Emerging National Space Launch Programs

Economics and Safeguards

Brian G. Chow

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Prepared for the
Under Secretary of Defense for Policy

RAND

PREFACE

This report investigates the economic viability of emerging space launch programs in the Third World and the implications of those programs for the proliferation of surface-to-surface ballistic missiles. The intended audience of this report is missile nonproliferation policy analysts and planners in the United States and other countries, as well as foreign governments that are pursuing or planning to pursue space launch programs.

This study was requested by the Office of the Deputy for Nonproliferation Policy, Office of the Under Secretary of Defense for Policy. The research was conducted within the International Security and Defense Strategy Program of RAND's National Defense Research Institute, a federally funded research and development center sponsored by the Office of the Secretary of Defense and the Joint Staff.

SUMMARY

Most ballistic missile nonproliferation studies have focused on trends in the numbers and performance of missiles and the resulting security threats. This report concentrates on the economic viability of emerging national space launch programs and the prospects for imposing effective safeguards against the use of space launch technology for military missiles. For the convenience of discussion in this report, a reference to ballistic missiles hereafter means surface-to-surface guided ballistic missiles only. Space launch vehicles (SLVs) are surface-to-space ballistic missiles, and they will be referred to explicitly as "space launch vehicles" or "space launchers." Surface-to-surface unguided ballistic missiles will be referred to as "rockets."

The study focuses on emerging space launch programs in the Third World; it finds that their costs cannot be recouped from space launch business. If the United States and other major launch providers give these programs technical assistance, the economic loss and technical difficulties will be reduced, enhancing their chances for continuing. This report also finds that it is not possible to safeguard space launch programs against technical transfers to ballistic missile development. Therefore, the report concludes that if the United States and other nations wish to slow the proliferation of ballistic missiles, they should not assist these emerging launch programs. At the same time, if nations with only emerging launch programs at this time terminate their programs, they will not have missed an opportunity for lucrative profits.

ECONOMICS OF EMERGING NATIONAL SPACE LAUNCH PROGRAMS

Space launcher, as well as ballistic missile, economics is relevant to missile nonproliferation. The poor economics we describe in this study might persuade some countries to forgo the pursuit of space launch and even ballistic missile programs and thereby slow the spread of ballistic missiles. Equally important, dismal economics will invalidate an argument used frequently by nations with emerging space launch activities. They can no longer claim that withholding launch technical assistance from them will deny them an opportunity to share in the highly profitable space launch business. Countries could also want an indigenous space launch capability for technology spinoffs, self-sufficiency, national prestige, or other legitimate purposes. These purposes, especially when they can be met through other technology programs that entail few proliferation risks, should not sway the United States and other members of the Missile Technology Control Regime (MTCR) into offering launch technical assistance.

Among Third World countries with emerging space launch programs, India and Israel have succeeded in launching satellites into orbit. Brazil and possibly South Africa have space launchers under development. South Korea, Pakistan, Indonesia, and Argentina have been in the planning stage. Taiwan publicly scrapped its space launch program in 1990, but it could be reactivated in the future. Nearly all of these countries have active military ballistic missile programs, and the transfer of technologies and components from space launchers to missiles is a serious concern. Iraq's missile programs, including space launch development, are required to be dismantled by the United Nations Resolution 687. All these Third World space launch programs involve small launchers as their first phase.[1]

Instead of assessing space launch economics individually, we find it both reasonable and efficient to select one country for detailed analysis and generalize the results to other countries. Brazil was selected for three reasons. First, economic data on emerging national space launch programs are generally closely held, but Brazil's data are available. Second, one can generalize findings from the Brazil case to other cases. Although Brazil has not succeeded in launching a satellite, we optimistically assumed that its future investment is not more than that of Israel and India and that Brazil can capture just as large a market share. Then, if Brazil's launch venture would still not be profitable, Israel's and India's would not be either. Space launch programs for South Africa, South Korea, Pakistan, Indonesia, Argentina, and Taiwan would be even less profitable than Brazil's, since they have invested far less than Brazil in space launch programs and would eventually have to spend similar amounts. Third, Brazil's space launcher and ballistic missile programs have been facing technical and financial difficulties, and the country's future plans are highly uncertain. An economic and strategic reassessment like the one conducted here might well influence the future direction of Brazil's programs

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[1]In this report we classify launchers with a delivery capability of 6000 pounds or less to low earth orbit (LEO, an altitude of 100 nautical miles) as "small launchers." "Regular launchers" are those that can deliver more than 6000 pounds to LEO.

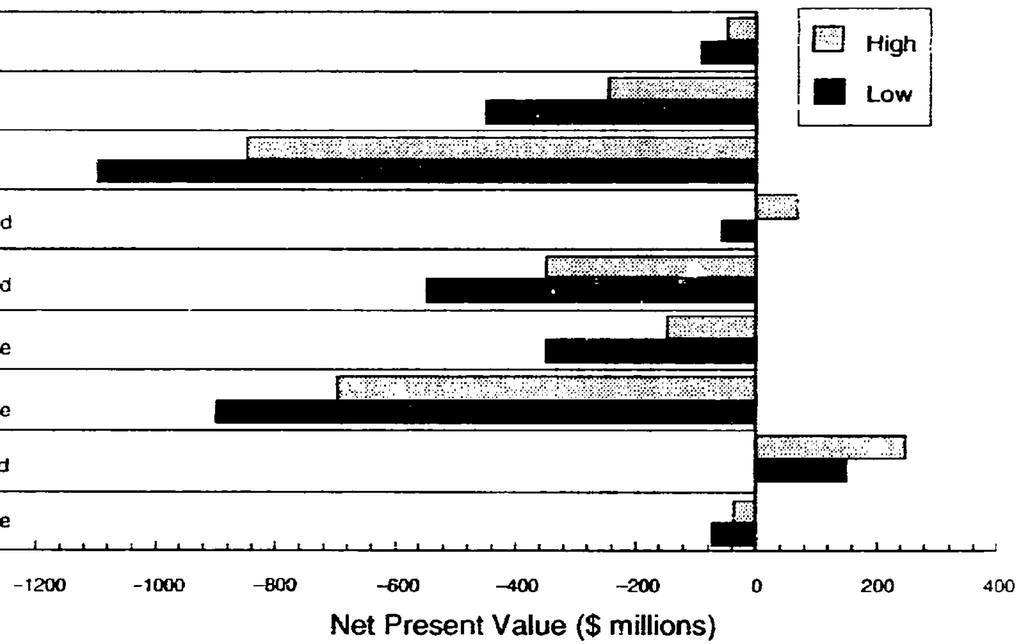
In addition to a detailed analysis of Brazil, we generalize the findings to South Africa, since it is also in the midst of deciding whether to pursue a space launch program.

PROFITABILITY OF BRAZIL'S SPACE LAUNCHERS

Figure S.1 summarizes the economic viability of Brazil's space launch and ballistic missile programs. In all cases, we assume that Brazil can either develop the needed technologies indigenously or incorporate foreign technologies into its space launch program. The high estimate is not adjusted for potentially lower launch reliability, while the low estimate is. The high estimates are discussed in this and the next section. The low estimates are reviewed in the section on launch reliability.

Even if Brazil's launch reliability is assumed to be as high as that of major launch providers, it would lose $50 million in net present value and 1992 U.S. dollars (case 1) or could recoup only 35 percent of its future investment in the small space launcher business. If Brazil expands into regular space launchers, it would fare worse economically. Even if it could lower the investment by obtaining licenses from foreign launch suppliers for key missile technologies (case 2), it would lose $250 million or could recoup only 30 percent of its future investment in small and regular space launchers. If technology licenses were denied (case 3), Brazil would have to spend at least $1 billion more to develop the needed technologies indigenously and would lose $850 million, or an increase of $600 million. It would recoup merely 20 percent of its future investment. This signals that the actions of the United States and others matter, even if Brazil insisted on continuing to pursue its space launch program. Technical denial can make the program financially, as well as technically, more burdensome to Brazil, and thus it will be less likely to carry on. Moreover, the likelihood of major launch-providing nations joining forces in withholding missile assistance has lately improved, Saddam Hussein having showed that even relatively ineffective Scud-type missiles can strain and could break up a coalition. The poor economics of emerging national launch programs should help convince major launch-providing nations that their withholding of technical assistance does not deprive Third World countries of a very profitable business opportunity. On the other hand, the losses showed by these launch programs might not be large in absolute dollar terms, but the high likelihood that the space venture would produce a loss, not a large profit,

Case	Launcher/ missile involved	Foreign technology available?	Competition in missile export
1	SSL	AY	NR
2	SSL & RSL	Yes	NR
3	SSL & RSL	No	NR
4	SSL, RSL & BM	Yes	Limited
5	SSL, RSL & BM	No	Limited
6	SSL, RSL & BM	Yes	Intense
7	SSL, RSL & BM	No	Intense
8	SSL & BM	AY	Limited
9	SSL & BM	AY	Intense



NOTES: SSL = small space launcher; RSL = regular space launcher; BM = ballistic missile. AY = "assume yes." See the section on the policy implications of space launch economics in Section 2 of the main text for the potential impact of failure to obtain foreign assistance. NR = "not relevant."

Figure S.1—Profitability in Brazil's Space Launch and Ballistic Missile Programs (assumed technical feasibility)

should negate Brazil's and others' argument that they need foreign missile technology assistance so that they can share in the economic benefits of the space launch business.

PROFITABILITY IN BRAZIL'S LAUNCHERS AND MISSILES

Brazil could net a small profit of $70 million by expanding into ballistic missile sales for domestic use and, most importantly, for exports (case 4). This profit will, however, turn into a $350 million loss if foreign missiles assistance is not forthcoming (case 5).

The most economically favorable case to Brazil is the one in which it forgoes the pursuit of regular space launchers but continues to develop small launchers and ballistic missiles (case 8). The profit here can be as high as $250 million.

It is, however, important to differentiate two kinds of profits that one might earn in missile sales. "Undercutting" profit is earned when other countries refrain from the missile export market. It is undercutting because the seller receives a profit not through competition but by exploiting others' actions to curb missile proliferation. The other kind of profit is the normal kind, that would be earned under open competition if missile proliferation were not a concern. If major launch providers were to compete with Brazil in the missile export market, Brazil would suffer a loss of $150 to $700 million (cases 6 and 7). Even in the most economically favorable case, Brazil could suffer a small loss of $40 million (case 9). The policy implication is not that we should compete with Brazil for missile exports. Rather, if other countries did not refrain from competition for nonproliferation reasons, Brazil's missile venture would not be highly profitable anyway.

LAUNCH RELIABILITY

There is a distinct possibility that Brazil cannot penetrate the market for small, as well as regular, space launches at all and thus cannot recoup any of its space launch investment. America's early small-launch experience with Scout, Thor/Delta, and Atlas revealed that it took an average of 57 flights to reach a reliability of merely 75 percent. More recently, India had four failures out of its first seven flights (all small launchers), yet its technological capability during 1979–1992 cannot be considered inferior to Brazil's during the coming ten years. Being a latecomer, Brazil with a poor or short launch record might have to subsidize its initial launchers heavily in order to attract customers, or it might be unable to compete at all. For example, the subsidy could raise Brazil's loss from a small and regular launch program from $250 million (high estimate in case 2) to $350 million. Worse yet, if Brazil is unable to compete, the loss could become $450 million (low estimate in case 2).

APPLICATION TO OTHER EMERGING NATIONAL SPACE LAUNCH AND BALLISTIC MISSILE PROGRAMS

We have classified emerging national launcher and missile programs into two groups. Group 1 consists of Israel, India, and Brazil. The future investment requirements of Israel and India would be only slightly lower than what we conservatively assume for Brazil. As for market shares in space launches and in ballistic missile exports, neither Israel nor India is likely to capture more than what we optimistically assume for Brazil. In fact, with all three countries participating in the business, the market share of each country is likely to be considerably smaller than what we assume for each. Thus, with similar projections of investments, demands, revenues, and net cash inflows, the economic findings for the space launch and ballistic missile programs of Israel, India, and Brazil would be similar.

Group 2 countries consist of South Africa, Iraq, South Korea, Pakistan, Indonesia, Taiwan, and Argentina. Iraq's missile programs are being dismantled. Other countries have made much smaller financial commitments than Brazil in space launch and ballistic missile programs. Consequently, a group 2 country would have to make a much larger investment than a group 1 country, if it decided to pursue these launcher and missile projects. On the other hand, the market share, revenues, and net cash inflows would not be larger than those of Brazil, Israel, or India. Therefore, the launcher and missile economics for any of these group 2 countries should be worse than for Brazil. Any joint program among countries in group 1 or group 2 overall would be no better off economically than Brazil's program.

We have applied and expanded our findings in the Brazil case to another example, South Africa. Its program and arguments are similar to those of countries in both group 1 and group 2. In June 1992, South Africa was reported to be planning to offer satellite launch services in three years. We have learned that a key reason for its pursuit is the potential economic payoff. But this study has shown that the South African program, like the Brazilian program, is unlikely to be profitable. Moreover, since South Africa has applied to join the MTCR, it must not rely on missile exports to recoup its investment.

Other plausible reasons—technology spinoffs, national prestige, and space launch self-sufficiency—for pursuing a space launch program are also weak.

Launch technology spinoffs depend heavily on the ability to obtain foreign technologies in the first place. MTCR makes such technical assistance difficult to obtain. Even South Africa's most likely partner for its space launch venture, Israel, has now agreed to abide by the MTCR rules. In any case, a joint venture with Israel is uneconomical overall, and Israel is unlikely to absorb the losses alone and let South Africa reap the benefits. Moreover, since the European consortium Arianespace does not find it profitable to develop a small launcher at this time, there is no reason to believe that joint efforts between Arianespace and South Africa would make the venture profitable.

As for national prestige, pursuing a satellite-making capability—small communications satellites, for example—would be equally prestigious. Obtaining foreign satellite technologies is also easier than getting launch technologies.

Self-sufficiency in space launch would be of low priority for a country with only 40 million people. In any case, since South Africa and other countries need geosynchronous communications satellites the most, no regular launcher means no self-sufficiency. Yet regular launchers are the most costly and difficult to develop.

Given worldwide concerns over missile proliferation, South Africa and other countries would be ill-advised to enter this arena. Whatever meager benefits could be derived from the pursuit would be easily outweighed by the political costs of being a missile proliferator. For example, a reduction in foreign investment or trade as a result of economic sanctions would far exceed the benefits, if any, of missile sales. It is to the benefit of South Africa and other countries in groups 1 and 2 to cancel their space launch plans. Refusal by MTCR members and abiders to supply technical help could also kill these programs.

SAFEGUARDING SPACE LAUNCH VEHICLES

MTCR members would be willing to assist even uneconomical space launch programs if launch technology could be safeguarded against use in military ballistic missiles. If it could be, then, as with the Treaty on Non-Proliferation of Nuclear Weapons (NPT), one could use the applications of peaceful ballistic missiles—space launchers—to reward those who are willing to support missile nonproliferation. This dream is, however, hard to fulfill.

A likely scheme for safeguarding SLVs, including sounding rockets, would include two basic elements. First, all critical SLV parts, systems, and production, storage, and launch facilities would be placed under an IAEA-like supervision regime. The second element would be the prohibition of flight tests of ballistic missiles beyond a stipulated range regardless of payload weight. The provision would aim to keep a country from gaining experience with high-speed reentry and system testing, which are critical technologies for the development of prohibited longer-range missiles.

Take the case of a 300 km range cutoff. During the period of compliance, SLV activities will serve as a conduit for the flow of guidance, propulsion, and structure technologies to the improvement of military shorter-range (<300 km) missiles. At breakout, when the country has decided to cease complying with the safeguards, the additional time needed to attain a longer-range (≥300 km) missile capability could be as short as several months. From the first flight test to massive employment against Iran, Iraq took only seven months to deploy its 600 km Al-Husayn missile. Even in the most optimistic cases for nonproliferation planners, where the time from breakout to operational weapon is measured in years, the MTCR members should not want to trade their SLV assistance for other countries' temporary refrain from developing longer-range missiles. SLVs could be the only avenue not closed out by export control for obtaining missile technologies. We might be providing an otherwise unavailable education on missile technologies.

In fact, if we were to take a cue from the drafters of the NPT, we should ban space launchers outright in a missile nonproliferation regime. NPT drafters recognized early on the impossibility of banning the development of military nuclear explosions but allowing peaceful nuclear explosions in a nuclear nonproliferation regime. Space launchers are actually "peaceful" ballistic missiles.

POLICY IMPLICATIONS AND RECOMMENDATIONS

In view of the difficulties of safeguarding space launch technologies, we support the policy of not supplying engine and other missile technologies to countries with emerging launcher programs. This forces such a country to take one of two options. First, it can continue to pursue a regular space launch capability. But even if the country is capable technologically, the prospects of heavy spending to develop indigenous missile technology and the dismal possibility of recovering the investment make it unlikely to pursue this expensive option. The other option is to forgo regular space launchers and concentrate on small space launchers and ballistic missiles. Such a pursuit will clearly reveal itself to be not for space launch self-sufficiency, since small launchers cannot launch the most needed geosynchronous communication satellites. Moreover, no matter a country's intent, MTCR members will clearly see that if regular launchers are not the goal, the bulk of their missile assistance winds up benefiting military ballistic missile programs. Such a transfer obviously works against the intent of MTCR. Finally, it should also be clear that the ballistic missile profits of a missile-exporting country came from exploiting MTCR countries' good intentions in refraining from missile exports. Therefore, even if a country is forced to forgo missile export, it is not being deprived of a deserved, highly lucrative profit opportunity. These revelations should make MTCR members even more likely to join forces in not providing technical assistance and in imposing political costs on missile proliferators. Moreover, even small launcher and ballistic missile programs can be affected by technical denial and politico-economic pressure from MTCR: the Argentine-led Condor-II was placed into disarray, Taiwan's space launch program was canceled, and Brazil's and India's programs were delayed.

