidder.

Whatever General Piva's true nature may be is of little consequence to this thesis, and his personal circumstances should not be overstated. General Piva is an individual actor, albeit an important one, in Brazil's missile and nuclear industries. He is one example of the military's role in Brazil's space and missile industries. The fact that he maintains such a high profile makes him an easy example to cite, and in this study, he is very illustrative of the patterns of behavior in question.

The pattern that emerges from a brief study of Brazil's civil-military relations is military intervention into government affairs primarily for economic reasons, the use of "Security and Development" type theories to expand arms industries for economic and defense purposes, and a tendency to protect those industries as the military deems necessary. From this aspect one can generalize that a strong military presence in a developing nation will influence a civilian space program towards missile production.

PART II

Part two focuses on the technological issues involved in space launch vehicles. The primary focus of this section is to examine some of the technologies, systems, and facilities in Brazil's space program. Brazil's systems and facilities will be juxtaposed with U.S. systems and facilities and comparisons will be made where practicable. This section will attempt to answer the following questions:

(1) Why does Brazil want its own launch facility?

(2) What bottlenecks in technology are slowing Brazil's space program?

(3) What critical technologies are required for Brazil's space program to be successful?

(4) How is the MTCR affecting Brazil's space program?

IV. TECHNOLOGY OF SPACE LAUNCH VEHICLES

A. INTRODUCTION

This chapter will examine some technologies that are needed in a space launch vehicle. This is more of a macro rather than a micro view of technology designed to familiarize the reader with some of the terminology that is used when discussing rockets and missiles. It is important to understand the predominant technologies in order to understand the questions that surround Brazil's space program such as:

(1) Why does Brazil want liquid fuel technology?

(2) What are the advantages of liquid versus solid fuel?

There are many technologies that go into the production of a space vehicle. The major "macro" systems fall under the headings of (1) propulsion and (2) guidance and control.

The area of propulsion is one of the more complex and least understood concepts in the field of rocketry. There are three main types of rocket propulsion: solid fuel, liquid fuel, and cryogenic engines. There are advantages and disadvantages to each type of propulsion and each has its own complexities.

B. SOLID FUEL

Brazil currently has a considerable level of experience and expertise in solid fuel technology. Although solid fuel engines are the most basic of the major propulsion systems they are still complex systems that require a high degree of advanced engineering, manufacturing, and technology. Some of the technologies it involves are:

(1) Propellant grain design.
(2) Motor casing design.
(3) Loading the propellent into the casing.
(4) Nozzle design.

1. Propellant Design

Overall, propellent grain design is intended to match the propellent with the launch vehicle and its mission. The designer must analyze the thrust-time curve for the required mission and develop a propellent that will match the mission profile, while taking into account variables such as weight, envelope, etc.(Scippa, 1988,p.7-1)

Some of the characteristics that must be considered when selecting a propellent are burn rate, temperature sensitivity, specific impulse, and density. Other properties include storage stability, hazard properties,exhaust properties, and cost. (Scippa,1988,p.7-1)

There are two basic types of grain architecture: free standing grains and case-bonded grains. Free standing grains are cartridge-loaded into the rocket motor casing after manufacture. Case-bonded grains are bonded to the motor casing during casting and curing steps of the propellent. Case-bonded grains tend to deliver somewhat higher performance, but free standing grains are less expensive and easier to handle, so there is a trade-off in uses. Free standing grains are usually used for smaller rockets (propellent diameter less than 100 mm and weight below 10 kg) where case-bonded propellants are almost always used for larger rockets (propellent grain diameter greater than 500 mm or weigh above 300 kg). (Zeller, 1988,p.8-2)

2. Motor Casing Design

The solid motor case is a minimum-weight pressure vessel. It (a) protects and stores the propellent grain, (b) serves as the combustion chamber for high temperature/pressure burning of propellent grain, (c) mechanically/structurally interfaces with other rocket components like the nozzle, igniter, etc., (d) is a primary airframe during missile flight. (Evans, 1988,p.4A-1)

The goal of motor case design is to create a case that is as lightweight as possible within the bounds of cost and technology. The results of proper motor case design are greater missile performance through a higher motor mass fraction (propellent weight/total motor weight). (Evans, 1988,p.4A-1)

Solid Rocket motor cases must be able to accommodate considerable levels of thrust and bending and concentrated loads from the skirts and any attachments. The motors typically operate from 500-3000 psi and the exterior surface temperature in excess of 1200 degrees fahrenheit due to propellent combustion temperatures between 5000-6000 degrees fahrenheit. (Evans, 1988,p.4A-1)

Nozzle design is another major factor in rocket motor architecture. There are several kinds of nozzles used in solid rocket motors and their control mechanisms are of extreme importance. The purpose of the nozzle on a solid rocket motor is to channel and control the expansion of hot gasses coming from the combustion chamber. In this way, thrust is created and controlled. (Truchot, 1988,p.3-1)

3. Nozzle Design

Nozzle design differs in scale and complexity depending on the mission of the vehicle. For instance, in a tactical missile with a short duration burn time, the nozzle may be a simple metal or reinforced plastic design whereas for ballistic or space applications, higher-level materials and control devices are required. (Truchot, 1988,p.3-1)

General parameters that must be considered in designing rocket motor nozzles are the propellent burn time, propellent type, operating pressures within the chamber and in the atmosphere, the exit cone expansion ratio, thrust vector controls, nozzle submergence, cost, shelf-life, etc. Propellent type, burn time, and internal operating temperatures dictate the materials and structural strength of the nozzles. (Truchot, 1988,p.3-2) The performance of the rocket seems more influenced by the external operating pressure (determined by the rocket stage), the exit cone expansion ratio, thrust vector control, and nozzle submergence.

The exit cone expansion ratio is the ratio of the width of the nozzle throat to the with of the exit cone. Generally, the higher the ratio the higher the thrust. The engine operates most efficiently when the static pressure of the exit plane is equal to the surrounding atmospheric pressure. Thus, expansion ratios of 7-15 are best suited for lower stages while ratios of 15-80 are typical of upper stages. (Truchot, 1988,p.3-2)

Nozzle submergence describes the position of the nozzle relative to the combustion chamber. A submerged nozzle is recessed into the combustion chamber whereas an external nozzle is outside of the combustion chamber. The two configurations give different flow patterns for escaping gasses. An external nozzle is typically a fixed nozzle with a simpler design. Given that it is farther from the propellent grain it suffers lower throat erosion. The submerged nozzle leads to more complex designs and higher cost, but it allows increased performance and can be configured with movable nozzles or flex bearings. (Truchot, 1988,p.3-3)

4. Thrust Vector Controls

Movable nozzles and flexible bearings are examples of thrust vector controls (TVC). TVC's are required on many solid rocket motors and can have relatively simple or complex designs. Movable nozzles are the most complex types. The nozzle is usually hinged by a flexible bearing, a ball and socket, or a hydraulic bearing joint. (Truchot, 1988,p.3-11) In essence, these systems control the direction in which the nozzle is pointing, and thus the direction of the thrust. Brazilian engineers are trying to perfect this technology for their satellite launch vehicle (VLS).