The United States and other major launch-providing nations should make a commitment to launch any country's payloads at a reasonable price and in a timely manner. At the same time they should make it known that emerging national space launch development is uneconomical and inherently dangerous. The United States and others should discourage such development rather than hope that it can be safeguarded. Otherwise, the MTCR members might end up promoting missile proliferation instead of slowing it.

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GLOSSARY

ASLV	Augmented satellite launch vehicle
ASTRO	Artillery Saturation Rocket System
BM	Ballistic missile
CEP	Circular error probable
CIS	Commonwealth of Independent States
CTA	Center for Aerospace Technology
DARPA	Defense Advanced Research Projects Agency
ESA	European Space Agency
FIR	Fraction of investment recouped
GPS	Global positioning system
GSLV	Geostationary satellite launch vehicle
GSO	Geosynchronous orbit
HEU	Highly enriched uranium
IAE	Institute for Space Activities
IAEA	International Atomic Energy Agency
IMU	Inertial measurement unit
IRR	Internal rate of return
Isp	Specific impulse
LEO	Low earth orbit
LH2	Liquid hydrogen
LOX	Liquid oxygen
MTCR	Missile Technology Control Regime
NASA	National Aeronautics and Space Administration
NPT	Treaty on Non-Proliferation of Nuclear Weapons
NPV	Net present value
OSC	Orbital Sciences Corporation

PSLV	Polar satellite launch vehicle
Pu	Plutonium
RSL	Regular space launcher
SDIO	Strategic Defense Initiative Organization
SLV	Space launch vehicle
SSL	Small space launcher
SSNM	Strategic special nuclear material
START	Strategic Arms Reduction Treaty
VLS	Vehicular Landador de Satellite
UHF	Ultra high frequency

1. INTRODUCTION

Recently, there has been a resurgence of public concern on the proliferation of weapons of mass destruction and the means of delivering those weapons. Saddam Hussein's actions before, during, and after the Persian Gulf War are a major cause. They showed that even relatively ineffective Scuds could strain and might break a coalition. They also pointed up the difficulties for the Treaty on Non-Proliferation of Nuclear Weapons (NPT) and the International Atomic Energy Agency (IAEA) in stopping a determined proliferator from developing nuclear weapons, even if the proliferator is an NPT signer and has placed its (declared) nuclear facilities under full-scope safeguards. Many proposals are being offered in the United States and abroad to strengthen and expand the existing safeguard regimes and to curb sensitive exports. Many countries have already made new commitments to retard the spread of weapons of mass destruction. In his address to Congress on September 11, 1990, President Bush proposed to "curb the proliferation of chemical, biological, ballistic missile, and above all, nuclear technologies."

The likelihood that nonproliferation measures will be enacted in the near future is good, and it is further enhanced by favorable recent events, some of which occurred even before Iraq's invasion of Kuwait. These events include (1) the growing willingness of the United States and CIS (Commonwealth of Independent States)[1] to cooperate on arms reduction and nonproliferation; (2) South Africa's accession to the terms of NPT; (3) the insistence by Germany, France, U.K., Belgium, and Switzerland that their nuclear-assistance recipients abide by full-scope safeguards; (4) France's decision to sign NPT after twenty years of abstention; (5) Brazil's and Argentina's agreement to negotiate with IAEA for nuclear safeguards and to take initiatives for enacting the Treaty on the Proscription of Nuclear Weapons in Latin America (Treaty of Tlatelolco); (6) India's and Pakistan's agreement to not attack each other's nuclear facilities; (7) China's announcement that it would join NPT; and (8) North Korea's signing of IAEA safeguards.

The nonproliferation efforts should not focus exclusively on nuclear weapons or even on all weapons of mass destruction, because prolif-

[1]On many space issues, one may have to deal with Russia or other former Soviet republics directly, but here we will use "CIS" to represent those cases as well.

eration can only be limited and slowed, not stopped. We should also plan for the contingency that these weapons will be possessed by some destabilized countries. For anyone who has them, ballistic missiles would certainly be a key means of delivery.[2] Moreover, even with conventional warheads, ballistic missiles have been used as terror weapons against innocent civilians.

In this report, the term "ballistic missiles" means surface-to-surface guided ballistic missiles only.[3] Space launch vehicles (SLVs) are actually ballistic missiles used in a surface-to-space mode to send payloads from the surface to earth orbit. Here they will be referred to explicitly as "space launch vehicles" or "space launchers." Surface-to-surface unguided ballistic missiles will be referred to as "rockets." Moreover, many numbers involved in intermediate steps in this report are not rounded to their significant figures, because other analysts can trace or replicate the calculations much more easily with unrounded numbers.

There are basically three ways for countries to obtain ballistic missiles. First, they purchase missiles directly from foreign suppliers. This was the route chosen by many countries in the past. One prominent example is the Scud missiles sold to many Third World countries by the former Soviet Union. But with all major missile suppliers except North Korea becoming members or abiders of the Missile Technology Control Regime (MTCR), it is much more difficult to obtain missiles this way.[4] The chances of North Korea's joining MTCR in the near future are better than ever. That country finally signed the IAEA safeguards in January 1992, after having joined NPT in 1985. Under political pressure from other countries, it may control missile exports as it yields to IAEA safeguards. As North Korea is the only major missile supplier outside MTCR, the pressure on it is high.

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[2]Cruise missiles and aircraft are other key delivery vehicles; they are not covered in this report.

[3]They are typically guided during the boosting phase.

[4]The seven original members of MTCR are the United States, the United Kingdom, France, Germany, Italy, Japan, and Canada. They have been joined by eleven countries: Australia, Austria, Belgium, Denmark, Finland, Luxembourg, Netherlands, Norway, New Zealand, Spain, and Sweden. Also, the former Soviet Union, Switzerland, Israel, and China had agreed to abide by the MTCR guidelines. Reginald Bartholomew, Under Secretary of State for International Security Affairs, has said that Poland, Hungary, Czechoslovakia, Romania, and Bulgaria have already adopted, or are in the process of adopting, controls comparable to those of the MTCR. (Reginald Bartholomew, *Curbing Destabilizing Arms Transfers*, presented to the Subcommittee on Foreign Operation, House Appropriations Committee, April 8, 1992.) Finally, although China agreed to abide by MTCR, there are complaints that it continues to sell missiles to other countries, such as Pakistan, Syria, and Iran. China denies all these charges.

The second way to obtain ballistic missiles is through indigenous development. For this to happen, foreign technical assistance is either critical or highly valuable. Again, MTCR explicitly prohibits such direct assistance to missile programs.

With the possibility of the above two pathways being closed out, the third way—indigenous ballistic missile development, with needed technologies obtained through a space launch program—will become even more important in the future. Much of the launcher technologies are useful for ballistic missile development, because space launchers are simply surface-to-space ballistic missiles. Some countries needing missile assistance have been interpreting the MTCR guidelines in their favor. MTCR states that "the Guidelines are not designed to impede national space programs or international cooperation in such programs as long as such programs could not contribute to nuclear weapons delivery systems." Moreover, even MTCR members in the past and possibly in the future might disagree on whether assistance can be extended to space launch programs.[5]

This study focuses on the third pathway. Since it is difficult to argue that space launch programs "could not contribute to nuclear weapons delivery systems," namely ballistic missiles, we believe much of the debate hinges on whether space launch technologies and components can be safeguarded. The feasibility of safeguard is a major issue addressed in this report.

Should the United States provide technical assistance to a space launch program, if the recipient country promises to forgo its ballistic missile program? We do not think so, if space launch programs cannot be safeguarded. A government and its policy can change. We also find it important to inform the top government officials of the direct connection between a space launch program and a ballistic missile program. Otherwise, even if a government head supports and announces a ballistic missile ban, some planners and scientists might convince their superiors of the separability of the two programs and manage to carry on the same missile activities under the space launch cover. They would hope that, in the event their government has a change of heart, they can quickly resurrect their ballistic missile development. Ironically, a sequential strategy—space launch program first, ballistic missile development later—might turn out to be the best tactic. Had a country insisted on a simultaneous ballistic missile

[5]For example, France in 1990 argued that certain transfers, such as liquid-fueled rocket technology, are permissible, while the United States considers them within the export control list. Even within the United States, opinions vary widely.

program, MTCR members would likely not have given it the missile technologies for its space launch program in the first place.

In addition, this report addresses the economic viability of space launch programs. The important link between economics and ballistic missile proliferation is not immediately clear. First, the urge, though not legal obligation, to assist other countries' economic development has long played a critical role in shaping the U.S. export control policy, which is itself a major tool for limiting proliferation. If a country found the economics of space launch highly favorable, it would have strong financial incentives to pursue space launch development. The obvious transferability of technologies and components from space launchers to military ballistic missiles would make slowing the missile spread a much more difficult task. On the other hand, if a country insisted on pursuing space launch development in spite of its poor economic prospects, the United States and other major launch providers would not feel they were jeopardizing that country's economic opportunities by denying its request for missile assistance. Further, if a country is counting on U.S. assistance to develop or improve military ballistic missiles for export, the United States should feel even less of a moral obligation to help military missile development, as opposed to peaceful space launch programs. Therefore, the poorer the prospects for making profits from a space launch business, the less uncomfortable the United States and other MTCR members would be in exercising export control.

Second, poor economics might persuade some countries to forgo space launch and even ballistic missile programs and thereby slow the missile spread. History offers some such examples. The miserable economics of many nuclear programs, including enrichment and reprocessing, played a key role in the scaleback of these activities in such countries as Brazil, South Korea, and Iran. The same could happen to space launch programs. This is particularly true when a country has already decided, in support of nonproliferation, to forgo military ballistic missile development. Then, poor economics in its space launch venture might make it forgo that program as well.

A country could want an indigenous space launch capability for technology spinoffs, self-sufficiency, national prestige, or other legitimate purposes. These purposes, especially when they can be met with programs that do not raise proliferation concerns, should not drive the United States to offer launch technical assistance.

Some might argue that space launch development is used to obtain foreign high technologies. The growing international support for the MTCR is making this reason much less persuasive. If a country wants to benefit from the import of foreign technologies for commercial applications, it should select a venture for which other countries are most willing to transfer their know-how. Proliferation concerns make countries most reluctant to transfer missile or nuclear weapon technologies. Thus, a strategy of using space launch development to obtain high technologies is less likely to succeed. One might turn the argument around to support indigenous missile development, because such technologies cannot be obtained otherwise. This is the same argument used to support nuclear weapon development. It is, however, precisely the sort of activity that MTCR wants to prevent, and the United States and other countries certainly have no obligation to help any country pursue it.

Some might also argue that indigenous space launch capability is an assurance of supply. There is, however, no need to worry about a cutoff in launch services; they are and will continue to be oversupplied by many countries of different ideologies. The likelihood of all of them denying services at the same time is negligible, unless the requesting country is contemplating acts as blatant as those of Saddam Hussein.

Still, some might believe that a space launch capability generates great national prestige. The importance of this factor may be overstated. In the export market of aircraft, armored vehicles and other military platforms, countries such as Brazil tend to aim for the lower performance segment of the market, which does not provide much prestige. Even if some countries assign high priority to projects that bring national prestige, there are many other equally prestigious projects, some of which are even space related. For example, a country may want to develop communications satellites, as opposed to launchers, for profits and prestige. It would be easier to get help with satellite technology than space launcher technology.

In any case, the amount of direct economic benefits from the space launch business and missile exports should be a key factor in a nation's decision on space launch development and the U.S. policy for assisting such development. Yet, to date there seems to have been little quantitative analysis of launcher and missile economics; this study attempts to develop an analytical framework and to conduct such an analysis.[6]

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[6]There are comprehensive reports on the noneconomic aspects, such as characteristics and threats, of ballistic missiles. See, for example, Janne Nolan, *Trappings of Power*, The Brookings Institution, 1991; Center for International Security and Arms Control, *Assessing Ballistic Missile Proliferation and Its Control*, Stanford University, November 1991; W. Seth Carus, *Ballistic Missiles in Modern Conflict*, Center for

In this study, we focus on emerging space launch programs in the Third World, or joint ventures among these countries. Nations and consortia that have space launch programs that are well established or well on their way—United States, CIS, European Space Agency (ESA), China, and Japan—are not studied here. Nor are joint venture programs with these major suppliers, such as Australia's Cape York project, that purchase launchers rather than develop them indigenously.

Section 2 derives the economics of emerging national space launch and ballistic missile programs. Section 3 examines the problems of preventing their diversion to military use. Study findings are highlighted in Section 4.

Strategic and International Studies, Washington, D.C., 1991; Robert Shuey et al., *Missile Proliferation: Survey of Emerging Missile Forces*, Congressional Research Service, February 9, 1989; and Martin Navias, *Ballistic Missile Proliferation in the Third World*, Adelphi Paper 252, Summer 1990.

2. ECONOMICS OF EMERGING NATIONAL SPACE LAUNCH PROGRAMS

In this section, we begin by reviewing space launch programs in the Third World. Then we explain the choice of Brazil's space launch program for detailed economic analysis. Next comes a discussion on what one can learn from Brazil's civilian and military nuclear programs. This is followed by an introduction to the quantitative methodology used in this study. The methodology is applied in turn to the determination of the profitability of Brazil's small space launch program, regular launch program, and ballistic missile sales. Finally, we generalize the Brazilian results to other Third World countries, particularly South Africa.

EMERGING NATIONAL SPACE LAUNCH PROGRAMS

Table 2.1 shows the current status of emerging national space launch programs. India, Israel, Brazil, Iraq, South Korea, Pakistan, Indonesia, Argentina, and South Africa have or plan to have such programs. Taiwan had one until it was publicly scrapped in 1990 because the United States refused to supply the critical booster technology.[1] India and Israel have succeeded in using their own space launchers to place satellites in orbit. Nearly all of these countries have active ballistic missile programs, and stopping the transfer of launch technologies, if not components, to these military programs will be shown to be impossible. These countries also use the same production facilities for both space launchers and ballistic missiles.

Instead of assessing space launch economics individually, we found it both reasonable and efficient to select one country for detailed analysis and generalize the results to other countries. We selected Brazil for three reasons. First, economic data on emerging national space launch programs are closely held, and Brazil's data are the most available. Second is the relative status of Brazil's space launch program. By comparing the stage and investment of Brazilian space

[1]"Taiwan Scraps Booster Plans," *Aviation Week and Space Technology*, October 22, 1990, p. 11. This case and that of Condor 2 demonstrated that MTCR members can influence the future of many of the emerging space launcher and ballistic missile programs.

Table 2.1

Emerging National Space Launch Programs

Group	Country	Space Launcher[a]	Status	Parallel Surface-to-Surface Ballistic Missile Program[b] (range in km)
1	India	SLV-3	Tested 1980	Agni (2500)
		ASLV	Unsuccessfully tested 1987/88	Prithvi (250)
		PSLV	Under dev.	Potential ICBM
		GSLV	Under dev.	
	Israel	Shavit	Tested 1988/89	Jericho II (1500) Jericho 1 (480) Lance (120)
	Brazil	VLS	Under dev.	SS-1000 (1000) SS-300 (300) MB/EE 600 (600) MB/EE 350 (350) MB/EE 150 (150)
2	South Africa	SLV	Under dev.	Jericho II (1500)
	Iraq	Al-Abid	Uncertain	Tammuz 1 (2000) Al-Abbas (900) Al-Husayn (600) plus shorter range missiles
	South Korea	SLV	Planned	Modified Nike Hercules (240)
	Pakistan	SLV	Planned	Hatf 3? (600) Hatf 2 (300) Hatf 1 (80)
	Indonesia	SLV	Planned	RX-250 (100)
	Taiwan	SLV	Canceled	Ching Feng (120)
	Argentina	SLV	Planned	Condor 1 (150) Condor 2 (1000)[c]

SOURCES: Entries for the third, fourth, and fifth columns were adopted and updated by the author mainly from the tables in Martin Navias, *Ballistic Missile Proliferation in the Third World*, Adelphi Paper #25, Summer 1990, pp. 29–31; Duncan Lennox (ed.), *Jane's Strategic Weapon Systems*, Jane's Information Group Inc., 1990; "Space Commission to Build Rocket for Satellites," JPRS-TND-91-014, *Latin America*, September 12, 1991, p. 3; and *Missile Monitor*, Fall 1991, pp. 4–5.

[a]SLV = space launch vehicle; ASLV = augmented satellite launch vehicle; PSLV = polar satellite launch vehicle; GSLV = geostationary satellite launch vehicle.

[b]Programs do not have a one-to-one correspondence with space launchers on the same line.

[c]Officially canceled. Argentina, however, wants to pursue "peaceful use" of Condor technology.

launch development with that of other countries, we can generalize that if Brazil's launch venture would not be profitable, Israel and India would not fare much better; moreover, space launch programs for South Africa, South Korea, Pakistan, Indonesia, Argentina, and Taiwan would be even less profitable. Third, an economic assessment, like this study, can alter the Brazilian program. The historic agreement with Argentina on November 28, 1990, on the banning of nuclear weapon development and the safeguarding of nuclear activities, demonstrated Brazil's resolve to reassess its security needs and make drastic changes, if necessary. Brazil's ballistic missile programs are on hold, and the plan for its space launch program is uncertain. Therefore, it is one of the countries most likely to change its course in space launch development as a result of the new strategic environment and the dismal missile economics. Let us now elaborate on how the Brazilian results will be generalized.

As shown in Table 2.1, emerging national space launch programs are classified into two groups. The first group consists of India, Israel, and Brazil. We shall soon see that Brazil has already made a substantial investment in its space launch program and that a satellite launch could be made by or even before the mid-1990s. It is, however, unclear whether it can accomplish the feat without foreign help. Since we optimistically assume that Brazil's future investment requirements and launch market shares will be similar to those of India and Israel, the Brazilian results can be generalized to the Indian and Israeli cases.

The second group's space programs are still in the early stage of development, and their investments made thus far are significantly less than those in the first group. Group 1 countries already have large sunk costs, which are not counted in an analysis to decide whether to continue or to terminate the existing projects. On the other hand, group 2 countries deciding to pursue space launch development would have to pay for costs which are sunk to group 1 countries. Therefore, if the economics turned out to be poor for group 1 countries, it would be worse *a fortiori* for group 2 countries.[2]

[2]Alternatively, if one wants to go through the analysis for another country, such as South Africa, one can replace Brazil with that particular country every time Brazil appears and ask the question: will the investment be the same or even higher, or will the revenues and cash inflows be the same or even lower? One can then conclude whether the profitability is the same as or even worse than it is for Brazil.

EXPERIENCE FROM BRAZIL'S NUCLEAR PROGRAM

Before we examine Brazil's space launch program, we can learn from its nuclear experience. There are similarities between the two programs.

The recent revelation of the military parallel nuclear program during the Figueiredo administration in the late 1970s to mid-1980s confirmed long-held worries about the diversion of civilian nuclear power technology for nuclear weapon development. Although Brazilian officials at the time publicly denied any bomb-making intentions, many in the program were developing the nuclear technology covertly and expecting to obtain the president's approval to build the bomb later.[3] Similarly, we cannot be assured that space launch technologies will not be transformed to missile programs.

Of all the power plants called for in the 1975 Brazil–West Germany nuclear agreement, only two have a chance to go into operation: Angra II by 1996 (14 years behind schedule) and, with much less chance, Angra III, on which the work is not scheduled to resume until 1993. As for the agreement's uranium enrichment project, active since 1980, it has failed to place the needed jet nozzle process into operation. In fact, many Brazilian engineers have long written off that technology and placed their efforts elsewhere, especially in the navy's ultracentrifuges. The nuclear agreement has thus far cost Brazil $8.3 billion and is expected to cost $7 billion more by year 2000, but it has accomplished very little.[4] This expensive agreement should be an important lesson for both Brazil and others. The ultimate cost for space launch programs could be drastically higher.

Moreover, the Brazilians had once anticipated the eventual connection between space launchers and nuclear warheads. During the parallel nuclear program, a 3000-km bomb-carrying missile was to be based on Brazil's developing satellite launch vehicle. Some might argue that the recent declaration on the common nuclear policy of Brazil and Argentina, which endorses bilateral inspection, should alleviate the concern of nuclear proliferation. But this is far from certain. After an in-depth investigation of the parallel program, Brazil's influential Commission for Congressional Investigation (CPI) actually proposed the prohibition of IAEA inspection on Brazilian nuclear fa-

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[3] "Development of Solimoes Nuclear Project Detailed," JPRS-TND-91-001, *Latin America*, January 4, 1991, p. 15.

[4] "Angra II Projected for Completion in 1996," JPRS-TND-91-001, *Latin America*, January 1991, p. 15.

cilities. More important, government policies can change for the worse, and we need to prepare for it.

BRAZIL'S SPACE LAUNCH PROGRAM

The organization in charge of developing the Brazilian space launch program is the Institute for Space Activities (IAE). It is an institute within and controlled by the Centre for Aerospace Technology (CTA), which is operated by the Brazilian air force.[5] The connection between the space launch program and the military is apparent. Brazil is developing a four-stage solid-fuel satellite launch vehicle (Veiculo Lancador de Satellites or VLS), which is based on the sounding rocket program of Sonda (see Table 2.2). Sonda is also the basis of both the MB/EE and SS series of tactical ballistic missiles. Two firms are in charge of developing them: Avibras and Orbita. Avibras was formed in 1961 by former CTA engineers, and Orbita was formed in 1987. These missile programs are currently on hold.[6] It is not too late for Brazil to change the course of these programs.

Table 2.2

Brazil's Space Launch Vehicle and Reported Ballistic Missile Programs

Program	Derivative of	Propellant	Range (km)	Payload (kg)
VLS	Sonda	Solid	LEO	160
MB/EE-150, 350, 600, and 1000; by Orbita	Sonda	Solid	150–1000	Up to 500
SS-300 and 1000; by Avibras	Sonda	Solid	300–1000	Up to 1000

[5]For a review of Brazil's space launch program, see Clifford Graham, "The Brazilian Space Programme—An Overview," *Space Policy*, February 1991, pp. 72–76; and Scott D. Tollefson, *Brazil, The United States, and the Missile Technology Control Regime*, NPS-56-90-006, Naval Postgraduate School, Monterey, California, March 1990.

[6]Avibras filed for bankruptcy in January 1990 and placed all its programs on hold. Scott Tollefson also noted that "Orbita is virtually defunct, with no manufacturing, products, or sales, and little, if any actual research and development." (Tollefson, *Brazil, The United States, and the Missile Technology Control Regime*, op. cit., pp. 42–49.) Avibras reemerged from bankruptcy in 1992. (Charles Bickers, "Avibras Escapes Bankruptcy," *Jane's Defense Weekly*, April 11, 1992, p. 609.)

Brazil has already applied the know-how and components of Sonda sounding rockets to the production of battlefield rockets, the SS-07, SS-40, and SS-60.[7] Moreover, Avibras' ASTRO (Artillery Saturation Rocket System) developed for the Brazilian army and the export market is actually a multiple launcher for SS-30s, SS-40s, and SS-60s. Both the launchers and the rockets have been sold to Iraq, Libya, and Saudi Arabia since the mid-1980s. Certainly Brazilians could continue to transfer both technologies and, whenever possible, components from sounding rocket and space launcher programs to military ballistic missile programs. In fact, Major General Piva, former head of CTA, said "It is obvious that if we have a satellite launcher rocket it is relatively easy, although not as easy as some may think, to transform this launcher rocket into a ballistic missile."[8]

The space launch program was established in 1977. Problems both technical and nontechnical have placed the program well behind schedule. In December 1985, a one-third scale test model of the VLS was destroyed in flight after some of the engines failed to fire. Sonda IV also had an unsuccessful flight test in 1987, when its first two stages failed to separate due to an on-board computer problem.[9] MTCR also poses problems for Brazil in having Sonda's components such as the two Miniature Inertial Digital Altitude Systems repaired in other countries and in having some key items such as the hardened metal casings for rockets imported.[10] Since both the space launcher and the ballistic missile programs shown in Table 2.2 are facing technical and financial difficulties, a scaledown or even cancellation of these programs is a distinct possibility. One can no longer argue that Brazil's space launcher and missile development is inevitable and that the United States might as well help in order to maintain influence.

PROFITABILITY MEASURES

We will measure the profitability of a venture in three ways. First is the net present value (NPV). We use 1992 as the year of reference: all monies are in constant second quarter, 1992 U.S. dollars (hereafter, simply 1992$) and are discounted to end of 1992. We assume

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[7]The number in the SS designation refers to the rocket's approximate maximum range in kilometers.

[8]FBIS-LAM-83-245, December 20, 1983, p. D1.

[9]Clifford Graham, "The Brazilian Space Programme—An Overview," op. cit., p. 75.

[10]Ibid. and "Rocket Casing Export to Brazil Approved by State Over DoD Protest," *Aerospace Daily*, September 24, 1990, p. 487A.

that the investments are made over a period of years in equal annual amounts. Similarly, net annual cash inflows (or simply net cash inflows), which are yearly revenues minus yearly expenses, are received in equal amounts over 15 years.[11] The required real rate of return after inflation and before tax[12] is assumed to be 10 percent. Other rates of return can be seen through internal rate of return, discussed below. The net present value of the venture is the sum of discounted net cash inflows minus discounted investments. If it is positive, the investment will earn a rate of return greater than the required rate.

The second measure is the internal rate of return (IRR). Given a stream of projected net cash flows, IRR is the annual rate of return that the investment will earn. For example, if the IRR is 10 percent and the investment is $100 million, the investor will earn back $100 million plus an annual rate of 10 percent on any unpaid balance of the investment over time.

The third measure is the fraction of investment recouped (FIR). For example, let the investments discounted to year 1992 at 10 percent be added up to $100 million, which is the present value of investments. Let the present value of net cash flows be $40 million. Then, FIR is 40 percent. In other words, only 40 percent of investment earns a 10 percent annual return. The remaining 60 percent is totally lost: not only is no interest earned on the $60 million, none of the $60 million principal is recovered. On the other hand, if the present value of net cash flows amounts to $200 million, the FIR is 2. The venture is earning at the required rate as if the investment were twice as large.

We introduce FIR because when IRR is negative in some of our cases, FIR gives a more intuitive interpretation than IRR. For example, in the case where the present value of investments is $100 million, a negative IRR means that the net cash inflows are insufficient to return even the $100 million principal, not to mention earning any interest on it. Under such circumstances, while the magnitude of IRR is hard to interpret, the FIR tells us what fraction of the investments will earn the required rate of return. On the other hand, FIR is less

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[11]In other words, we assume that a space launch investment will generate 15 years of revenues and net cash inflows and will have no residual value afterward. With rapid improvements in launcher technology, design, production, and processing, an investment made 15 years ago would have little value left. New investment would have to be made to remain competitive.

[12]We use a before-tax rate here for two reasons. First, many space launch ventures are funded by governments, and no taxes need to be paid. Second, our investment and net cash flows are both before-tax estimates, and we are interested in the benefits to countries, not corporations.

useful than IRR when IRR is positive. Whether IRR is positive or negative, NPV is always useful.

We call a venture profitable when it will earn the required rate of return or more. Thus, a profitable venture is when NPV is no less than zero, IRR is no less than the required rate of return, or FIR is no less than 100 percent.

THE ECONOMICS OF BRAZIL'S SPACE LAUNCH VENTURE

Can Brazil recoup its space launch investment from the space launch business? Our economic analysis follows steps shown in Figure 2.1. First, what part of the small launcher market worldwide is likely to be captured by Brazil?[13] Second, what is the investment needed to develop a small launcher capability? Third, how profitable or unprofitable is Brazil's venture in small launchers? Fourth, if Brazil expands into the regular launch market, what is Brazil's market share there? Fifth, what is the additional investment needed to develop a regular launcher? Sixth, how profitable is Brazil's venture in small and regular launch markets?

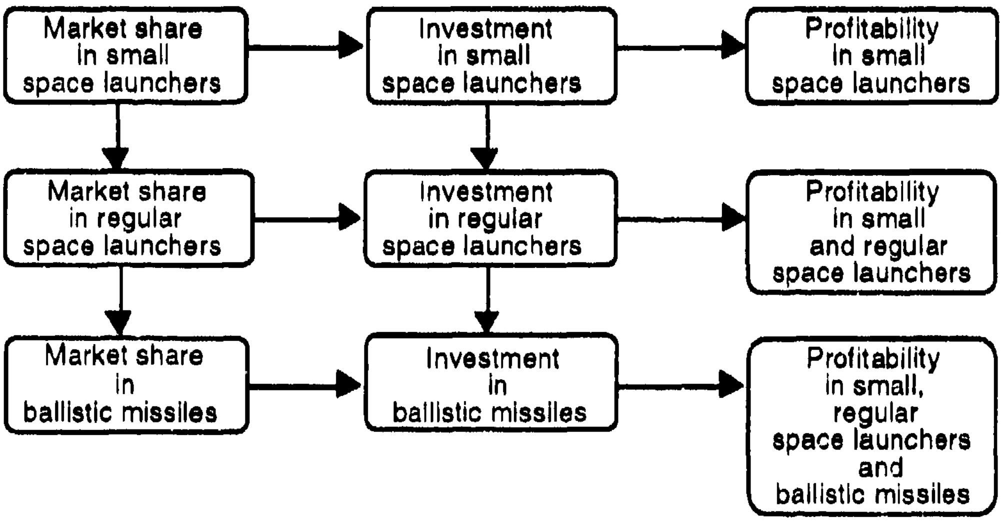

Figure 2.1—Approach to Estimate the Profitability of a Country's Space Launch and Ballistic Missile Business

[13]In this report, we classify launchers with a delivery capability of 6000 lbs or less to low earth orbit (LEO, an altitude of 100 nautical miles) as small launchers. Regular launchers are those that can deliver more than 6000 lbs to LEO.

Following an economic analysis on the profitability of a space launch business, we will estimate the profitability of Brazil's overall space launch and ballistic missile business. To do that, we will also need to determine Brazil's investment in ballistic missiles and their domestic and export market potential.

We will examine one important development strategy, namely, small launchers plus ballistic missiles but no regular launchers. Finally, we will discuss the distinct possibility that Brazil's space launchers could be less reliable than those of its major competitors. We will estimate how unreliability affects profitability.

Market Share in Small Launchers

The Brazilian VLSs, if they ever come to market, will initially have a lift capability of only about 350 lbs (160 kg) to low earth orbit (LEO) and, even with upgrades, will probably be in the same class as the American Pegasus, which can lift 1100 lbs to LEO. Such a capability is especially suitable for launching LEO lightsats.[14] We need to consider several points before determining Brazil's potential share of the market.

First, most of the U.S. lightsats currently being launched by small launchers are U.S. government payloads for the Air Force, Navy, DARPA, SDIO, and NASA, and U.S. government payloads are off-limits to foreign launch providers. Although the National Space Policy Directive issued in September 1990 sets the goal of a "free and fair" space launch market in ten years, this goal should aim at dealings with consortia or nations, such as the European Space Agency (ESA) and Japan, that have attained technological sophistication in space launches as well as other high-tech endeavors. It would be a mistake for the United States to offer government payloads to countries whose primary goal is to use space launch development as a cover for getting technology for military ballistic missile applications.

Second, the number of lightsats that were open for international competition during 1988–1991 was at most eight per year.[15] The Department of Transportation made worldwide "traditional" and "modi-

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[14]Lightsats are defined here as satellites weighing no more than 1000 lbs. Heavier satellites are called "regular" satellites.

[15]We counted 24 non-U.S. government lightsats worldwide during the three-year period 1989–1991, or an average of eight per year. Many were launched by their own countries' launchers. Moreover, 7 of the 24 weighed less than 50 lbs each and are most economically delivered to orbit as secondary payloads on regular launchers instead of small launchers.

fied" estimates for commercial payloads for the period 1991–2000. The traditional estimate was based on "identifiable, firm scheduled" payloads, while the modified estimate also included "planned proposals" and postulated "further growth for each of several identifiable types of payloads."[16] The modified estimate of payloads is about twice the traditional estimate. The traditional estimate includes our upward adjustment of the artificially low figure for the second half of the decade. The original estimate was low simply because firm commitments are often not made more than five years in advance. We used *a fortiori* the modified estimate, which amounts to 56 payloads per year in 1995–2000 and contains all payloads possibly pertaining to LEO lightsats, composed of 25 for communications, 5 for remote sensing, 15 for microgravity, and 11 for scientific experiment and other purposes.[17] This estimate represents a sevenfold increase over the actual demand of only 8 payloads per year during 1989–1991 and is likely to have included many speculative proposals of lightsats that will not materialize. The actual number is likely to be less than half our estimate, but we do not want to underestimate a country's sales and profit potential. Demand beyond year 2000 is highly uncertain, and we assume that it will continue to be 56 per year.[18]

Many of these payloads, however, will not be launched by small launchers, the area in which Brazil will be competing. Take Motorola's Iridium system as an example. It is the most promising candidate for greatly expanded use of LEO lightsats and is included in the projection. Small launchers are likely to be used for Iridium replacements, say one launcher per month. The initial 77 satellites, however, will probably be more economically launched by regular launchers. For example, they may be launched, several at a time, by Delta- or Atlas-class launchers. Moreover, the number of Iridium-

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[16]Office of Commercial Space Transportation, Department of Transportation, *Projection of Commercial Space Activity: Likely Scenarios for Commercial Operations Between 1991 and 2000*, October 1,1990.

[17]There is a possibility that some of the communications satellites at LEO would be replaced by lightsats in geosynchronous orbit (GSO), which can still be launched by the larger small launchers. We assume that the total number of communications satellites launchable to LEO or GSO by small launchers to be 25 per year. In a more recent study prepared for the Department of Transportation, both the average number of LEO communications satellites and the average number of LEO satellites of any kind to be launched per year during 1993–2005 are estimated at only about half the projections used in this report. The average was taken over projections made by 43 industry, academic, and government experts. (*The Future of the Commercial Space Launch Market: 1993 2005*, Decision Science Consortium, Inc. and Berner, Lanphier, and Associates, Inc., May 1991, p. 30.)