Some of the simpler TVC designs are the fluid injection system and introduction of a solid device into the nozzle supersonic stream. Brazil uses the fluid injection system in the Sonda IV. In the fluid injection system, an inert liquid is injected into the supersonic stream of gasses escaping through the nozzle. The liquid disrupts the gas flow and causes a shock wave and thus a side force which controls the thrust direction. In the solid device method, a solid, or mechanical device is introduced into the supersonic stream. The gas flow disruption has the same effect as the injected liquid in controlling thrust direction. (Truchot, 1988,p.3-15)

C. LIQUID FUEL

Liquid fuel systems are the premier technologies that the Brazilian government would like to import or perfect. The term liquid propellent describes both oxidizers (liquid oxygen, liquid fluorine, etc.) and fuels (kerosene, alcohol, liquid hydrogen, etc.). Propellants furnish the energy and working substance for the engine and are one of the most important considerations in rocket engine design. Propellant selection is sharply influenced by price, supply, handling, and storage concerns. (Huzel, 1971,p.18)

Liquid propellants typically come in two forms, either monopropellants or bipropellants. Liquid monopropellants are either a mixture of oxidizer and fuel or are a single compound that can be decomposed, giving off the necessary heat and gas. Monopropellants must be stable in natural or controlled environments, but should give off hot gasses when pressurized, heated, or fed through a catalyst. Liquid monopropellant engines have the advantage of simplicity in tankage, plumbing, flow control and injection. Their major drawback is a lack of performance. They have a lower density impulse (to be addressed later). However, their use is appropriate as a secondary power source in rocket engines in driving turbopump gas generators and auxiliary power drives that govern attitude and roll control jets. Some monopropellants do offer high performance, but they are somewhat unstable and are deemed unsafe for rocket use. (Huzel, 1971,pp.18-19)

Bipropellants offer the performance that monopropellants do not. The trade-off comes in the form of a more complicated system design. Bipropellant systems have the oxidizer and the fuel in separate tanks. The two remain separated until they reach the combustion chamber. This system offers high performance with greater operational safety. (Huzel, 1971,p.19)

When bipropellants are mixed in the combustion chamber, they are ignited through one of a number of devices: (a) chemical pyrotechnics, (b) spark plugs, (c) injection of a spontaneously combustible material before the propellant, or (d) a small combustor which utilizes either (a) or (b) for initial ignition. (Huzel, 1971,p.18)

Some bipropellants, known as hypergolics, ignite spontaneously upon mixing. Hypergolics permit greatly simplified ignition, but pose the risk of violent explosions in the case of accidental mixing or other hardware failures. (Huzel, 1971,p.18)

Cryogenic propellants are liquified gasses with a boiling point between -230 and -430 degrees fahrenheit and a critical temperature between 10 and -400 degrees fahrenheit. The most common cryogenic propellants are liquid oxygen, liquid hydrogen, liquid fluorine, and oxygen diflourine. Combinations of the above liquids are also common. Cryogenic propellants offer even greater density impulse but the tradeoffs again come in the form of more complex systems. One of the drawbacks of cryogenic systems comes in the storage ard handling of the propellants. Complex insulation systems must be used to keep the propellant from evaporating. The complexity of the system often depends on the length of time for which the material is being stored. Adequate ventilation is a must in preventing dangerous buildups of escaping gas. Also, because cryogenic systems are of such demanding specifications and tolerances, handling equipment must be very sensitive to atmospheric moisture, given that any impurities may cause jamming of subsystems like valves and flow mechanisms. (Huzel, 1971,p.19)

The term dynamic impulse has been used several times thus far. Simply stated, dynamic impulse is the total impulse delivered per unit volume of propellant. It is the specific impulse of a fuel multiplied by its density (Huzel, 1971,p.20). A graphic illustration of the differences between propulsion methods can be seen in **Figure 2**, which

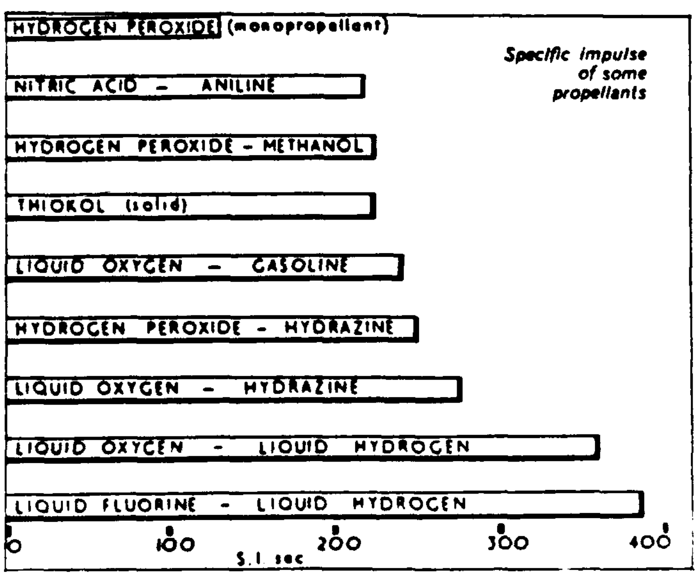

Figure 2: Specific Impulse Of Various Propellants

(Briscoe, 1963,p.20)

compares the specific impulses of various types of fuel. One can clearly see the advantages of bipropellant and cryogenic systems over solids and monopropellants in terms of impulse and potential lift capability.

D. CONCLUSIONS

High technology improves the performance of space flight in two critical areas. Liquid and cryogenic engines produce more thrust than solid fuel. Their efficiency represents "more bang for the buck." In addition to improved efficiency, high technology tends to improve system reliability. Of course, well trained maintenance personnel are vital in order to maximize efficiency and reliability. As in any business the goal of the space launch industry is to produce the highest quality goods and services at the lowest possible price. And when the payloads being lifted are billion dollar satellites, there is no room for error. If Brazil wants to compete in the arena of space flight, it needs high technology systems to be efficient and reliable.

The high cost of technology that allows a developing nation's space program to take advantage of more advanced propulsion systems is a serious question. The technological, educational, and manufacturing hurdles that must be overcome in developing a modern space program can drain the private sector of the manpower and brainpower that would otherwise be put into other sectors of the economy.