[18]Ibid. This is higher than a more recent projection of up to 33 LEO satellites per year during the period 2000–2005.

type systems could be limited by the scarce resource of the electromagnetic spectrum, especially in the popular UHF L and neighboring bands for which these concepts are designed. Both regulatory and political factors could also lead to delay and further limitation. LEO lightsats using higher and more available frequency bands would have a narrower beam for both downlinks and uplinks and would need more expensive ground equipment to track them. Another factor in reducing the demand of small launchers is the practice known as "hitchhiking." U.S. space shuttles, Ariane, Delta, Atlas, and other launchers have all been used to carry small payloads when they have extra space available.[19] They typically charge a price that is difficult for a small launcher to compete with.

We assume that half of the aforementioned 56 satellites per year will be launched by regular launchers and shuttles; the remaining half will result in 28 small launches per year. Table 2.3 and Figure 2.2 show the key competitors in the small launcher market and a possible market share breakdown in the late 1990s. With Orbital Sciences (the manufacturer of the Pegasus and Taurus launch vehicles) and other current and potential competitors, it would be a heroic feat for Brazil to capture four launches per year.[20]

It is unlikely that there is a supply shortage. When Brazil is ready to enter the market in the latter half of the 1990s, the United States alone could have the capability to supply all 28 small launches per year. This does not include the possibility that surplus missiles can be economically converted to small space launchers. These surplus

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[19]For example, the University of Surrey launched two small satellites as hitchhikers on an Ariane 4 launch. "Britain Weighs Lightsat Options," *Space Business News*, February 4, 1991, p. 6. The Ariane Structure for Auxiliary Payloads is a device that can be fitted into Ariane 4 to place up to 200 kilograms of satellites into orbit. Peter de Selding, "Europe's Launcher Availability Stalls Lightsat Development," *Space News*, August 17–23, 1992, p. 6. Since most of the launch cost has already been recovered from the primary larger satellite, Arianespace can charge a very low price for launching these hitchhiker or secondary payloads. It would be difficult for small launchers to compete.

[20]This includes the domestic demand of 0.5 to 1 small launch per year on the average. Only one small satellite has been placed in orbit for Brazil. It was the Microsat 2, an amateur radio satellite. Since it weighed only 12 kg, future satellites of the same kind will continue to be delivered least expensively as a secondary payload on regular launchers. They are unlikely to be delivered by small launchers. Brazil also had a plan to place two data-collection satellites (253 lbs each) in orbit during 1989 and 1991 and two remote-sensing satellites (374 lbs each) in low earth orbit in 1993 or shortly thereafter. (Graham, "The Brazilian Space Programme—An Overview," op. cit., p. 75.) In spite of the satellite program's delay, Brazil's small launchers are unlikely to be ready in time to launch them. Future satellites of similar kinds could be launched by Brazil's small launchers. Two to four small satellites in four years translates into 0.5 to 1 small launch per year.

missiles are a result of the Strategic Arms Reduction Treaty (START) and other arms-reduction agreements.[21] Moreover, it would only take a few years for major launch suppliers such as Arianespace to start or greatly expand their capabilities. Any supply shortfall, if it arises at all, will disappear quickly.

One does not have to accept wholly our market share projection shown in Table 2.3 and Figure 2.2 in order to accept that Brazil's share will be unlikely to much exceed four launches. In other words, it would be difficult for anyone to develop a credible scenario in which Brazil's market share greatly exceeds four launches per year. Moreover, Brazil's launch reliability could be lower than that of its major competitors.[22] Since a failed launch could destroy a satellite (typically at least as expensive as the launcher) and disrupt the services of the satellite system, any reliability problems could eliminate Brazil completely from the launch market. We will discuss this case in the subsection below on our adjustment for lower launch reliability. For now, we assume that Brazil could attain the same reliability as others.

We estimate Brazil's revenues to be about $20 million per year.[23] Brazil could make additional investment to increase lift capability and increase the launch revenues. We will discuss two excursion cases in the upcoming subsection on profitability in the small launcher business. A major portion of the revenues will be used for labor and material in launcher production and launch processing. Only a small fraction will be available for profit and for amortization of past investments. What is the size of that fraction? Ideally, our determination should be based on data from small launcher providers

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[21]The United States and CIS will retire some 2000 missiles under START. (Andrew Lawler, "Treaty Reignites Missile Use Issue," *Space News*, August 5–18, 1991.) Agreements signed after 1991 will increase the number even more. On the other hand, some have argued that converting these missiles will cost more than using new space launchers. (From an analysis sent to Dennis Granato, Offensive and Space Systems, Office of the Director of Defense Research and Engineering, from David Thompson, Orbital Sciences Corporation, on February 1, 1991.)

[22]India had only three successes in its first seven space launches. Brazil could fare the same.

[23]The Pegasus launch price in 1990$ was from $9.5 to $12.1 million. (Edward Kolcum, "NASA, Pentagon Chart Ambitious Unmanned Launch Vehicle Program," *Aviation Week & Space Technology*, March 16, 1992, p. 131.) We translated it to $10 to $13 million in 1992$. The Pegasus XL, to be available in 1993, has a capacity of 960 lbs to LEO, or $10,400 to $13,500 per pound. Since the Brazilian VLS will carry 350 lbs, even using the higher figure will lead to only $4.7 million per launch. We round the number to $5 million per VLS launch. With four launches per year, the revenue amounts to $20 million.

such as Orbital Sciences Corporation. These providers, however, have only a short operating history, and their revenues and profits have not yet stabilized. Instead, we will base our determination on the three major providers of regular launchers: McDonnell Douglas, General Dynamics, and Martin Marietta. They, however, do not segregate depreciation, revenue, and other items associated with their

Table 2.3

Small Launch Providers

Nation	Launcher	Availability	Capacity to LEO (in pounds)	Possible Market Share (28 annual launches)
United States	Pegasus	1990	810	
	Pegasus XL	1993	960	
	Taurus	1993	3400	
	Scout I/II	1960s/early 1990s	570–1100	9
Japan	MU-311S	1971	1400–1800	
	J-1	1994	2000	2
China	Long March 2C	1973	2800	3[a]
	Long March 1D	1992	660	
India	SLV,ASLV,PSLV	1980–1990	80–2200	2
CIS	COSMOS	1992	1000	
	START	Mid-1990s	300	2
ESA/Sweden	Mariane	Early 1990s	4000	4[b]
Israel	Shavit	1992	400	2
Brazil	VLS	Latter 1990s	350	4

SOURCES: Data in the first four columns, except for Israel, were selected and updated by the author from a database of Karen Poniatowski, "Compendium of Small Class ELV Capabilities, Costs and Constraints," NASA, Undated. Data on Pegasus and Pegasus XL are from Edward Kolcum, "NASA, Pentagon Chart Ambitious Unmanned Launch Vehicle Program," *Aviation Week and Space Technology*, March 16, 1992, p. 131. Data on Taurus are from "Rocket Research to Unveil Small Upper Stage," *Space Business News*, August 19, 1991, p. 8. Data on Shavit are from "Israel Eyes U.S. Launch Market," *Space News*, August 26–September 8, 1991, p. 2.

[a]Several contracts for use of the two launchers have been signed. We assume that the combined launch rate per year is three.

[b]A conceptual vehicle, Mariane, is being studied; it would be developed by the European Space Agency (ESA), marketed by Arianespace, and launched from Sweden. ESA might, however, develop its own small launcher and launch it from Kourou instead. Arianespace has also shown interest in marketing the Pegasus launchers in the international market. This row of the table is used to represent these three and other similar possibilities.

launch businesses from those of other lines of business. The best we can do is to base our estimate on the corporate earnings and cash flows of the three companies. We found that during 1987–1989, annual before-tax earnings, plus depreciation, averaged 6.9 percent, 8.6 percent, and 11.2 percent of revenues for McDonnell Douglas, General Dynamics, and Martin Marietta respectively.[24]

Allowing for the possibility that the launch business could be different, and wanting to be very conservative, we chose a fraction that is about three times as large. In other words, we assume that the net annual cash inflows will be 30 percent of revenues.[25] The net annual cash inflows or simply net cash inflows are defined as yearly cash flows available for profit and for amortization of investments, and they are net of cost of goods sold and yearly expenses (except depreciation). In short, net cash inflows are the monies left after pay-

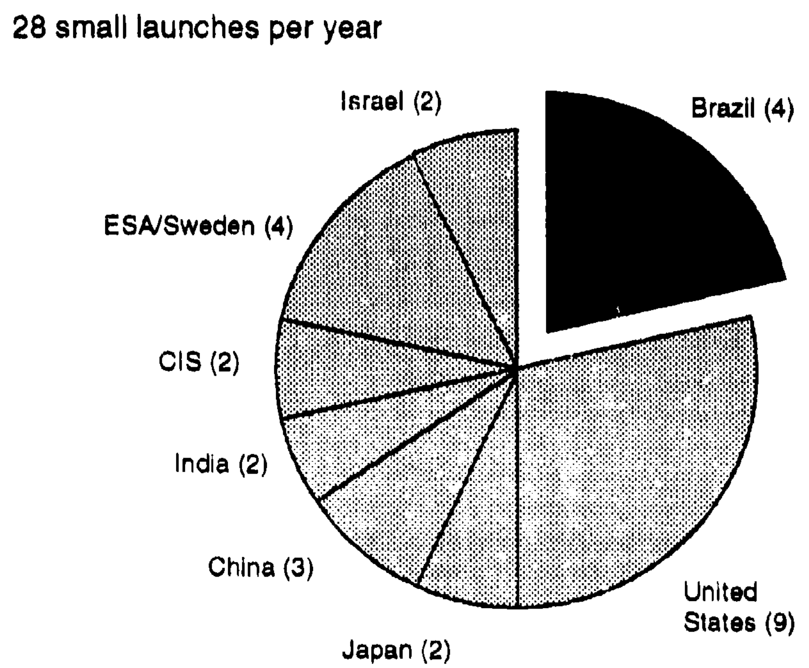

Figure 2.2—Projected Market Shares in Small Commercial Launches

[24]The estimates were derived from data contained in the companies' 1989 annual reports.

[25]The net cash inflows are after the paying of the licensing fees, if any, to the technology providers. On the other hand, these net cash flows are before taxes because taxes are part of the investment returns to the government.

ing for the current expenses of producing the launcher and making the launch. For the current case of small launchers, net cash inflows will be $6 million out of $20 million per year. To see whether these cash inflows are sufficient for Brazil to recoup its investments, we need to estimate next the costs of its space launch development.

Investment in Space Launch Program

Table 2.4 shows the projected costs of Brazil's space program. The development costs for the small space launch vehicle, VLS, are projected to be $283 million by the year 1992. The costs for the Alcantara launch facility are projected to be about the same as the costs for the VLS. Thus, the total space launch investment by 1992 will be $566 million. The key questions are whether much of the project will be completed by 1992 and whether the eventual total costs will greatly exceed $566 million. To help answer them, we will examine the costs of recent launch projects in other countries: Australia's Cape York launch venture, the U.S. launch industry's modernization of its manufacturing and processing facilities, and Europe's small launcher plan.

The proposed Cape York project is estimated to cost $500 million, or about twice the Alcantara cost.[26] The former is, however, intended

Table 2.4

Brazil's Investment in Space Launch Development

Project	Projected Expenses, 1982–1992[a]	Projected Expenses After 1992
VLS	$283 million	$32 million
Alcantara launch facility	$283 million	$57 million
Total	$566 million	$89 million

[a]From Clifford Graham, "The Brazilian Space Programme—An Overview," *Space Policy*, February 1991, p. 75. The dollar year was not specified there. Given the publication year of 1991, we assume that either 1990 or 1991 was used. Since the inflation rate was low in those years, we have made no adjustment in changing the dollars to 1992 dollars. The GNP Implicit Price Deflator changed from 1990 and 1991 to the first quarter of 1992 by 2 percent and 6 percent respectively.

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[26]In fact, an Australian newspaper reported a higher cost of $826 million for the Cape York project. Another source reported a range of $500 million to $1 billion. (Frank Sietzen, Jr., *World Guide to Commercial Launch Vehicles*, Pasha Publications Inc., Arlington, Virginia, 1991, p. 18.)

for regular launchers. The costs of gantries and processing facilities for Brazil's smaller space launch vehicles should be lower. Lower labor costs could be another factor in the cost difference. There is also the possibility that Brazil has simply underestimated the eventual cost. However, we use the figure of $283 million for Brazil's launch site investment for small launchers.

In addition to launch facilities, Brazil needs launcher manufacturing facilities.[27] In recent years, the U.S. launch industry has invested over $600 million in private funds in launch manufacturing and processing facilities for Atlas, Delta, Pegasus, and others.[28] Brazil's cost should be considerably lower, because it does not need to support multiple classes of launchers. We will use the cost of $283 million in Table 2.4 as Brazil's investment in VLS manufacturing facilities. This is consistent with recent U.S. experience, considering (1) the size of investments made separately by General Dynamics, McDonnell Douglas, and Orbital Sciences for their own launchers, (2) some of the U.S. investments being made for just upgrading facilities, as opposed to procuring them from the ground up, and (3) the differences in class and design of Brazil's VLS from Atlas, Delta, and Pegasus. Finally, the French company Aerospatiale estimated that the development of a European small launcher would cost $550 million.[29] This figure is very close to the Brazilian figure of $566 million.[30] Thus it is reasonable to assume that Brazil's total investment for small space launchers will be $566 million.[31] As to future investment for small launch-

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[27]Brazil is planning to use the Pegasus to launch its first domestically produced, data-collecting satellite. The former Soviet Union did propose a transfer of technology and the possible launch from the Alcantara launch center. Brazil did not accept the offer because the Soviets could not meet the launch deadline. "Government to Choose Foreign Satellite Launcher," FBIS-LAT-91-046, *South America*, March 8, 1991, p. 24. On the other hand, Brazil seems to use the award of a launch contract as a lure to secure launch technology. At the same time, Brazil does not appear to have planned to use foreign launchers for all of its launch needs or to suspend the VLS program, as Argentina has done with its CONDOR II medium-range ballistic missile program.

[28]*COMSTAC Innovation and Technology Working Group, FY 1990 Final Report*, a report to the Commercial Space Transportation Advisory Committee (COMSTAC), October 18, 1990, pp. 3 and 6.

[29]Peter de Selding, "Europe's Small Launcher Still an Idea," *Space News*, July 6–19, 1992, p. 6.

[30]Europeans can, however, take advantage of their know-how and infrastructure in Ariane development. Brazil, without a similar base, might have to spend much more to develop its small launcher.

[31]One could argue that since a portion of the investment has been made in earlier years, the same discount rate should be used to bring the stream of past investments to our reference year of 1992. Because the inflation rates in the United States since 1982 have been much lower than our reference discount rate of 10 percent, bringing past

ers, we first subtract the actual 1982–1988 expenses of $209 million (latest data available) from the total projected expenses of $566 million.[32] Then, the expenses after 1988 would be $357 million. If the small launcher program were on schedule, the post-1988 expenses of $357 million would have been made by 1992 at an average annual rate of $89 million. In reality, the small launcher program has slipped its schedule and is likely to have total expenses exceeding $566 million. Instead of additional investment, we assume that the budget has been stretched and only a year's worth of expenditure, $89 million, needs to be made after 1992.[33]

Profitability in the Small Launcher Business

Before determining profitability, we need to specify the streams of investments and revenues. Table 2.5 gives our assumptions. In the case of small launchers, we assume that there is only one more annual investment to be made. Future revenues will commence in 1997 and last for 15 years in equal annual constant-1992 dollar amounts.

Table 2.5

Assumptions on Starting Year and Duration of Future Investments and Revenues

	Future Investment		Future Revenues	
Program[a]	Starting Year	Duration in Years	Starting Year	Duration in Years
SSL	1992	1	1997	15
RSL	1993	9	2002	15
BM	1992	5	1997	15

[a]SSL = small space launcher; RSL = regular space launcher; BM = ballistic missile.

investments forward would result in a figure larger than $566 million. The breakdown of past investments by year is, however, not available, and in any case using $566 million would be more conservative.

[32]Graham, "The Brazilian Space Programme—An Overview," op. cit., p. 75.

[33]On the other hand, we do not consider it reasonable to assume that all expenditures have been made by 1992 and that no more investment will be needed after 1992, because we do not expect Brazil's small launcher program to be commercially viable until at least 1997. More realistically, additional investments will be made every year until at least 1997. The present value of future investments is likely to exceed the $89 million assumed in this report, if Brazil continues the program.

Figure 2.3 shows that the stream of $6 million annual net cash flows commencing in 1997 for 15 years amounts to a present value of only $31 million. With a total investment of $566 million, the FIR is only 6 percent. In other words, only 6 percent of Brazil's $566 million is earning a normal return, and the remaining 94 percent, or $535 million, will be totally lost.

One can, however, argue that the above calculation includes Brazil's past space launch investment, which is a sunk cost. Although one should not include past or sunk cost in determining whether to continue or terminate a project, the above calculation is of interest for two reasons. First, it tells, in retrospect, whether Brazil made a wise investment decision in space launches. The world has been littered with uneconomic projects kept alive by persistent underestimation from planners with a vested interest in doing so. Their argument is often the same: we should make one more investment because even if it will not let us recoup all the sunk cost, it will bring the project to fruition and allow us to recoup at least more than that last investment. The result is often a case of throwing good money after bad. On that score, the poor economic record of Brazil's nuclear program, discussed earlier, is discomfiting. Second, the calculation indicates that pursuit of similar space launch projects by group 2 countries, such as South Africa, is likely to be unprofitable, since they still have to make some of those initial investments that are already sunk costs to Brazil.

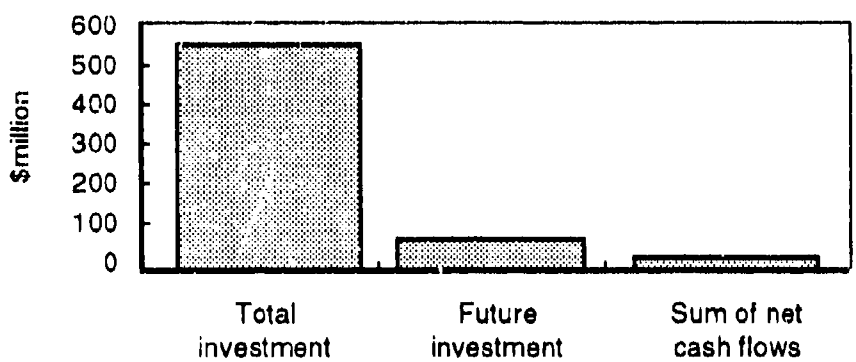

Figure 2.3—Brazil Cannot Recoup Investment from Small Launch Business

Ignoring sunk costs, will Brazil recoup at least its future investment of $89 million in small launchers? The annual net cash inflows of $6 million determined earlier will recoup only 35 percent of the future investment. The absolute dollar loss is $58 million out of the future investment of $89 million. This case is listed as case 1 in Tables 2.6 and 2.7.

In Table 2.7, the profitability in each case is given as a range. The lower bound corresponds to the situation that Brazil could not capture any of the space launch business. We will elaborate the lower bounds in all cases in the subsection below on adjusting for lower launch reliability.

The likelihood for a profitable small launcher program can be viewed from the perspective of a break-even analysis. Brazil has to capture 11 of the 28 small launches per year to break even on its investment. Looking at the unreasonable market shares shown in Figure 2.4, one would conclude that Brazil is highly unlikely to capture such a large market share, thus its small launcher program will not be profitable.

An assumption in the above case is that the VLS has the current design lift capability of 350 lbs to LEO. We provide two excursion cases here. First, VLS is upgraded to match the 960-lb lift capability of Pegasus XL. The revenue will increase from $20 million to $52 million, and the net cash inflows from $6 million to $15.6 million. We found that if the present value of the additional future investment is $50 million (over the $89 million), the dollar loss will remain at $58 million. Second, VLS is upgraded to match the 3400-lb capability of Taurus. The revenue would increase from $20 million to $84 million, and the net cash inflows from $6 million to $25.2 million. We found the same loss of $58 million, if the additional investment is $100 million. Considering the large increase from the original 350 lbs to 1100 or 3700 lbs, we believe the additional investment might well be $50 million, $100 million, or even more. In other words, upgrading the lift capacity to 960 or 3400 lbs would likely make the small space launcher venture incur even larger losses. In all three cases of 350, 960, and 3400 lbs, Brazil needs to continue to make new investments to remain competitive. If these new investments were included, the venture would be even more unprofitable. These losses might not be large in absolute dollar terms, but the fact that the space venture would produce a loss, instead of a profit, eliminates the economic development justification frequently used by Brazil and others for seeking foreign missile technology assistance.

Table 2.6

Key Input to Brazilian Cases

	Case			Future Investment (1992 $million before discounting)		Projected Annual Revenues (1992 $million before discounting)		
#	Launcher and/or Missile Involved[a]	License Foreign Missile Technology	Competition in Missile Export	Space Launcher	Ballistic Missile	Small Space Launcher	Regular Space Launcher	Ballistic Missile Sales
1	SSL	AY[b]	NR[c]	89	NR	0–20	NR	NR
2	SSL, RSL	Yes	NR	606	NR	0–20	0–100	NR
3	SSL, RSL	No	NR	1606	NR	0–20	0–100	NR
4	SSL, RSL, BM	Yes	Limited	606	200	0–20	0–100	340
5	SSL, RSL, BM	No	Limited	1606	200	0–20	0–100	340
6	SSL, RSL, BM	Yes	Intense	606	200	0–20	0–100	170
7	SSL, RSL, BM	No	Intense	1606	200	0–20	0–100	170
8	SSL, BM	AY	Limited	89	300	0–20	NR	340
9	SSL, BM	AY	Intense	89	300	0–20	NR	170

[a]The column indicates whether space launchers and/or ballistic missiles are involved in the developmental program. SSL = small space launcher, RSL = regular space launcher, and BM = ballistic missile.

[b]AY = assume yes. It is difficult to determine precisely what foreign technologies Brazil needs for SSL and BM and, if they could not be obtained, how much investment and time would be required for indigenous development. See the subsection below, "The Policy Implications of Space Launch Economics," for the potential impact of failure to obtain foreign assistance.

[c]NR = not relevant.

Table 2.7

Brazil's Space Launcher and Ballistic Missile Program Is Profitable Only in Cases 4 and 8

	Case			Profitability		
#	Launcher and/or Missile Involved[a]	License Foreign Missile Technology	Competition in Missile Export	Internal Rate of Return[d]	Fraction of Investment Recouped[e]	Net Present Value[f] (1992 $million)
1	SSL	AY[b]	NR[c]	-ve to 0%	0 to 35%	(89) to (58)
2	SSL, RSL	Yes	NR	-ve to -ve	0 to 30%	(420) to (292)
3	SSL, RSL	No	NR	-ve to -ve	0 to 16%	(1060) to (889)
4	SSL, RSL, BM	Yes	Limited	8 to 12%	90 to 112%	(59) to 69
5	SSL, RSL, BM	No	Limited	2 to 5%	57 to 71%	(523) to (352)
6	SSL, RSL, BM	Yes	Intense	-ve to 5%	45 to 67%	(323) to (195)
7	SSL, RSL, BM	No	Intense	-ve to -ve	29 to 43%	(875) to (704)
8	SSL, BM	AY	Limited	16 to 17%	156 to 165%	189 to 220
9	SSL, BM	AY	Intense	7 to 8%	78 to 87%	(75) to (44)

[a]The column indicates whether space launchers and/or ballistic missiles are involved in the developmental program. SSL = small space launcher, RSL regular space launcher, and BM = ballistic missile.

[b]AY = assume yes. It is difficult to determine precisely what foreign technologies Brazil needs for SSL and BM and, if they could not be obtained, how much investment and time would be required for indigenous development. See the subsection below, "The Policy Implication of Space Launch Economics," for the potential impact of failure to obtain foreign assistance.

[c]Not relevant.

[d]"-ve" denotes a negative internal rate of return. In other words, the principal of the investment will not be fully recouped and no interest will be earned.

[e]100 percent means that investment is expected to provide a 10 percent rate of return. 50 percent means only half of the investment is recouped.

[f]Numbers in parentheses are losses.

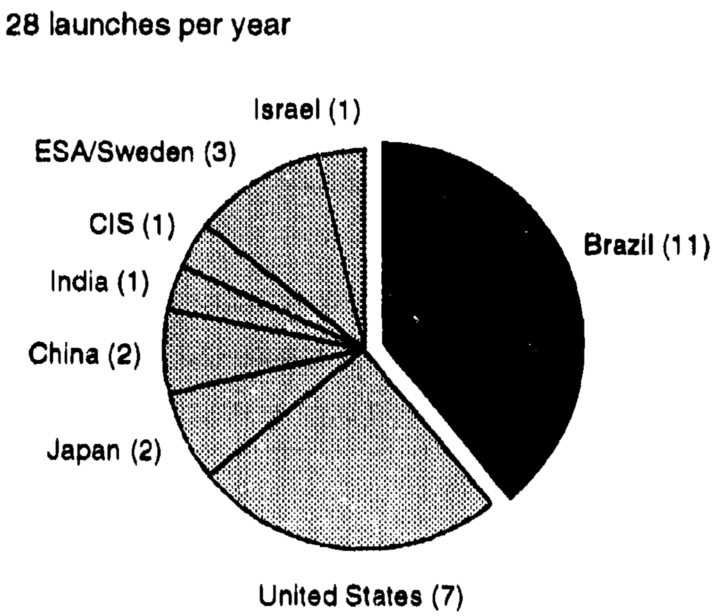

Figure 2.4—Brazil Needs an Unreasonably Large Share in Small Launches to Break Even

Moreover, even if small launcher demand turned out to be much higher than projected, the profit potential for Brazil would be limited by a burst of new entrants. Charles Bigot, chairman of Arianespace, said "We did not see anything [demand for small launchers], at least in the mid-term. Maybe in the year 2000 there will be something, but we need only three years' development time [to develop a small launcher]."[34] The ability of major launch providers to draw on their existing experience and resources and to enter the market quickly severely limits the upside profit potential for countries, like Brazil, that have little background in the launch business.

Demand for Commercial Regular Launchers

One could argue that Brazil's ultimate goal is to go beyond small launchers and compete with Ariane, Atlas, Delta, and others for traditional payloads, such as communications satellites. Unfortunately, the picture there is no brighter for Brazil because the added revenue cannot compensate for the added investment.

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[34]Peter de Selding, "Europe's Small Launcher Still an Idea," *Space News*, July 6–19, 1992, p. 6.

Table 2.8 shows four demand projections of regular commercial satellites that are expected to be launched by regular launchers worldwide. Geosynchronous communications satellites account for the bulk of the demand. Both the U.S. Department of Transportation and the U.S. Air Force gave similar projections of about 15 geostationary comsats a year. Earth observation and scientific satellites account for most of the remaining demand. The demand projections of NASA and Arianespace for regular commercial satellites range from 17 to 19 satellites per year. The number of launches is smaller than the number of satellites that need to be launched, because Ariane and Titan III launchers can each carry two payloads. We assume conservatively that the number of regular launchers needed for geosynchronous satellites is still as high as 18 per year. Recall that half of the 56 lightsats could be launched by regular launchers. Assuming four lightsats per launch, we add 7 more regular launches to the demand, for a total of 25 launches per year.

Table 2.8

Regular Satellite Demand for Regular Commercial Launchers Worldwide

Office/Study	Organization	Projected Period	Satellite Types	Average Number Per Year
Commercial Space Transportation	U.S. Dept of Transportation	1993–1999 2000–2005	Communications	14.5 14.8
Commercial Space Launch Policy Study	U.S. Air Force	NA	Communications	15
Space Flight	NASA	1990–1994	Not specified	17.6[a]
Arianespace	European Consortium	1993–2003	Communications, Earth observation and scientific	16.6–18.9[a]

SOURCES: Averages adopted or derived from Decision Science Consortium and Berner, Lanphier, and Associates, *The Future of the Commercial Space Launch Market: 1993–2005*, prepared for the U.S. Department of Transportation, May 1991, p. 10; Karen Poniatowski, *Expendable Launch Vehicle Capabilities, Constraints, and Costs*, NASA Office of Space Flight, March 1989; The Air Force Commercial Space Launch Policy Study, *Implications of Commercial Space Launch Policy Issues*, final briefing, July 1990; and an Arianespace chart (the two figures represent nominal and maximum estimates) quoted on page 5 of "Six Centuries in Space," a supplement to *Via Satellite*, September 1992.

[a]These figures might have included payloads other than geosynchronous communications satellites. If so, it would make the average number of 18 that we use in the report more optimistic and, therefore, more conservative.

Figure 2.5 shows a possible distribution of market shares among launch providers. Six of these launches are likely to be awarded to Ariane by its members. Moreover, Ariane has captured at least 50 percent of the commercial launch market and is committed to maintaining a 50 percent market share in the future. While a commitment does not guarantee that Ariane will meet its goal, its shortfall, if one occurs, is likely to be a result of the United States gaining back some of the market share or Japan, CIS, and China wresting more share than we assume here from Ariane. Moreover, there will continue to be an overcapacity in regular launches among Arianespace, the United States, and Japan, not even counting the West's launch demand to be met with Chinese or CIS launchers. Therefore, it is unlikely that Brazil will capture more than two regular launches per year.[35] Two launches translate into $100 million in revenues and $30 million in net cash flows per year.[36] Including the earlier $6 million for small launches, the total inflow per year is $36 million.

While major launch providers are likely to use their competitiveness or heavy government subsidies to maintain or gain market share, Brazil lacks the competitive edge to win additional launch orders. It also lacks the financial resources to win bids by continually subsidizing the launch business. In any case, winning orders through subsidies would not generate any additional profit for Brazil, although it could keep Brazil in the launch business.

Additional Investment for Entering the Regular Launcher Market

To increase Brazilian launcher lift capability from the currently designed VLS to heavier vehicles would require additional investments in development, manufacturing, and processing. We will discuss later how the indigenous development cost of a more powerful engine and a larger launcher could amount to $1 billion. It is financially very burdensome for Brazil and other countries to make such a sum available.

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[35]The demand includes Brazil's own domestic demand of about 1/4 regular launch per year. Two Brazilian satellites have been placed in orbits, both by Arianespace, on February 8, 1985, and March 28, 1986. Brazilsat 1 and 2 are geosynchronous satellites for domestic communications and have a design life of 8 years. (Mark Long, *World Satellite Almanac*, Howard W. Sams & Company, Indianapolis, Indiana, 1987, p. 264.) Future satellites of similar kind could generate an average demand of 1/4 regular launch per year.

[36]We assume that Brazil's regular launcher is in the Delta II class, which has a launch price of about $50 million.

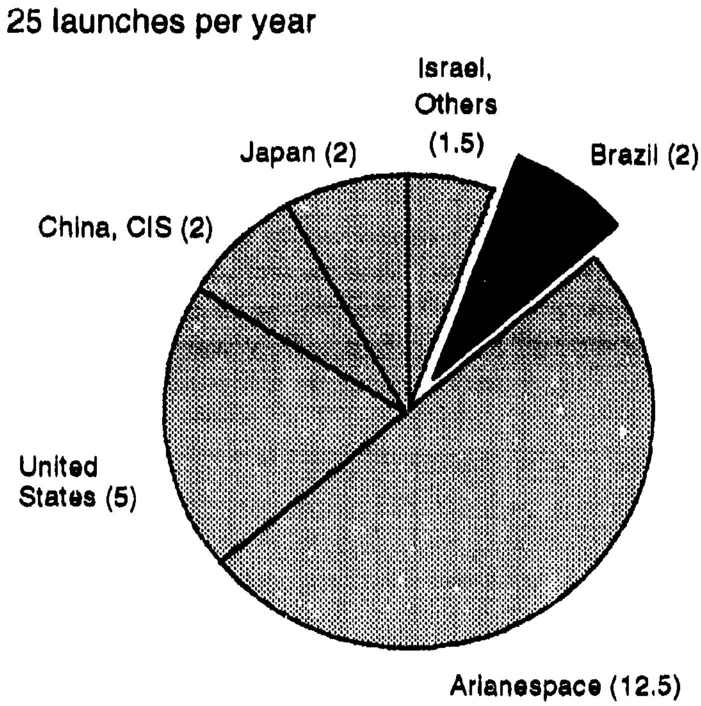

Figure 2.5—Projected Market Shares in Regular Commercial Launches

In this section, we optimistically assume that Brazil could license the larger engine and even the whole vehicle design from France, China, or other major launch providers.

Even then, based on the experience of the modernization programs of Delta and Atlas, we estimated that Brazil's marginal (or additional) cost to expand its manufacturing facilities for a regular launcher could be $300 million. Moreover, recall that the Cape York launch complex is estimated to cost at least $500 million, and that a Brazilian complex is likely to cost about the same. Since the Alcantara facility for small launchers is estimated to be costing $283 million, we assume the marginal cost for expanding it to launch regular satellites to be simply the difference of $500 and $283, or $217 million. Currently, Brazil's launch facilities can handle solid fuels only. Since liquid fuels are likely to be used in regular launchers, a portion of the funds would have to be used to establish the facilities for handling liquids. The marginal costs for both the manufacturing and launch facilities would be $517 million,[37] and total (past and future) investment costs, $1,083 million.

Profitability of Participating in Both Small and Regular Launcher Business

The net cash inflows of $36 million would account for only 14 percent of Brazil's total space launch investment, or a loss of $769 million. Excluding the sunk cost of $477 million as of the end of 1992, we calculated that the annual $36 million inflow would still represent only 30 percent of the future investment, or a loss of $292 million (shown in case 2 in Tables 2.6 and 2.7). Therefore, Brazil is unlikely to recoup its space launch investment from launch business.

Figure 2.6 shows the market share in small and regular launchers that Brazil needs to capture to break even. To capture six small launches per year, Brazil has to fare better than any other launch provider except the United States. Even more unlikely, Brazil has to capture more regular launches than any provider, including Arianespace and the United States.