The potential payoff from the space program must justify the overall costs it imposes.

Therein lies the dilemma facing Brazil. Although in the short term it would be more economical for Brazil to buy, rent or lease its space needs (satellites, lift vehicle, launch facilities, etc.) from an already developed nation, Brazil has decided to invest in space with no guarantees of a positive payoff. The vision of Security and Development that was started in 1964 is still being pursued today. The space industries that Brazil created have labored to produce modern systems and engineer advanced technologies. Brazil has invested heavily in its space program and still has not developed liquid fuel engines or movable nozzle systems. In order for Brazil to succeed as a contender in the commercial space launch market, it must have the technology with which to compete on a First World footing. This will require (1) perfection of existing solid fuel systems to compete in commercial satellite launches, (2) an even larger investment in space research and development, or (3) importing technology from developed nations.

V. SPACE SYSTEMS

A. INTRODUCTION

This chapter will familiarize the reader with some of the rocket systems that are relevant to Brazil. In particular, the U.S. Scout system and the Brazilian Sonda and VLS programs are described. The Scout is very important as a comparison because it is similar to systems like Brazil's Sonda and India's Agni in technical characteristics. But more importantly, the Scout was a building block for future US space projects and it was used for peaceful purposes. The success of the Scout program is a model for aspiring space nations to follow, but it makes U.S. criticism of similar systems look very cartelist and hypocritical.

The systems that Brazil has developed are very similar to early U.S. space systems due largely to U.S. influence in early stages of Brazil's space program. The United States supplied Brazil with its first sounding rockets and helped develop its launch facilities. The Sonda (sounding rocket) series is based on the Scout design and one can readily draw a parallel between the Scout's mission and the stated peaceful intentions of the Brazilian government's Sonda project. But when examining the capabilities of both systems, one must also keep in mind their potential military applications. The follow-on to the Sonda series is the Satellite Launch Vehicle (SLV) which is a multi-stage Sonda IV with strap on boosters. It is designed to lift future Brazilian satellites into orbit and, if practicable, compete on the world market lifting foreign commercial payloads into space. One such satellite, the Brazilsat, will also be addressed in this chapter.

B. SCOUT

The Scout series was initiated by the U.S. Air Force but was transferred to NASA in 1958. The NASA Scout, a four-stage lift vehicle using a solid rocket motor, became operational in 1960 and was designed to lift a 190 pound payload into a 100 nautical mile circular orbit. Various modifications to the diameter, heat shielding, and propellant improved the performance of the solid rocket motors, as the Scout grew from four to five stages by 1968. (Hazard, 1977, pp. 5-15, 5-16)

By 1971 the improved Scout had the capability to place a 570 pound payload into a 100 nautical mile orbit or a 50 pound payload into a sunsynchronous orbit. (Hazard, 1977,p. 5-17) The Scout was still in service in 1977 and was, at that time, planned for continued use and production as an expendable launch vehicle even after the arrival of the space shuttle. (Hazard, 1977,p.5-15)

The four-stage Scout is approximately 72 feet long, with a 45-inch diameter and a launch weight of 40,000 pounds. It develops 100,000 pounds of lift off thrust and can lift a payload for orbital, re-entry, or probe missions. An optional fifth stage is used for placing an object in a highly elliptical orbit using an apogee kick motor (AKM). (Hazard, 1977,p.5-18)

Scout uses an inertial guidance system for its first three stages. The inertial guidance is used with a proportional control system to govern the vehicle through its first stage burn. The second and third stages are controlled by hydrogen peroxide reaction jet motors operated by on-off switches. The inertial reference unit is then used to aim the spin axis for the payloads proper spacial orientation. (Hazard, 1977,p.5-18)

C. SONDA

The Brazilian Sonda or sounding rocket program began in 1965 with the Sonda I. This was a small meteorological rocket designed by the private firm Avibras. The Sonda I was a two-stage vehicle propelled by solid rocket motors. It was designed to conduct atmospheric studies at an altitude of 60-75 kilometer. The Sonda I gave Avibras experience in the field of solid propellants and short-range tactical missiles. (Boscov, 1982,p.201)

The Sonda II program began in 1966 and soon overtook the Sonda I program. The Sonda II was a one-stage rocket designed to carry a 20 kilogram payload to an altitude of 100 kilometers. The Sonda II was to become the basis for Brazilian rocket technology. It was produced regularly in three different versions and became the test platform for new propellants, electronics, aerodynamics, and thermal protection. (Boscov, 1982,pp.201-202)

The Sonda III program commenced in 1969 with the beginning of the design and development of a two-stage rocket that would carry a 50 kilogram payload to an altitude of 500 kilometers. The Sonda III was the first Brazilian rocket to carry a complete instrumentation system which consisted of the following: separation system, second stage ignition, data acquisition during all phases of flight, teledestruct, three axes attitude control of payload, a sea recovery system, and an enhanced electronics package. The Sonda III prototype was launched in February 1976. (Boscov, 1982,p.202)

Two versions of the Sonda III were developed. The basic configuration was for payloads of 50-80 kilograms and higher altitudes. A second version was used for heavier payloads 130-160 kilograms, and lower altitudes. In the first version the propellent block in the second stage was twice as long as in the second variant. (Boscov, 1982,p.202)

The Sonda IV program was designed to develop technologies that will later be used in the Satellite Launch Vehicle (VLS). As part of the growing technological base the Sonda IV incorporated many new advances, although new technologies must still be developed or acquired for the VLS.

One of the technological advances from the Sonda III to Sonda IV was the use of a secondary injection system (SIS) for control of the upper stage. (Boscov, 1982,p.208) The SIS uses the injection of an inert gas, nitrogen in this case, into one side of the nozzle. The impact on the gas expansion causes a side force which changes the direction of the rocket. (Truchot, 1988,p.3-15)

D. SATELLITE LAUNCH VEHICLE (VLS)

The Brazilian Satellite Launch Vehicle (VLS) is planned to be a four-stage rocket using conventional solid rocket propellant. The VLS main booster will strongly resemble both the Scout and Sonda rockets but will have four strap on boosters. The VLS is designed to carry a 175 kilogram payload into a 750 kilometer circular equatorial orbit. Brazil's Alcantara facility will be the primary VLS launch site. ("Description Of VLS System", 1988,p.1-18)

The following subsystems comprise the main elements of the VLS:

(1) First Propulsive Stage

(2) Second Propulsive Stage

(3) Third Propulsive Stage and Guidance Control Module

(4) Fourth Propulsive Stage and Satellite Adapter

(5) Shroud (Heat Shield)