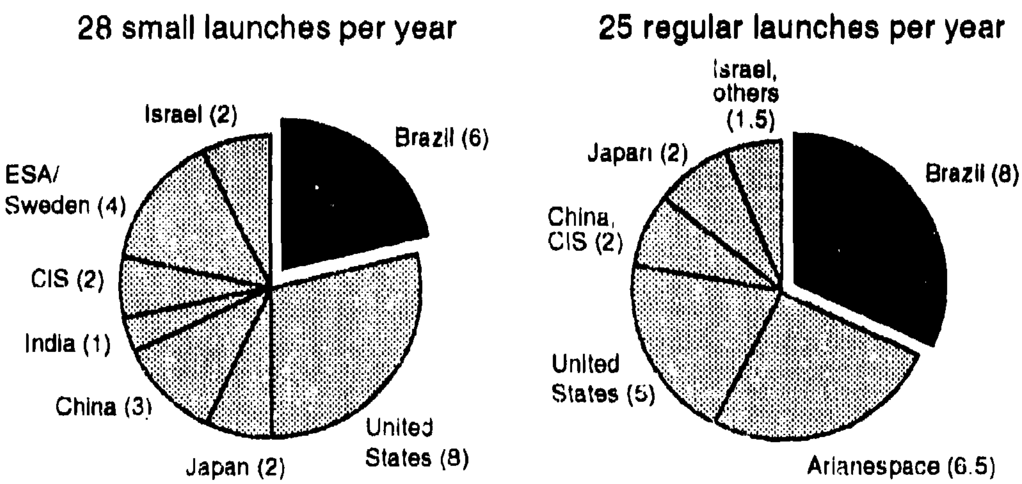

Figure 2.6—Brazil Needs an Unreasonably Large Share in Small and Regular Launches to Break Even

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[37]Our estimate is very close to the $500 million cited as the investment needed for a regular-size launch capability in Brazil. JPRS-TND-89-020, *Latin America*, October 26, 1989, p. 27.

Increasing Profitability by Leasing

Brazil has also considered recouping some of its investment by leasing the Alcantara launch center to foreign nations such as France and CIS. France would probably be a hard sell. Its national launch center at Kourou is already near the equator. Moreover, the complex there has been used to launch an average of 11 satellites per year for the past four years. It can support the aforementioned Ariane market share of 12.5 launches per year even without greatly expanding its capacity. If Arianespace decided to enter the small launcher market, it would find it cheaper to build upon the existing facilities and launch crew at Kourou than to use another site. Thus, France should not be interested in leasing Alcantara.

For the CIS, the attractions of Alcantara are near-equatorial launches and, perhaps even more important, political circumvention. But it is unlikely that the West would permit CIS launchers carrying western-technology-based satellites to be launched from more than one site. The United States should be even less enthusiastic about Brazilians using CIS or Chinese launchers than about Australians using them. The Cape York project plans to use foreign launchers only and does not plan to produce space launchers or ballistic missiles indigenously. The Australians could gain some experience in processing launches, but not much more. On the other hand, Brazilians could gain not only the same experience but also financial support for its space launch venture. Helping to keep the uneconomic venture alive contributes to missile proliferation, given the unstoppable transfer of missile know-how to Brazil's military ballistic missile exporting business. The U.S. trade negotiators are facing a difficult task in developing fair prices for nonmarket launch providers to charge. Until the CIS adopts a free market system, the West has to limit its launches of western satellites to a specific number, as has been done with the Chinese launches.

CRITICALITY OF FOREIGN ASSISTANCE TO BRAZIL'S LAUNCH PROGRAM

Current debate on the criticality of foreign assistance to emerging space launch development has focused on technological aspects. In this report we concentrate on the economic aspects, which are also important. The prospect of heavy economic losses would reduce considerably the civilian legitimacy of space launch ventures.

In the economic analysis thus far, we assumed that Brazil can license much of the needed launch technologies, including a new engine, from foreign launch providers such as France, CIS, and China to develop a regular (Delta II/Atlas II-class) space launcher. But even if it receives foreign help, we have found that Brazil's space launch venture would be unprofitable. The economics would be even worse if Brazil had to develop a liquid-fuel engine and other launcher technologies on its own.

Indigenous development would cost a lot more. Although Brazil might have invested about $500 million in SLV development and infrastructure, countries with which Brazil has to compete for regular launch business have invested more on each family of their regular launchers, such as Delta, Atlas, and Ariane. Moreover, all these countries will continue to make space launch investments that Brazil will have difficulty matching. Brazil has few competitive advantages to compensate for its lack of capital or domestic demand. Also, it is not feasible to minimize the investment cost by scaling up Brazil's currently developing space launcher, VLS, because an all-solid-fueled vehicle is uncompetitive for regular payloads and the capability upgrade from 350 lbs to, say, 11,000 lbs to low earth orbit is simply too great a step.

Brazil's least costly option to enter the regular launch market, other than licensing, would be the development of a narrower family of lighter launchers like Delta or Atlas, as opposed to a more extended family of launchers like Ariane 4. There is, however, a limit to how narrow a family can profitably be. The transferability of many of the launch components and technologies and the need to spread the high fixed investment and overhead over a large number of units places a smaller family at a disadvantage.

How much additional investment would be required for Brazil to develop indigenously a family of regular launchers? We first need to determine what lift range would be most suitable for a country with an emerging space launch program. One option would be a Delta II-class launcher, which has three stages and a lift capability of up to 11,000 lbs to LEO and 2000 lbs to GSO. The advantage of this option is the savings in not developing a cryogenic LOX-LH2 (liquid oxygen–liquid hydrogen) engine. Unfortunately, without it one may not be competitive at or above about 2500 lbs to GSO. Most major competitors in the regular launch business, however, already have such an engine: Centaur for Atlas, HM7B for Ariane 4, YF-73 for Long March CZ-3, and LE-5 for Japan's H-1.[38] Even McDonnell Douglas has con-

[38]One might argue that although China's largest current operational launcher, the two-stage CZ (Chang Zheng) 2E with an apogee kick motor, does not use a LOX-LH2

sidered developing a LOX-LH2 upper stage as a key element in increasing Delta's lift capability. India has budgeted $212 million for the development of such an engine.[39] Since typical GSO communications satellites are getting heavier and heavier, a country wanting to compete in the regular launch business seems to need a LOX-LH2 upper stage. We estimated (1) the developmental cost of a LOX-LH2 upper stage engine to be at least $200 million,[40] (2) the cost of another engine (such as a liquid bipropellant Rocketdyne RS-27A powering the Delta II-7925 launcher) for the first stage to be $300 million, and (3) the cost of the regular launcher development other than engines to be another $500 million.[41] Thus, the total development cost is about $1 billion.[42]

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engine, it can deliver 3300 lbs of payload to geosynchronous orbit at a very competitive price of $40 million. (Data from Steven J. Isakowitz, *International Reference Guide to Space Launch Systems*, American Institute of Aeronautics and Astronautics, Washington, D.C., 1991, p. 11.) The price charged by a nonmarket nation, however, has little relevance to the underlying cost structure, and it does not mean that Brazil with a similar launcher can compete in the world market. In any case, even China has found the need to have a LOX-LH2 engine, YF-73, available for use as a third stage in CZ-3. A more powerful engine, YF-75, which is based on YF-73, will be available by 1995.

[39]"France Offers Engine for Satellite Launch Vehicle," JPRS-TND-89-022, *Near East & South Asia*, November 29, 1989, p. 27.

[40]Since India has budgeted $212 million for the development of a LOX-LH2 engine, it is unlikely that the total developmental cost will be less than the budgeted amount. At one time, France also offered to sell an advanced rocket engine "at about five times the amount India has allocated for local development of the cryogenic engine to be used in the launch vehicle." ("France Offers Engine for Satellite Launch Vehicle," JPRS-TND-89-022, *Near East and South Asia*, November 29, 1989, p. 27.) Since the Indian budget for a liquid hydrogen and oxygen engine was $212 million, we assume that France is referring to its HM7B LOX-LH2 engine used as stage three in Ariane 4 and is asking $1 billion for licensing its technology. This is for the engine alone, not the full launcher. More recently, the Indians refused to cancel the $200 million deal between Glavkosmos and the Indian Space Research Agency, which involved the transfer of Russian cryogenic rocket technology, in spite of strong objections from the United States and other MTCR members. (*Space Business News*, April 27, 1992, p. 8, and JPRS-TND-92-018, *Near East and South Asia*, June 10, 1992, p. 8.)

[41]Alternatively, one could have only one engine development program instead of two. The choice may be a LOX-LH2 engine of a compromise size for different stages—perhaps using three engines for the first stage, two for the second, and one for the third. The large LOX-LH2 engines (LE-7 and Vulcain) for the first stage being developed by Japan and Arianespace are reported to have high development costs: $740 million and $1.3 billion, respectively. (Peter de Selding, "Advanced Rocket Engine Work Driven by Varying Agendas," *Space News*, March 11–17, 1991.) A country is likely to pay no less than $500 million for development of a LOX-LH2 of compromise size. Moreover, it is unclear whether the resulting vehicle is as competitive as that derived from a two-engine development program.

[42]This cost is in constant 1992 dollars before discounting. Table 2.5 shows that the starting year is 1993 and the duration of investments is 9 years. Recent cost data on vehicle development are on much larger launchers. Ariane 5 development is estimated at $3.5–$5 billion, including over $0.5 billion for a new launch pad and support facilities. (Congressional Budget Office, *Encouraging Private Investment in Space Activities*,

Of course, one should not ignore the technical feasibility of such a feat. For example, the Delta family has gone through a long series of progressions, starting from a 1960 version that could launch barely 100 lbs to LEO.[43] Using an additional investment of $1 billion for indigenous launch technology development, Brazil is expected to recoup only 11 percent of its total space launch investment or 16 percent of the future investment (excluding sunk cost).[44] The dollar loss would be $889 million of the future investment. Comparing this with the second case in Table 2.7, one finds that licensing missile technologies to Brazil helps it recoup 30 percent, instead of 16 percent, of its space launch investment, cutting its loss by $597 million (i.e., 889 – 292), as shown in Figure 2.7. Cutting losses in a space launch venture helps to make one's overall space launcher and ballistic missile program more viable and more likely to continue.

The MTCR wants simultaneously to avoid "imped[ing] national space programs" and "contribut[ing] to [a] nuclear weapons delivery system." MTCR members have held different views on the feasibility of accomplishing both aims. While the United States has restricted the transfer of space launch technologies, some European members, such as France, Germany, and Belgium, once believed that they could assist others' space launch programs without jeopardizing missile nonproliferation efforts. Our analysis in Section 3 will show the opposite. Yet, a group of companies from France, Germany, Belgium, and Sweden once agreed to sell Brazil the Viking liquid-fuel engine and other technologies for space launch development.[45] Another potentially serious problem is the oft-rumored agreement or negotiation between Brazil and China for the exchange of Brazilian conventional weapons or solid-fuel technology for Chinese liquid-fuel technology and guidance system assistance. Ironically, the more effective the

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February 1991, p. 23.) The development cost for a new U.S. heavy lift launch vehicle (HLLV) has been estimated at $10–15 billion. (Vincent Kiernan, "Air Force Seeks Outside Support For New Boosters," *Space News*, October 29–November 4, 1990, and Andrew Lawler, "Quayle Defers Action on New Launch System, Cost Plan," *Space News*, April 22–28, 1991.) Ariane 5 has a payload to LEO of 42,000 lbs, and the U.S. HLLV, up to 100,000 lbs. In contrast, Delta II has a capacity of only 11,000 lbs.

[43] McDonnell Douglas Corporation, *Delta II Commercial Spacecraft Users Manual*, July 1987, p. 2-14.

[44] For this case, where engine and other high-cost items are developed indigenously, we assume the annual cash inflows for profits and amortization are increased from 30 percent to 40 percent of revenues, because Brazil will not have to pay the license fees for using those items.

[45] Gary Milhollin and Gerard White, "The Brazilian Bomb," *The New Republic*, August 13, 1990, p. 10.

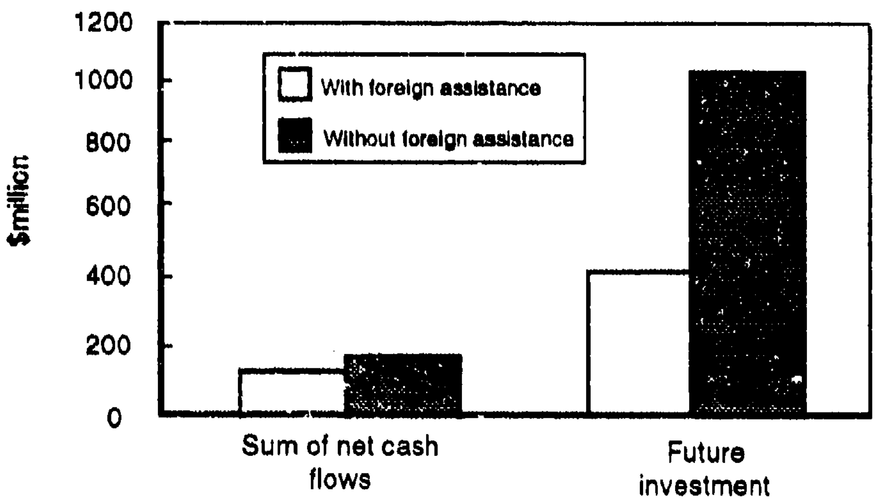

Figure 2.7—Brazil Cannot Recoup Investment from Small and Regular Launch Business

MTCR, the more pressure that persistent nations will put on the major launch-providing nations to supply space launch assistance, because space launch activities would be the only remaining cover for obtaining missile technology for military programs. On the other hand, if the launch providers continue to join forces in withholding missile assistance, the technical and financial burdens may significantly delay Brazil's space launch program and might well prompt it to reassess and halt its space launch program.

BRAZIL'S MISSILE EXPORT POTENTIAL

From the economic perspective, a country could pursue a space launch venture not because an indigenous capability was important, or because it expected to recoup all of its investment from launch business, but because it wanted to gain the know-how to improve the profitability of its ballistic missile export business. Table 2.9 shows our estimate of Brazil's recent missile exports, which amount to merely \$20–\$60 million per year or 0.06 to 0.18 percent of total exports.[46] Missile exports as a percentage of arms exports are 4 to 13 percent.

[46]Brazil's Avibras has exported ASTRO multiple rocket launch systems to Iraq, Saudi Arabia, and Libya. Brazil has delivered 78 ASTRO-II SS-30s during 1983–1989 and 20 ASTRO-II SS-60s during 1985–1989 to Iraq. (Tony Capaccio, "Iraq's Military Bankrolled By USSR, China, France," *Defense Week*, August 2[illegible] 1990, p. 16.) It aver-

Table 2.9

Brazil's Exports

Exports	Amount (constant 1992$)	As a Percentage of Total Exports
Historical		
Annual total exports (1983–1989)[a]	$33,000 million	100%
Annual arms exports[a] (1983–1989)	$450 million	1.4%
Annual missile exports (1983–1989)[b]	$20–$60 million	0.06–0.18%
Projected		
Annual missile exports (2000)[b]	$300 million	0.9%

[a]Derived from U.S. Arms Control and Disarmament Agency, *World Military Expenditures and Arms Transfer 1990*, p. 97.

[b]For ballistic missiles and rockets with range of 30 km or greater.

We now project Brazil's missile exports by year 2000. We assume that the CIS will not export Scuds or other missiles and that China and North Korea will continue to do so. If the CIS sells, the market share captured by Brazil will be less. First, we will estimate Brazil's missile sales in the Scud range of 300 km as well as a longer range of up to 1000 km. Many of the missile-aspiring nations (Algeria, Argentina, Cuba, Egypt, India, Indonesia, Iran, Iraq, Israel, Kuwait, Libya, North Korea, North Yemen, Pakistan, South Korea, Syria, and Taiwan) will not purchase many missiles from Brazil, because of (1) the preference for indigenous production, (2) the lack of financial resources for procurement, or (3) in the case of Iraq, the prohibition by United Nations Resolution 687. We estimated that the likely purchasers are Syria, Egypt, Iran, and Libya. We assume that Iran and Syria plan to have a missile force of a thousand missiles, consisting of

ages to about 15 systems per year. The prices for these transactions were not available. Based on (1) a typical load of 96 missiles, including reloads, for each ASTRO-II SS-30 system (*Jane's Armour and Artillery 1990-91*, p. 694) and (2) a systems price per missile of $13,000 for the U.S. Multiple Launch Rocket System M-26 (Ted Nicholas and Rita Rossi, *U.S. Weapon Systems Costs*, 1991, p. 4-17), we estimated the cost of an ASTRO-II system with 96 SS-30s to be $1.3 million. We assumed the cost of an ASTRO-II SS-60 system to be the same. Thus, the averaged annual revenues of ASTRO sales to Iraq amounted to $20 million. The actual prices charged by Brazil could be significantly higher, if there is a lack of competition. We will discuss the important distinction of "normal" profit and "undercutting" profit in the text shortly. Since the details of the sales to Saudi Arabia and Libya are unavailable, Brazil's total missile sales were probably between one to three times that to Iraq, or $20 to $60 million.

five hundred 300 km missiles and five hundred 1000 km missiles, while the missile forces of Egypt and Libya have half that number. The missile life is ten years. Considering the competition of China and North Korea, we projected optimistically that Brazil will capture half of the missile market in Libya and Syria and a third of the market in Iran and Egypt. The total number of missiles in the 300–1000 km range is 125. The price of each 300 km missile is assumed to be the same as a Scud, which costs $1 million. Since the guidance, warhead, and some other components of a 300 km missile and a 1000 km missile would be similar, the cost of a longer-range missile does not increase linearly with the range. We assume the price of a 1000 km missile to be $1.5 million. Thus, Brazil's missile exports in the 300–1000 km range would amount to $156 million per year.