The first stage is composed of four S-43 solid rocket motors strapped onto the second stage. Each motor has an 11 degree fixed inclined nozzle. The thrust vector control (TVC) is the secondary injection system (SIS) used in the Sonda IV. Separation between the first and second stages occurs at an altitude of approximately 25 kilometers. ("Description Of VLS System", 1988,p.6-18)

The second stage also used the S-43 motor with a nozzle exit to throat ratio of 36:1 as opposed to 12:1 on the first stage. This larger expansion ratio is available due to the lower atmospheric pressure at 25 kilometers. The larger expansion ratio generates higher vehicle velocity. ("Description Of VLS System", 1988,p.8-18)

The third stage has a S-40 solid rocket motor. The S-40 uses a flex joint movable nozzle TVC for control. The guidance and control modules are located in the third stage and contain the inertial platform and the electronics that ensure the proper flight sequencing and trajectory during the first three stages. This section also contains the telemetry equipment and attitude control systems. The attitude control system permits control in the roll axis during 2nd and 3rd stages, maneuvering and orienting the vehicle for spin-up, to spin 2-3 revolutions per second (rps) and to remove coning motions before the separation and ignition of the fourth stage. ("Description Of VLS System", 1988,p.10-18)

The fourth stage is a S-44 motor, satellite adapter structure and electronics. The S-44 is made of a composite material of Kevlar/epoxy resin and has a fixed nozzle. The satellite adapter is a conical structure that contains the separation system and supports the electronic equipment which transmits functional parameters to the ground station. ("Description Of VLS System", 1988,p.12-18)

A heat shield protects the satellite during ascent through the low atmosphere. The heat shield is a cone-cylinder-cone shape made in two halves of a composite fiberglass material. ("Description Of VLS System", 1988, p.13-18)

E. BRAZILSAT

The Brazilian complete space mission (MECB) is a project designed to place Brazilian-made satellites into space using indigenously produced launch vehicles and facilities. ("Brazil's Space Program...", 1987,p.75) The VLS is an integral part of the MECB while the project's goals are to launch at least four satellites and exploit the data received from them. ("Brazil's Space Program...", 1987,p.75)

Brazil already has two communications satellites known as Brazilsats in geosynchronous orbit. Brazilsat 2 was launched in 1986 aboard an Ariane 3 launched from Kourou, French Guiana. Brazilsat 2 is capable of relaying 12,000 phonecalls or 24 television channels simultaneously. ("Brazil's Space Program...", 1987,p.75) Arianespace also lifted two remote Earth sensing satellites for Brazil. Those satellites are ostensibly designed to help Brazil in agricultural planning and resource protection planning. In addition to communications satellites, Brazil hopes to orbit two environmental data collection satellites and two remote sensing satellites in the early 1990's. (Brazil's..., 1987,p.75)

The satellite programs, and especially the Sonda IV and VLS programs are currently stalled for two reasons: (1) a shortage of funds caused by economic problems and (2) limited cooperation and technology transfers from first world nations, fearing Brazilian projects will increase world wide missile proliferation.

F. BOTTLENECKS

Economically, Brazil is in precarious shape. With a $120 billion debt, it is barely able to service the interest on the debt. It was bad enough that in 1987, then-president Sarney declared a moratorium on payments on a portion of the nation's debt. This has led to some imaginative arrangements in order to keep funding for the space program, including allegations of both official and unofficial ballistic missile cooperation with Libya and Iraq.

Technologically, Brazil is fairly primitive in comparison to the United States as evidenced by the aforementioned systems. The latest Brazilian lift vehicle, the Sonda IV, is based on the 40-year Scout system. Brazil's ability to close this technological gap is being hindered by the United States and other signatories to the Missile Technology Control Regime (MTCR).

There are many bottlenecks in Brazil's missile and space launch vehicle production capabilities. These are caused as much by economic difficulty as they are by MTCR restrictions. As demonstrated in the previous examples, liquid fuel, supercomputer, and heat treatment technologies are among the most obvious inhibitors to Brazil's progress. But other technological deficiencies exist in pyrotechnics for rocket stage separation, inertial guidance and accelerometers, composite materials production, computer hardware and software, and other high technology capabilities. The inability to domestically produce these critical items is widely held to be a consequence of a poorly educated work force, and the lack of a broad industrial base with advanced manufacturing and quality control capabilities. For Brazil to successfully compete in space, it must (1) renovate its entire national industrial base and educational system, or (2) procure what it needs from outside sources.

The question of how quickly Brazil can make up the gap in technology is a function of its economy, the effectiveness of the MTCR, and the Brazilian government's policy towards MTCR compliance. Brazil is trying to expand its industrial base. Economic pressures are making such an expansion increasingly difficult, but Brazil is trying to make the structural changes it needs to invigorate its economy. During President Fernando Collor de Mello's visit to Washington, D.C. in early July of 1991, he said that Brazil was undergoing structural reforms. Those reforms include selling government-owned enterprises, offering investment incentives, deregulating some industries, reforming its tax system, and reducing trade barriers. As well, Brazil plans to insert its economy into the international economy. (Michaels, 1991,p.3)

While in Washington, President Collor had high visibility meetings with President Bush. He also met with Treasury Secretary Nicholas Brady, Federal reserve Chairman Alan Greenspan, and Treasury Undersecretary David Mulford to assure them of Brazil's intention to repay interest in debt arrears in the sum of $8 billion. This strategy is designed to put lenders at ease about renegotiating Brazil's debt. (Michaels, 1991,p.3) These structural changes in Brazil's economic policies are vital to the restructuring of Brazil's industrial base. A timetable for these changes is impossible to predict, as much of it depends on future negotiations on debt restructuring.

Meanwhile, the MTCR continues to restrict the flow of technology to various space and missile-related projects. But there are ways around some of the restrictions in the MTCR. One loophole is the range and payload limits. Both the Orbita MB/EE-150 (range 150 kilometers) and the unmodified Scud-B (range 280 kilometers) do not fall within the MTCR limits. (Schmidt, 1990,p.17) Although this might not help in the construction of larger projects directly, technologies received for these smaller projects could conceivably be modified or re-engineered for other projects.

Brazil is still seeking technology in the form of offset agreements and bartering. In addition to pursuing liquid-fuel technology from the French, Brazil has approached the Chinese in 1985 and offered to trade its solid fuel technology to China in return for help in liquid fuel and guidance system technology. (Milhollin, 1991b,p.7) Although there was an agreement in principle to launch the Chinese Long March rocket out of Alcantara, that event has yet to materialize.

To further complicate Brazil's quest for missile technology, in December 1990, President Bush announced the Enhanced Proliferation Control Initiative, which was took effect in the summer of 1991. Among other things, this new initiative added trade in missile technology as an activity that triggers automatic sanctions. (Milhollin, 1991a, p.8) It will take time to determine what effect the new initiative will have on Brazil's missile industry.