Second, we will estimate Brazil's ASTRO rocket sales by year 2000. We assume sales will be at double the current mid-value, to $80 million. This is optimistic because Iraq, one of Brazil's largest arms customers, is unlikely to purchase as many arms in the future as it did in the 1980s, for a variety of reasons. The Iraq-Iran War during the 1980s boosted Iraq's arms needs. Brazilians are also troubled by the Iraqi default on debts for prior arms sales. Iraq's poor financial condition makes it ill-suited for arms purchases. In any case, the United Nations will continue to place severe restraints on Iraqi arms imports and replenishment. On the other hand, Brazil might find new customers outside the Middle East for its ASTRO rockets.[47]

Third, we assume that Brazil also succeeds in competing with China in the CSS-2 class (2600 km range for the version sold to Saudi Arabia) and manages to sell five missiles per year for $25 million. Brazil's missile sales in the above three classes amount to $261 million. We rounded Brazil's total missile exports to $300 million per year by the turn of the century. If competition is lacking, Brazil could charge a higher price and have a higher export volume. The total export sales could exceed even the optimistic figure of $300 million. We will discuss the "undercutting" profit shortly.

Sales of $300 million a year in missile exports amount to only 0.9 percent of total annual experts. On the other hand, considering that current arms exports amount to only $450 million a year, missile exports could be a significant fraction of Brazil's arms sales.

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[47]It was reported that India wanted to purchase ASTRO rockets. FBIS-LAT-89-101, *South America*, May 26, 1989, p. 39.

One adjustment should be made to the missile export figure of $300 million per year to arrive at the amount of export attributable to the space launcher and ballistic missile programs studied in this report. We have estimated that ASTRO rocket exports account for $80 million per year. Since ASTRO rockets are unguided, Brazil can compete in future ASTRO sales as it has in the past, even without technology transfer from parallel SLV and BM programs. On the other hand, these parallel programs could improve the propellants, structure, and other components of ASTROs and thus increase their sales. We assume that half of the ASTRO sales, or $40 million, is credited to these parallel programs and the other half is not. Subtracting the $40 million, we arrived at a figure of $260 million for missile exports attributable to the space launcher and ballistic missile programs. We estimated that missiles for Brazil's own military use could add about a third, or $80 million, for a total of $340 million.[48] Thus, the total revenue would be $460 million, including $20 million from small space launchers and $100 million from regular launchers.

What is the future cost to develop and produce these ballistic missiles? Brazil already uses some common facilities to produce missile components for space vehicles and ballistic missiles. Moreover, some of the investment has already been made by Orbita on the MB/EE-150, -350, -600 and -1000 ballistic missiles and by Avibras on the SS-300 and -1000 (see Table 2.2 for the ranges of these missiles). We therefore believe the future investment cost for ballistic missile development and manufacturing facilities to be about $200 million, or only a third of that for space launch vehicles. This brings the total future investment for space launchers and ballistic missiles to $806 million, if engine and other major technologies can be licensed. Otherwise, the future investment will be $1806 million.

Comparing the investment and cash inflows, we can state the following: if Brazil can obtain missile technologies inexpensively from foreign suppliers, and if it can exploit other countries' refraining from exporting missiles, it can have a profitable return on its missile investments as a whole. Table 2.7 shows that in case 4, Brazil's space launcher and ballistic missile program will have an NPV of $69 million or an IRR of 12 percent. On the other hand, if the United States, France, China, and others do not license missile technologies to Brazil and it is forced to pay for the expensive indigenous development, Brazil will have a negative NPV of $352 million (case 5 in Table 2.7)

[48]Thus, missile sales referred to in this report would include some rocket sales (15 percent of the dollar value of missile sales).

or an IRR of merely 5 percent. This analysis indicates that without foreign technology assistance, Brazil might forgo space launch development on economic, if not only on technical, grounds. Technology assistance turns a loss of $352 million into a gain of $69 million.

From a purely economic perspective, the best missile investment strategy for Brazil could be to forgo space launch development and concentrate on ballistic missile development with foreign technical assistance. Politically, this strategy would not be viable because the MTCR members clearly rule out assistance to Brazil's military ballistic missile programs.

Finally, without an indigenous launch program, Brazil can still perform scientific experiments in space, use satellites for many applications, and make satellites for others. With an oversupply of launch services from a diversity of countries, Brazil need not worry about having an assured supply of launch services, even with none of its own. Instead, it can take advantage of the low-priced launch services brought about by competition and oversupply.

DISTINGUISHING NORMAL AND UNDERCUTTING PROFITS

It is important to differentiate two kinds of profits that Brazil might earn in missile sales. The first kind is the "normal" profit, which would be earned if missile proliferation were not a concern and if Brazil were to win its profit by competition. Under such an environment, the United States and other MTCR members would be selling missiles with 300 km/500 kg or better capability to many of Brazil's potential customers. In fact, CIS had done just that in the past with the Scud-B. If these major providers were to compete with Brazil in the missile export market, it is very doubtful that Brazil's export profit would come anywhere near the profit normally associated with $300 million in sales, as projected above. After all, our estimate hinges critically on the assumption that the CIS will cease to export Scud missiles and its upgrades and that Brazil markets itself as one of three key suppliers (with China and North Korea) in filling the void. If the CIS continued to stay in the market, it would be hard for Brazil to compete in terms of price or performance. Obviously, the participation of the western countries would make the market that much tougher for Brazil. Therefore, the normal profit in missile exports for Brazil would be significantly lower than the profit we projected above.

We call the second kind of profit "undercutting" profit. This is a profit that is earned when other countries refrain from the missile export market because of proliferation concerns. It is undercutting because the seller receives a profit not by fair competition but by exploiting others' good intentions. Our projected sales and profits for Brazil described above already contain some of this undercutting element. On the other hand, it is quite conceivable that the sales and profits could be even higher if Brazil could fully exploit the situation. In 1988, China probably did that by acting as the only supplier of missiles in the 2600 km range to Saudi Arabia. The CSS-2 missile sales have been reported to be worth $1 to $3 billion.[49] In cases like this, the price could be many times the cost and involve an usually high profit. If Brazil and other countries complain that our nonproliferation measures are depriving them of such huge profit opportunities, we should point out that they are opportunities for undercutting profits that no one deserves.

In cases 6 and 7 in Table 2.7, we assumed that missile proliferation was not a concern and that Brazil had to compete with MTCR members and CIS for missile exports. Brazil could exclude foreign competition in its domestic missile markets. As to missile exports, the fierce competition and others' better missile performance could reduce Brazil's annual revenue of $260 million to a third of that or even more. Assuming domestic and export missile sales of $170 million, we estimate that Brazil would only recoup 67 percent of its investment in the license case and 43 percent in the no-license case. A license in technology could reduce Brazil's loss from $704 million to $195 million. Of course, the policy implication is not that we should compete with Brazil for missile export. Rather, these two cases show that if other countries did not refrain from competition for nonproliferation reasons, Brazil's space launch and missile venture would still be unprofitable. Therefore, our nonproliferation measures toward Brazil and equally toward other nations have not deprived these nations of any highly profitable opportunities.

AN ALTERNATIVE BRAZILIAN MISSILE DEVELOPMENT STRATEGY

Reviewing the first seven cases in Table 2.7, we found that the most uneconomic component of Brazil's launcher and missile program will be the development of regular-size space launchers. A viable economic alternative we found in this study would be for Brazil to forgo

[49] $1 billion was reported in "Arms for Sale," *Newsweek*, April 8, 1991, p. 25, and as much as $3 billion was reported in W. Seth Carus, *Ballistic Missiles in the Third World*, Praeger, New York, 1990, p. 18.

the regular launchers. Case 8 shows that Brazil could have much higher profitability or an IRR of 17 percent without regular launchers.[50] The NPV could be $220 million. One might further reason that the best economic strategy for Brazil is to terminate the space launch program completely and concentrate on ballistic missiles. Brazil would not, however, choose this route because the growing international push to control missiles would make it unable to obtain missile assistance in the absence of a space launch program.

Are there other reasons that Brazil might want to pursue regular launchers and to obtain foreign technologies, such as a liquid-fueled engine, for such a program? One reason might be that Brazil grossly overestimated the economic benefits of regular space launch business in particular and space launch business in general. Brazil made an even larger overestimation and suffered an even larger loss in its civilian nuclear program. A key objective of this section has been to correct this overestimation. Brazil's pursuit of regular launchers might also be influenced by the desire for self-sufficiency in launching its own geosynchronous satellites, and other noneconomic reasons described earlier. If Brazil can reduce its future investment by obtaining foreign missile technology assistance and can increase its sales by counting on others to refrain from missile export, its project with regular space launchers (case 4) could still be profitable, although case 4 is far less profitable than case 8 (without regular launchers).

ADJUSTMENT FOR LOWER LAUNCH RELIABILITY

High missile reliability is not easy to achieve. Launch failures still occur in major launch-providing countries with years of experience. Brazil's VLS, like other countries' space launchers, is a highly complicated piece of equipment. Jayme Boscov, VLS's project chief, said that this complexity is reflected in over 8000 meters of electrical wiring and 70,000 different components.[51] It has also been said about space launch vehicles in general that most of their thousands of parts must operate correctly the first time under extreme conditions of acceleration, vibration, and temperature.

[50]For case 8, we increase the future investment cost for ballistic missile development from $200 million to $300 million. In case 4, part of the $517 million investment for regular space launches would be useful for ballistic missile development and production. Without such an investment, we assume that $100 million more would be needed for ballistic missile projects.

[51]FBIS-LAT-89-156, *South America*, August 15, 1989, p. 30.

There is a distinct, or even likely, possibility that Brazil's launch reliability might be lower than that of its well-established competitors. If so, we need to adjust the profitability in Table 2.7 downward. Worse yet, Brazil might not capture any appreciable market share in small launchers or in regular launchers, despite its heavy investment.

Let us assume optimistically that Brazil will have made three launch attempts with its VLS by as early as 1997—each of which is likely to be either a launch test or a domestic payload carrier. We represent the possibilities by two scenarios. First, all three launches are successful. Brazil announces that it is ready to offer commercial services to foreign customers. Most optimistically, we assume that after only three successful launches, potential launch customers are confident that Brazil's launch reliability is as high as that of its competitors, including the United States, Japan, and France. All cases that we have discussed thus far have assumed this scenario. In the other scenario, there has been only one success in the first three launches. This was India's early space launch experience during 1979–1981. Then, customers would be concerned that Brazil would follow in the footsteps of India, which has only three successes in seven space launches with its SLV-3s and Augmented Satellite Launch Vehicles (ASLVs).

How long will it take before Brazil reaches even as low a reliability as 75 percent? As shown in Table 2.10, the U.S. experience with early small launchers (100 to 2000 lbs to LEO) during 1958–1966 was hardly encouraging.[52] It took an average of 57 flights and 6.3 years to reach an average reliability of 75 percent. We have shown earlier that even if Brazil could instantly achieve good launch reliability of, say, 85 percent, it would still get only about four launches per year. With a much lower reliability initially, Brazil would have to provide significant inducement in order to capture four launches per year. Brazil could pay for a sizable fraction of the launch insurance premium or offset the lower reliability by reducing price. We estimate the subsidies to be at least $100 million.[53] Moreover, it might take

[52]On the other hand, the international experience with early heavier launchers (660–9000 lbs to LEO) is better. It, however, still needs some subsidies during the initial four to eight launches. We do not make this a separate scenario, because it is approximately represented by the one in which no subsidy is needed at all.

[53]It takes an average of 57 flights to reach a cumulative reliability of 75 percent. Assume the competitors' reliability is as low as 85 percent. The number of successful flights, if launched by competitors, would be 48.45. At 75 percent reliability, it would take 64.6 flights to produce the same number of successful flights. In other words, there would be 7.6 additional flights. Assuming the payload and the launcher cost $5 million each, we get $76 million. Including some of the penalties for delay in satellite services, the total value would be at least $100 million.

Brazil about 14 years or until around year 2011 to reach 75 percent reliability. At the same time, many other launch providers, being technologically more sophisticated to begin with, are likely to become more competitive by gaining further experience and providing further investment. Under this scenario, the large subsidies and the long time to become competitive would likely force Brazil to make a decision in 1997 to not enter the international commercial launch market. Brazil could keep its launch program alive by insisting that domestic satellites be launched on its own launchers. The fact is that even these satellites are few in number and can be launched more cheaply by others. We represent this scenario in Table 2.7 by the lower bounds in the profitability column. For example, without capturing any profitable launches, Brazil would recoup zero percent of investment in cases 1 to 3, where only the profitability in space launch business is counted. In case 4, involving business in both space launchers and ballistic missiles, lacking a profitable space launch business turned a small gain into a small loss.

We also estimated the impact of lower launch reliability on the upper bounds of profitability in Table 2.7. Suppose Brazil achieves a reliability that is ten percentage points lower than that of its competitors. This is also a likely case, as discussed above. Even if customers were willing to use launchers of lower reliability, at the least they would demand that the expected loss of launcher and payload be reimbursed by Brazil or an insurance company. In either case, the subsidies or

Table 2.10

When Space Launchers Reached a Reliability of 75 Percent

Launcher	Years to Build Up Reliability Record	Pounds to LEO During Buildup Period	Number of Launchers	Number of Years from First Launch
Scout	1960–1966	130–315	44	6
Thor/Delta	1958–1965	100–1700	28	5.5
Atlas	1958–1966	500–2000	100	7.5
Titan	1964–1965	7900–9000	4	1
Ariane	1979–1984	4070–5690	8	5
Long March	1970–1976	660–7040	8	6.5[a]

[a]The data include those of CZ-1 (Chang Zheng), CZ-2A, CZ-2C and FB-1 (Feng Bao). Although FB-1 was not officially considered part of the Long March family, it might be similar to CZ-2s. It should be included in China's early launch record. If FB-1s were excluded, the number of launchers and years to reach 75 percent reliability would have been 4 and 5.5 years respectively.

insurance premiums would reduce the net cash inflows.[54] In Table 2.11, we show how the nine cases in Table 2.7 will be adjusted.[55] The lower reliability cuts the FIR by two-thirds in cases 1 and 2 and by half in case 3. Brazil's space launcher and ballistic missile program is only profitable in case 8, where regular space launchers are not pursued and most of other nations refrain from competing in the ballistic missile export market. As explained before, these profits are undercutting, instead of normal, profits. The United States and other suppliers have no obligation to help Brazil earn this kind of profit.

ROUNDING THE NUMBERS IN THE SUMMARY TABLE

Thus far, we have not rounded the numbers in our calculations and results so that the readers can trace our analysis more precisely. Since Table 2.11 summarizes the key output, we present the corresponding Table 2.12 with rounded numbers. We round the numbers in such a way that, for each entry, the range formed by the rounded numbers brackets those formed by the unrounded numbers. The numbers discussed in this report's summary came from Table 2.12.

DIFFICULTIES IN MAKING SPACE LAUNCH VENTURES PROFITABLE

Why is it difficult for an emerging national space launch program to be profitable? First, there is already an oversupply in launch services for the foreseeable future. Second, developing nations do not generate enough domestic demand to guarantee a demand floor. Since a satellite has an on-orbit life of several to ten years, the few satellites that a

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[54]Take case 2 as an example. We assume that the payload and the launcher cost the same. Then, a 10 percent lower reliability is equivalent to 20 percent lower value in the launcher. Since we assume in case 2 that the net cash flows are 30 percent of the launcher revenues, they are now only 10 percent (i.e., 30 percent – 20 percent) or only a third of the unadjusted cash flows. As shown in Table 2.11, the FIR is only 10 percent instead of 30 percent.

[55]However, we do not make any downward adjustment on ballistic missile revenues and net cash inflows. First, Brazil only needs to compete with North Korea and China. Although China's M-missiles could be quite reliable and accurate, Brazil at least does not have to compete with the United States, Japan, and Arianespace, as in the case of space launchers. Second, lower launch reliability may be due to stage separation, which is absent in shorter-range ballistic missiles. In any case, reliability is relatively less important in ballistic missiles, because the warhead used is considerably cheaper than the missile. Third, it is difficult to adjust ballistic missiles' net cash inflows for lower accuracy, because for many missions, such as city busting, high accuracy may not be important.

Table 2.11

Adjusting For Lower Reliability Reduces Profitability of Brazil's Space Launch and Ballistic Missile Program

Case	Program and Environment[a]	Internal Rate of Return[b] Unadjusted	Internal Rate of Return[b] Adjusted	Fraction of Investment Recouped Unadjusted	Fraction of Investment Recouped Adjusted	Net Present Value[c] (1992$ million) Unadjusted	Net Present Value[c] (1992$ million) Adjusted
1	SSL	-ve to 0%	-ve to -ve	0 to 35%	0 to 12%	(89) to (58)	(89) to (79)
2	SSL, RSL Foreign help	-ve to -ve	-ve to -ve	0 to 20%	0 to 10%	(420) to (292)	(420) to (377)
3	SSL, RSL No foreign help	-ve to -ve	-ve to -ve	0 to 16%	0 to 8%	(1060) to (889)	(1060) to (974)
4	SSL, RSL, BM Foreign help Limited competition	8 to 12%	8 to 10%	90 to 112%	90 to 97%	(59) to 69	(59) to (16)
5	SSL, RSL, BM No foreign help Limited competition	2 to 5%	2 to 4%	57 to 71%	57 to 64%	(523) to (352)	(523) to (437)
6	SSL, RSL, BM Foreign help Intense competition	-ve to 5%	-ve to 2%	45 to 67%	45 to 52%	(323) to (195)	(323) to (280)
7	SSL, RSL, BM No foreign help Intense competition	-ve to -ve	-ve to -ve	29 to 43%	29 to 36%	(875) to (704)	(875) to (789)
8	SSL, BM Limited competition	16 to 17%	16 to 16%	156 to 165%	156 to 159%	189 to 220	189 to 199
9	SSL, BM Intense competition	7 to 8%	7 to 7%	78 to 87%	78 to 81%	(75) to (44)	(75) to (65)

[a]This column indicates whether space launchers and/or ballistic missiles are involved in the developmental program. SSL = small space launcher, RSL = regular space launcher, and BM = ballistic missile. Moreover, this column shows whether the program is carried out with or without foreign assistance and whether Brazil's ballistic missile export business is conducted under limited or intense foreign competition. See footnote b to Table 2.7 for more elaboration on cases 1, 8, and 9.