G. CONCLUSIONS

Brazil has continued with its ambitious space program, the MECB, with mixed results. Its domestically-produced satellites are still awaiting a Brazilian-manufactured space launch vehicle. Brazil's funding shortage and the restrictions on technology transfers imposed by the MTCR make it difficult to know when Brazil will have a commercially competitive space launch capability.

Further complicating the issue are events in the Soviet Union, Middle East, and Eastern Europe which make it even more difficult to predict the future of the "New World Order." Brazil's missile and space industries depend heavily on other nations for the capital necessary for industrial modern_zation, and research and development. Likewise, Brazil needs to find partners that are willing to trade technology, and enter co-production and licensing agreements. Whether the collapse of the bi-polar world and the surfacing of old ethnic tensions, accompanied by the emergence of new Third World nations, will spur a resurgence in the arms market remains to be seen. Although the Middle Eastern arms market appears to have collapsed in the wake of the recent Gulf War, the modified Scud-B proved itself to be a useful weapon in terrorizing Israeli and Saudi cities, diverting U.S. military assets, and capturing the attention of the news media. A resurgence in new regional tensions could revitalize and recapitalize Brazil's missile industry.

In the meantime, Brazil will continue to sluggishly pursue its VLS program, whose first launch has been pushed back from 1991 to 1993, owing to domestic fiscal realities. Unless Brazil can get massive amounts of foreign currency and foreign technology, it is unlikely that the VLS will be launched before 1995.

VI. SPACE FUNDAMENTALS

A. INTRODUCTION

This chapter is designed to introduce the reader to rudimentary orbital mechanics and demonstrate why the geographic location of a launch facility is of such importance to a space program. Some of the questions that this chapter will answer are:

(1) Why does Brazil want its own launch facility?

(2) Why does Brazil not just rent or lease what it needs from the US?

(3) What advantages would a Brazilian launch facility provide?

Answers to these questions will show that, due to latitude and range safety, satellites can be placed into commercially desirable orbits much less expensively from Brazil than from the United States. This will show the commercial potential of Brazil's space program and offer some rational justification for it.

B. LAUNCH VEHICLE CONSIDERATIONS

There are many factors that must be considered when launching a space vehicle. Those factors include:

(1) Payload mission and Altitude.

(2) Orbital Inclination and Range Safety.

1. Payload Mission and Altitude

Payload mission determines most of the latter requirements. Different missions require different altitudes and inclination and thus drive the launch location decision. **TABLE 1** shows the best altitudes for various missions.

TABLE 1

ALTITUDE	SATELLITE MISSION
90-300 miles	Imaging, Reconnaissance, Manned Space Station, Scientific
300-630 miles	Earth Observation, Roving Weather Satellite, Navigation, Surveillance
630-1250 miles	Surveillance, Electronic Monitoring, Communications, Transit Navigation
3100-6200 miles	Sparsely Populated, Scientific
6200-13,700 miles	NavSat Precision Orbit
13,700-21,750 miles	Little Used
21,750-22,370 miles	Geosynchronous, Broadcast, Communication and Data Relay, Surveillance, Weather

(Smithsonian Air and Space poster)

Achieving the desired altitude for a specific mission is another consideration. In order to place an object deeper into space, the payload will require a higher characteristic velocity in order to overcome the Earth's gravity and attain its proper altitude. **TABLE 2** gives a sample of the characteristic velocity needed to achieve different mission altitudes.

TABLE 2

MISSION ORBIT	CHARACTERISTIC VELOCITY feet/second	EXCESS VELOCITY OVER REFERENCE
100 nm ref Circular Orbit	25,570	0
200 nm Circular Orbit	25,922	352
500 nm Circular Orbit	26,900	1,325
1000 nm Circular Orbit	28,296	2,726
Synchronous Transfer Ellipse	33,652	8,082
Synchronous (Equatorial)*	39,791	14,120

* From Cape Canaveral requires a 28.5 degree plane change.

(Hazard, 1978,p.3-3)

2. Orbital Inclination and Range Safety

Due to its latitude of 28.5 degrees above the equator, Cape Canaveral cannot launch a payload directly into a geosynchronous orbit. Instead, it must launch into a transfer ellipse and then execute a 28.5 degree plane change to place a satellite into an equatorial orbit. An explanation of inclination, plane change, transfer ellipse, and various synchronous orbits follows. The term inclination refers to the angle above the equator created by the path of the satellite. **FIGURE 3** on the following page, is a good representation of inclination, although inclination is typically measured northward from the east rather than the west.

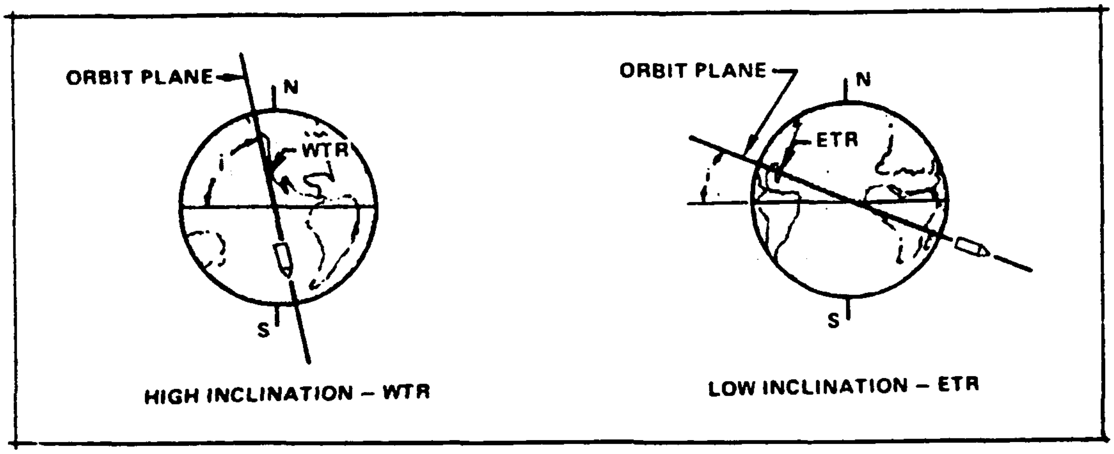

Figure 3: Inclination

(Hazard, 1978,p.3-4)

The ability to achieve the desired inclination is a function of the rocket's fuel supply and by range safety considerations. A plane change can occur outside the atmosphere but it is costly. It requires that the orbiter have its own onboard fuel supply. Even small changes can incur large penalties. **FIGURE 4** illustrates how a plane change occurs. This figure demonstrates a plane change of less than 5 degree.

As the satellite crosses the equator, a propulsion burn is initiated in order to move the satellite in the desired direction. When the satellite has reached its desired orbital plane, its engines are again fired to counter the initial side force and fix the satellite in its new orbit.

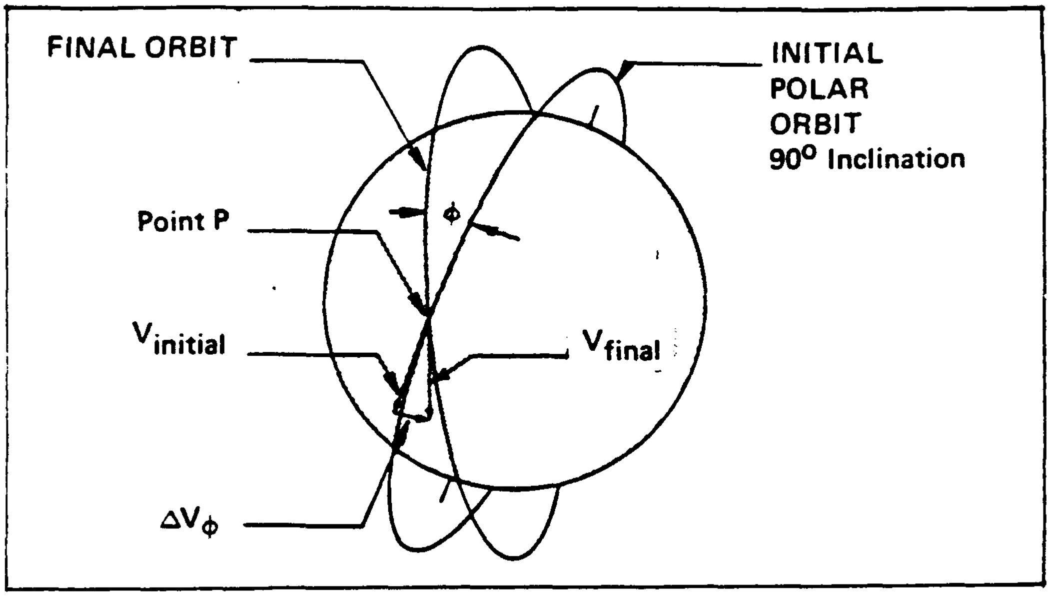

Figure 4: Orbital Plane Change

(Hazard, 1978,p.3-21)

The more desirable and cost effective maneuver is to launch a payload directly into its preferred orbital plane. This is not always practicable from all launch facilities. Geography and range safety considerations limit the launch options for some missions. One does not wish for expended boosters to drop over populated area or on highly travelled sea lanes. Most difficulties arise when attempting to launch directly into a geosynchronous or sunsynchronous orbit.

C. ORBITS

1. Geosynchronous

Synchronous satellites are an often misunderstood concept. When a satellite stays over the same point on the earth constantly it is said to be in a geosynchronous orbit.

This only occurs when the orbiter is positioned over the equator, it is travelling due east relative to the earth, and it is in a circular orbit at an altitude of 19323 nm. When all of these criteria are met, the satellite will orbit the earth with the exact period that the earth is rotating and thus will remain directly over one spot on earth. (Hazard, 1977,p.3-23)

If a satellite is offset to the north or south of the equator at the synchronous altitude its orbit will be in concert with earth's rotational period. However, it will oscillate above and below the equator within the degree of the offset. For example, a satellite placed in a synchronous orbit 10 degrees north of the equator will oscillate between 10 degrees north and 10 degrees south latitude, crossing the equator every 12 hours, while maintaining its longitude relative to the earth. (Hazard, 1977,p.3-23)

2. Sunsynchronous

Sun-synchronous orbits are orbits in which the satellite passes over the same point on earth at the same local time daily. As the earth orbits around the sun and the amount of sunlight changes, the time in which a satellites passes over a given point on earth changes accordingly. In this way a satellite passes over an object when the sun's light is the same position, rather than when the clock's hands are in the same position. In order to achieve a sun-synchronous orbit, a satellite must be placed into a slightly retrograde orbit. A retrograde orbit is one in which the inclination is over 90 degrees.

D. LAUNCH FACILITIES

The following discussion of launch facilities in the United States and French Guiana will provide the context for understanding Brazil's geographic advantages.

1. United States

In the United States, three launch sites have traditionally been used for the space program, Cape Canaveral, Florida, Vandenberg AFB, California, and Wallop's Island, Virginia.

a. Cape Canaveral, Florida

Cape Canaveral, home of the Kennedy Space Center, is the most famous of all the launch centers. It was from there that the Gemini, Apollo, and Space Shuttle missions were launched. Cape Canaveral offers the United States a facility for launching in an easterly direction, capitalizing on the rotation of the earth for satellite orbiting. Range limits (**Figure 5**) prohibit retrograde orbits and orbits with an inclination much above 57 degrees north latitude. Cape Canaveral's latitude also limits the ability to launch satellites into an equatorial plane for a true geosynchronous orbit. But Cape Canaveral is probably the most developed of the U.S. space facilities accommodating all types of launch vehicles including the Space Shuttle.

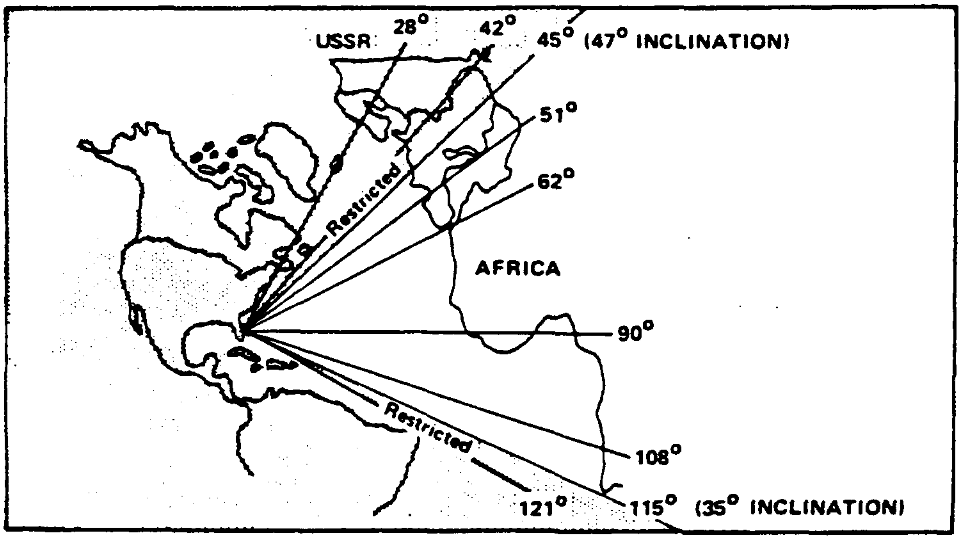

FIGURE 5: GEOGRAPHIC LAUNCH CONSTRAINTS FROM CAPE CANAVERAL

(Hazard, 1978,p.3-6)

b. Vandenberg, Air Force Base

Vandenberg AFB in California is located about 80 miles north of Los Angeles along the Pacific coast. Vandenberg is responsible for west coast missile and space launches. It operates the Western Test Range tracking network and follows launches into the Indian Ocean where the Eastern Test Range tracking system (Cape Canaveral) takes over. Vandenberg provides the United States with access to polar launches. Polar missions are launched due south for range safety considerations. See **Figure 6**. Vandenberg also maintains an alternate space shuttle launch facility. It has been maintained in an active caretaker (mothball) status since 1986 and is intended to be ready to launch shuttle missions on 18 months notice. Vandenberg AFB primarily launches satellites and is still active ICBM base. (Interavia, 1990,p.480)

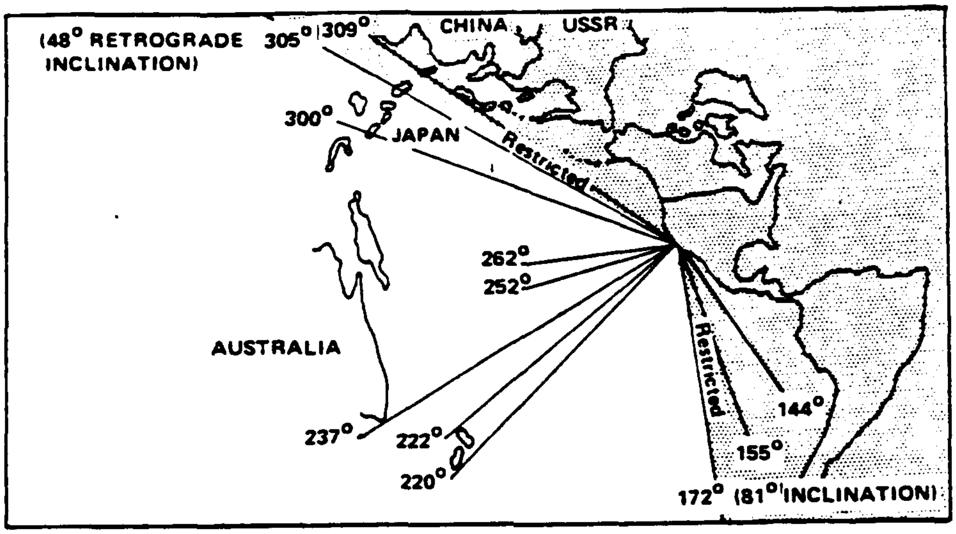

Figure 6: Geographic Launch Constraints From Vandenberg

(Hazard, 1978,p.3-6)

c. Wallop's Island, Virginia

Although a relatively obscure launching facility, Wallop's Island , Virginia was an important facility in the development of the US Space program. Wallop's Island is located near the mouth of the Chesapeake Bay, close to Virginia's Eastern Shore. It was the third U.S. launch facility, behind Cape Canaveral and Vandenberg, and was established in 1946. It was primarily used for sounding rocket experiments but was also used to place satellites into orbit. See **Figure 7**. It was the home for the Scout program and is connected with the Goddard Space Center (Greenbelt, MD). Since 1979 only one satellite has been launched from Wallop's Island. In 1986, General Dynamics received permission from NASA and the Department of Transportation to commence commercial launches from Wallop's Island. (Jane's, 1988,p.489)

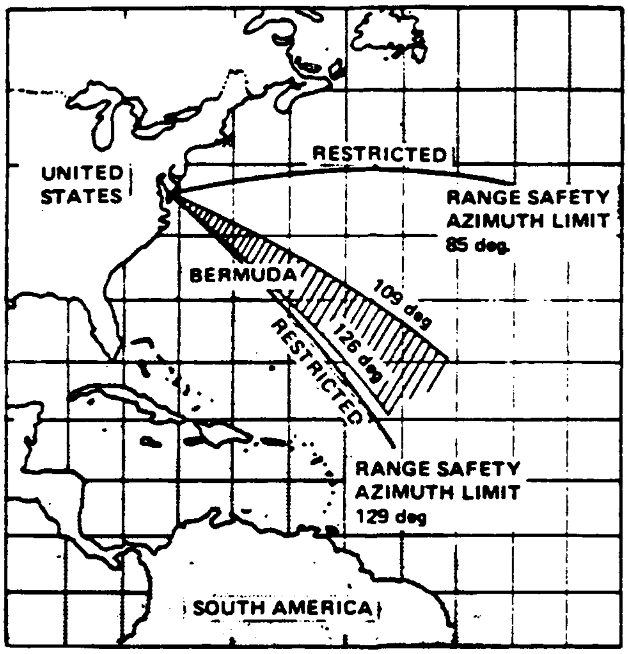

Figure 7: Geographic Launch Constraints From Wallop's Island

(Hazard, 1978,p.5-27)

2. France

The Arianespace launch facility is in Kourou, French Guiana. The Guiana Space Center (CSG) is located just 5 degrees north of the equator. Its location and range clearance allow for northerly launches for sun-synchronous orbits and easterly with only minor maneuvering to achieve a geostationary transfer orbit. The original facility was opened in 1971 and in 1986 a second launch facility was opened. With the expansion of the CSG, the goal of Arianespace is to launch half of the world's commercial satellites. (Ariane, 1991,pp.22-25) Current revenue estimates based on eight launches annually indicate planned sales of 5 billion French francs per year. (Ariane, 1991,p.4)

3. Brazil

a. Barreira do Inferno

Brazil has two major launch facilities, Barreira do Inferno and the Alcantara Launching Center (CLA). Barreira do Inferno, literally translated as "Barrier of Hell" was the first major launching facility in Brazil. It is located near Natal, which is 5 degrees 55 minutes South latitude and 35 degrees 10 minutes West longitude. ("Brazil's Space Program...", 1981,p.77) It was here that the Brazilian space program received its start with the Sonda program.

b. Alcantara (CLA)

The CLA is located at 2 degrees 17 minutes South latitude and 44 degrees 23 minutes West latitude. Alcantara was built to launch the VLS, but also has launch pads for Sonda III and Sonda IV rockets. ("Brazil's Space Program...", 1987,p.77) The CLA was officially inaugurated on 21 February 1990 by then-President Jose Sarney. The occasion was marked by the launching of a Sonda II, even though the control center had yet to be completed. As of December 1990, the VLS pad at Alcantara was projected to be completed by 1993. ("Rocket Launched From...", 1991,p.19) The CLA facility is the closest launch facility to the equator and has range clearance that allows launches from equatorial to retrograde. It can place an object in an even smaller geostationary transfer orbit than can the Ariane facility at Kourou. Additionally, Alcantara provides the advantage of fuel savings due to its proximity to the equator and range safety. It is estimated that a launch from Alcantara would require 25% less fuel than from Cape Canaveral and that there would even be noticeable savings compared with launches from Kourou. (Jane's, 1988,p.489)

E. CONCLUSIONS

Examining some space fundamentals and launch facilities shows that there is an economic rationale behind Brazil's space program. Geosynchronous and sunsynchronous orbits are the most commercially desirable orbits. The latitude and range safety offered at Alcantara is similar, and even better than that of Kourou, French Guiana. These properties allow direct launches into geostationary transfer orbits at a considerable fuel saving over Cape Canaveral. They also allow for direct launches into retrograde orbits which must be done from Vandenberg rather than Cape Canaveral.

The ability of Brazil's Alcantara launch facility to offer direct ascent into commercially desirable orbits and operation of one, rather than two facilities makes the development of Alcantara a potentially profitable commercial space center.

VII. CONCLUSIONS

A. CONCLUSIONS

Summarizing the analysis presented above returns the reader to the purpose of the thesis which was to answer four questions:

(1) What are the critical technologies, facilities, and processes required for a successful space program?

Clearly the critical technologies include liquid fuel engine and TVC technologies. Liquid fuel engines deliver more thrust and can lift payloads into orbit more efficiently than can solid fuel systems. This allows larger payloads, possibly multiple satellites on a bus, to be placed into orbit. The Ariane IV and the U.S. Space Shuttle are the main competition facing Brazil and both systems use liquid fuel engines. Solid fuel technology is applicable in some capacity for orbiting satellites, but liquid engines are needed to economically compete in the space launch market.

However, solid fuel technology has significant advantages over liquid fuel systems in ballistic missile applications. Specifically, solid fuel missiles are easier to hide, transport, and fire than are liquid fuel systems like the Scud. These advantages make Brazil's solid fuel technology attractive to customers seeking ballistic missiles.

Additional technologies that are vital to both liquid and solid fuel systems include composite materials for heat shielding and reentry vehicles, pyrotechnics for stage separation, heat treatment capability to strengthen motor casings, and computer technology to help design engineers and assist in on-board guidance.

Probably the most critical process required for a successful space program is a strong national educational system. There must be a constant source of educated, literate, trainable citizens entering the workforce that can build, operate, and maintain high technology space systems. In the workplace, modern factories, management practices, and quality control is a must to ensure near-zero defect equipment for the space program.

(2) What technologies must be imported and which can be indigenously produced? What critical industries are typically absent in Third World nations which inhibit progress in space?

Computer technology is the primary technology that must be imported. The lack of advanced computers inhibits not only design development, simulation, and testing in space applications, but it also inhibits industrial efficiency and manufacturing processes. This has a ripple effect throughout the whole support structure for space industries.

Computer technology is used in every facet of space production from the control of precise milling machines that produce missile hardware to the on-board guidance systems. The lack of a sophisticated computer industry combined with restricted access to First World computer technology is one of the biggest inhibitors to progress in Brazil.

(3) What indicators would be present to show military intentions and at what point would a military divergence take place?

The conclusion of chapter II generalized that the presence of a strong military can predispose a civilian space program to military purposes. This can certainly be seen in Argentina, Iraq, Israel, etc. In many developing nations the military wields enormous power domestically and can often change the directions of programs from civilian to military purposes. Regarding space programs, this would fit the civilian-military pattern discussed in chapter II.

As in Brazil's case, "Security and Development" is a common theme among other Third World military leaders. Again it is possible to quickly point to countries like Argentina, Iraq, Israel, South Africa, and many others that are pursuing industrial modernization by emphasizing their arms industries. Although it is not clear at what point that a military divergence would occur, it seems that the patterns discussed above, civilian-military projects and "security and Development" would indicate that Third World nations such as Brazil with a strong military and a developing space program are likely to use the cover of their open space program to divert technology and resources covert military projects.

(4) Can generalizations be formed which accurately depict the military potential of another nations' space program?

This is the most important and most difficult question of all. The difficulty lies in the variables that inhibit and/or promote each nation's space program. The generalizations concluded from chapters II and III and mentioned in the previous question seem to demonstrate the potential of a civilian space program being subverted into a military program, but they give no feel for the degree of co-option. Variables such as level of industrial development, national and global economics, success of the MTCR, access to technology, education level of the population, robustness of the industrial base, militarism of society, geopolitics, openness of society, national character, etc. help determine the degree of military potential of a developing nation's space program.

As for Brazil, it seems clear that it has decided to proceed with both space and missile programs for the time being. Brazil's economic situation will be the prime determinant in its military potential in space. A poor domestic economy combined with a resurgent demand for missiles may leave Brazil little choice but to build and sell missiles to keep its space program viable and to keep a positive trade balance. A poor domestic economy combined with a waning demand for missiles will most likely dry up Brazil's missile programs. If this is the case, then Brazil will be pushed towards conforming to MTCR guidelines concerning weapons systems and technology transfers. In this way, Brazil will try to join the First World space club and modernize its VLS system and compete in the commercial launch market. A strong domestic economy with a weak demand for missiles may keep missile projects in the research and development phase while the VLS will get much needed funds. And finally, a strong economy and a strong demand for missiles will keep both space and missile programs active. The most likely scenario is a weak economy and a weak demand for missiles. This would also be the best scenario from a U.S. security standpoint. It is therefore in the interest of the United States to try to lower the international demand for missiles.

B. RECOMMENDATIONS FOR FUTURE RESEARCH

The generalizations produced through this single case study should show a relationship between the strong presence of the military in a developing nation and a tendency for civilian space programs to be developed first, and then diverted covertly to missile projects. There should be a relationship between military governments and "Security and Development" programs that emphasize strong, robust defense industries.

Further research could validate or invalidate these generalizations and quantify the degree to which military potential exists in developing nations' space programs. This would best be done by using a comparative case study of developing nations with space and missile programs. Variables such as economic development, civil-military relations, regional threats, industrial capacity, GDP, etc. could be quantified, scaled, and tested for statistical significance. This type of approach, building on the generalizations formed here, could find significant relationships that will add predictability and a measurement of degree to the question of military potential in developing nations' space programs.

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