[b]"-ve" denotes a negative internal rate of return. In other words, the principal of the investment will not be fully recouped and no interest will be earned.

[c]Numbers in parentheses are losses.

Table 2.12

Profitability of Brazil's Space Launcher and Ballistic Missile Program (Table 2.11 entries rounded)

Case		Internal Rate of Return[b]		Fraction of Investment Recouped		Net Present Value (in 1992 $ million)[c]	
	Program and Environment[a]	Reliability Unadjusted	Reliability Adjusted	Reliability Unadjusted	Reliability Adjusted	Reliability Unadjusted	Reliability Adjusted
1	SSL	-ve to 0%	-ve to -ve	0 to 35%	0 to 15%	(90) to (50)	(90) to (75)
2	SSL, RSL Foreign help	-ve to -ve	-ve to -ve	0 to 30%	0 to 10%	(450) to (250)	(450) to (350)
3	SSL, RSL No foreign help	-ve to -ve	-ve to -ve	0 to 20%	0 to 10%	(1100) to (850)	(1100) to (950)
4	SSL, RSL, BM Foreign help Limited competition	8 to 12%	8 to 10%	90 to 120%	90 to 100%	(60) to 70	(60) to (15)
5	SSL, RSL, BM No foreign help Limited competition	2 to 5%	2 to 4%	55 to 75%	55 to 65%	(550) to (350)	(550) to (400)
6	SSL, RSL, BM Foreign help Intense competition	-ve to 5%	-ve to 2%	45 to 70%	45 to 55%	(350) to (150)	(350) to (250)
7	SSL, RSL, BM No foreign help Intense competition	-ve to -ve	-ve to -ve	25 to 45%	25 to 40%	(900) to (700)	(900) to (750)
8	SSL, BM Limited competition	16 to 17%	16 to 16%	150 to 170%	150 to 160%	150 to 250	150 to 200
9	SSL, BM Intense competition	7 to 8%	7 to 7%	75 to 90%	75 to 85%	(75) to (40)	(75) to (65)

[a]This column indicates whether space launchers and/or ballistic missiles are involved in the developmental program. SSL = small space launcher, RSL = regular space launcher, and BM = ballistic missile. Moreover, this column shows whether the program is carried out with or without foreign assistance and whether Brazil's ballistic missile export business is conducted under limited or intense foreign competition. See footnote b to Table 2.7 for more elaboration on cases 1, 8, and 9.

[b]"-ve" denotes a negative internal rate of return. In other words, the principal of the investment will not be fully recouped and no interest will be earned.

[c]Numbers in parentheses are losses.

country such as Brazil needs translate into one or less than one small launch and much less than one regular launch per year on the average. Third, to be competitive in the launch business, one needs to keep up technologically and make investment regularly. It would be difficult for Brazil and others to do especially the former. Fourth, space launchers are high-tech items. Traditionally, Brazil and many developing countries pursue the low end of the export market, such as lower-performance aircraft and tanks. Competitiveness in the space launch is measured by cost, reliability, and timeliness. The market is not characterized by a high-low cost split. On the one hand, it is hard for developing countries to achieve comparable launch reliability. On the other hand, launch customers are not willing to trade much reliability and timely delivery for cost savings, since the satellite generally costs more than the launcher and since any delay in services is a serious concern. Nations with emerging space launchers will have to compete head-on with well-established providers.

THE POLICY IMPLICATIONS OF SPACE LAUNCH ECONOMICS

The fact of the poor economics of space launch has strong policy implications. Although these implications are readily applicable to other countries, we use Brazil as the specific case since it was the subject of our economic analysis.

In view of the difficulties of safeguarding space launch technologies (to be discussed in Section 3), we believe that the United States should present the economic assessment of Brazil's space launcher and ballistic missile programs to France, Germany, Belgium, Sweden, and China, all of which had seriously considered supplying missile assistance to Brazil. After reviewing the poor prospects for Brazil's turning a profit in the space launch business, even with foreign technical assistance, these countries might decide or confirm their decision not to supply engine and other space launch technologies to Brazil. This would force Brazil to take one of two options. First, it could still pursue a regular space launch capability. But even if it is capable technologically, considering the prospects of spending an additional $1 billion and the meager possibility of recovering it, Brazil is not likely to pursue this expensive option, especially when the country is in poor financial health. The other option is to forgo the regular space launchers but concentrate on small space launchers and ballistic missiles. Such a pursuit will clearly not be undertaken for space launch self-sufficiency, since small launchers cannot launch Brazil's own geosynchronous communication satellites. Restricting itself to small launchers would also weaken the argument of national prestige as a reason for pursuing the program. Moreover, no matter the recipient country's intent, MTCR members will clearly see that without a regular launcher program, the bulk of the benefits of their missile assistance goes to military ballistic missile programs. This transfer obviously works against the intent of the MTCR. Finally, it should also be clear that the profits of a missile-exporting country result from its taking advantage of MTCR members' good intentions in refraining from missile exports.[56] These revelations should make MTCR members even more likely to join forces in not providing technical assistance and in imposing political costs on missile proliferators.

The engine is not the only critical component in space launch and ballistic missile programs. Other key elements are guidance systems and stage separation. Brazil has bought guidance systems from SAGEM, a French firm, and has been rumored to have an agreement with China to exchange Brazilian conventional weapons or solid-fuel technology for Chinese liquid-fuel technology and assistance in guidance systems.[57] MTCR has already caused delays in Brazil's space launch program. The Brazilian air force blamed the failure to build the VLS prior to 1992 on the fact that MTCR made Brazil no longer able to acquire the necessary components.[58] For example, Brazil has asked the United States, United Kingdom, and France for help with stage separation pyrotechnics to no avail. Without technical assistance, Brazil's space launch program could be further delayed, as happened to Taiwan, or even canceled. Finally, Brazil, as well as Argentina and South Africa, has applied to join MTCR. Without missile exports to recover part of its investment, Brazil is even more likely to terminate its space launch and ballistic missile programs. In fact, the Brazilian companies responsible for developing ballistic missiles, Avibras and Orbita (see Table 2.2), are already in very poor financial health and have placed their missile programs on hold. Pressure from MTCR members might well assure that these programs are terminated. In any case, at the least, the denial of technical help would cause Brazilian ballistic missiles to be less accurate and less reliable.

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[56]With competition, as shown in case 9 of Table 2.7, Brazil would turn the gain into a small loss.

[57]Various quotes in Robert D. Shuey, et al., *Missile Proliferation: Survey of Emerging Missile Force*, Congressional Research Service, Washington, D.C., Revised February 9, 1989, p. 93.

[58]Tollefson, *Brazil, The United States, and the Missile Technology Control Regime*, op. cit., p. 34.

APPLICATION TO OTHER EMERGING NATIONAL SPACE LAUNCH AND BALLISTIC MISSILE PROGRAMS

Recall that we have classified emerging national missile programs into two groups. Group 1 consists of Israel, India, and Brazil. All three countries should have similar future investment requirements.[59] Israel and India can still technically and economically benefit from foreign assistance, especially in regular launcher development. As to the market shares shown in Table 2.3 and Figure 2.2, neither Israel nor India is likely to capture more than four small launches per year, which we optimistically assumed for Brazil. Neither will Israel or India be likely to capture more than two regular launches per year, which again we optimistically assumed for Brazil.[60] Finally, the market share of missile export captured by Israel or India is unlikely to exceed the size we assumed for Brazil. In fact, with all three countries participating in the space launch and missile export business, the market share of each country is likely to be considerably smaller than what we assume for each individually. Thus, with similar projections of investments, demands, revenues, and net cash inflows, the economic findings for the space launch and ballistic missile programs of Israel, India, and Brazil would be similar.

Group 2 countries are South Africa, Iraq, South Korea, Pakistan, Indonesia, Taiwan, and Argentina. Iraq's missile programs are required to be dismantled by UN Resolution 687. Other countries have made much smaller financial commitment to space launch and ballistic missile programs than Brazil has done. Consequently, their future investments would be much larger if they decided to pursue launcher and missile projects. On the other hand, the market share, revenues, and net cash inflows would not be larger than those of Brazil, Israel, or India. Therefore, the economics for any of these

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[59]Since Israel and India have placed satellites into LEO, their future investment in small launchers could conceivably be less than Brazil's. We have, however, conservatively assumed that Brazil's small launcher investment has mostly been made and that the future investment amounts only to $89 million. Therefore, we do not expect Israeli or Indian future investment in small launchers to be any less. As to future investment for regular space launchers, large amounts remain to be made by all three countries.

[60]As to net cash inflows from space launcher revenues, one could assign Israel and India a percentage higher than the 30 percent assumed for Brazil, because they could purchase fewer foreign parts and pay lesser license fees for foreign assistance. Even if the net cash inflows were increased by a third, the carrying charge recouped would still be at most 40 percent, instead of 30 percent in the Brazilian case (case 2 in Table 2.7). Investments in space launchers by Israel or India still cannot be fully recovered from space launch business.

group 2 countries would be worse than for Brazil. Any joint program among countries in group 1 and/or group 2 would be no better economically overall than Brazil's program. It is also unrealistic for one partner to expect other partners to bear most of the cost and to let it receive the bulk of the profits.

Among non–Third World countries, Germany and the United Kingdom have shown interest in having their own small and regular space launchers, while Sweden and Italy have considered using others' small launchers.[61] All four countries are members of Arianespace. Since Ariane launchers compete effectively in the world market, there seems little incentive for Germany or the United Kingdom to carry out independent regular launcher development. Similarly, it is more cost effective for Arianespace to develop small launchers for its members and others. All four countries are also MTCR members, which agree to refrain from exporting missiles with a capability of 300 km/500 kg or better. Their missile business is likely to be constrained and cannot be used effectively to spread the cost of space launch development. Therefore, their pursuit of space launch programs individually, instead of through the Arianespace consortium, might also be uneconomical.

We have applied and expanded our findings in the Brazil case to another example, South Africa. Its program and its arguments are similar to those of group 1 and group 2 countries.

In June 1992, it was reported that South Africa plans to establish a space launch center and enter into the satellite launching business

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[61]For many years, the German company Orbital Transport and Raketen AG (Otrag), was developing, as a private venture, low-cost launch vehicles and sounding rockets. Modules, composed of tanks and engines, were to be clustered in various numbers for a range of delivery capabilities up to 22,000 lbs to low earth orbit or 4400 lbs to geosynchronous orbit. By late 1985, it was reported that the venture was being abandoned. (*Jane's Spaceflight Directory 1988 89*, Jane's Information Group, Inc., Alexandria, Virginia, p. 442.) In 1971, the United Kingdom succeeded in launching a 160-lb satellite to orbit with the Black Arrow launcher. In spite of the success, the launch program was canceled in the same year. Recently, the Royal Ordnance Corp. of Buckinghamshire, U.K., is developing a family of small solid-fueled launchers, Small Orbiters, which are based on the Skylark sounding rockets and Stonechat motors and can lift up to 420 lbs to LEO. British Aerospace, General Technology Systems, Royal Ordnance, and Saab are developing another small launcher, Littleleo, that can deliver 2000 lbs to LEO. It was originally designed to be an all-European vehicle. It was, however, redesigned to use the Castor booster motors and Star upper-stage kick motors from Thiokol, a U.S. company, instead of the British motors. (Sietzen, *World Guide to Commercial Launch Vehicles*, op. cit., pp. 36–39.) For the Swedish program, see the second footnote to Table 2.3. Italy has considered using Scout II (with a delivery capacity of 1100 lbs to LEO) produced by the U.S. company LTV. (Berner, Lanphier, and Associates Inc., *Assessment of Foreign Activities That Affect NASA's Commercial Space Program*, May 1, 1990, p. 2.)

within three years.[62] We have learned that a key reason for South Africa's decision to pursue space launch development is the venture's potential economic payoff. Given that Brazil's space launch business is unlikely to be profitable, South Africa, with the need for larger future investment, is even less likely to earn profits here. Moreover, since it has applied to join the MTCR, it must not be relying on the export of the ballistic missiles that MTCR prohibits or counting on recouping a sizable portion of its space launch investment through missile exports.

A less capital-intensive strategy for South Africa to pursue space launch development is to seek U.S., European, or other partners. South Africa's government has established a conglomerate, Denel, for that purpose. When MTCR members are convinced that their technical assistance in space launch programs cannot be safeguarded against diversion to ballistic missile development, which we will show in the next section, the chance for them to forbid their firms to join forces with South Africa in this venture is fairly good.

Other plausible reasons—technology spinoffs, national prestige, space launch self-sufficiency, and maintenance of employment to space launch scientists—for pursuing or continuing space launch programs are also weak.

Launch technology spinoffs depend heavily on the ability to obtain foreign technologies in the first place. A country could not have chosen a worse area (with the exception of nuclear weaponry) for obtaining foreign assistance. With all major launch suppliers in or abiding by MTCR, it would be difficult for the South Africans to obtain launch technical assistance. Even South Africa's most likely partner for its space launch venture, Israel, has now agreed to abide by the MTCR rules. Israel will be subject to tremendous political pressure not to transfer launch technology to South Africa. In any case, a joint venture with Israel is uneconomical overall. It is unlikely that Israel would absorb the losses alone and let South Africa reap the benefits. Moreover, Arianespace has been monitoring closely the prospects for small launch business and has decided not to develop a small launcher at this time. There is no reason to believe that joint efforts between Arianespace and South Africa would improve the profitability of a small launcher venture. South Africa should also note that highly experienced launch providers can enter the small launch market quickly, and that entry would limit the upside profit potential of South Africa's launch venture, even if it enters the market early.

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[62] *Military Space*, June 15, 1992, p. 4.

There is no denying that a space launch capability will bring national prestige. But pursuing a satellite-making capability, such as small communications satellites, would be equally prestigious, and it is easier to obtain foreign satellite technologies than launch technologies.

It is very hard for a country with 40 million people to be self-sufficient in many areas. Space launch is a low-priority area. In any case, to achieve space launch self-sufficiency, South Africa and other countries need to have not only small launchers for sending satellites to LEO but also regular launchers for GSO. Technical assistance for regular launchers might not be forthcoming because of MTCR, and indigenous development could be too costly to pursue. Since a country needs geosynchronous communications satellites the most, no regular launcher means no self-sufficiency.

That past space launch investment needs to be recouped is not a valid argument. South Africa, like Brazil, cannot recoup even future investment alone and should not throw good money after bad. Keeping missile programs alive in order to keep rocket scientists employed is also invalid. Why would a country want to keep its most talented people in projects that generate not profits, but poor image? These scientists can be turned into teachers and researchers to improve scientific education, engine efficiency, material heat-resistance and lightness, and other areas.

Given worldwide concerns about missile proliferation, South Africa and other countries would be ill advised to enter this arena. Whatever meager benefits could be derived from the pursuit would be easily outweighed by the political costs of being a missile proliferator. For example, a reduction in foreign investment or trade as a result of economic sanctions would far exceed the benefits, if any, of missile sales. It is to the benefit of South Africa and other countries in groups 1 and 2 to cancel their space launch plans.

South Africa's plan to establish a space launch center and to launch satellites within three years hinges critically on the availability of foreign technical assistance. If the MTCR members and abiders hold the line, South Africa and others might well drop their plans.

3. SAFEGUARDING SPACE LAUNCH VEHICLES

THE URGE TO STRIKE A BARGAIN

MTCR stated that "the Guidelines are not designed to impede national space programs or international cooperation in such programs as long as such programs could not contribute to nuclear weapons delivery systems." On the other hand, in Category I of the MTCR Annex, rocket systems clearly include ballistic missile systems, space launch vehicles, and sounding rockets. During 1987–1989, some MTCR members were on the verge of selling space launch technologies to other countries. In this section, we will present arguments for why no member should revert to the old stance of treating space launchers and ballistic missiles differently. On the other hand, one undoubtedly wishes that space launch vehicles could be safeguarded, because then, as with the Treaty on Non-Proliferation of Nuclear Weapons (NPT), one could use the peaceful applications of ballistic missiles to reward those who were willing to support missile nonproliferation.

LEARNING FROM IAEA

What lessons can we draw from the nuclear safeguard experience of the International Atomic Energy Agency (IAEA) for devising SLV safeguards? The basic principle of nuclear safeguards is material accountancy, which attempts to account for all the nuclear materials, within measurement uncertainties, flowing in and out of the monitored facilities. In addition, two types of measures, containment and surveillance, are used to reinforce material accountancy.[1] Containment refers to the use of physical barriers to restrict access to nuclear materials, and surveillance refers to the use of sensors and human inspections of nuclear materials, equipment, and records to detect unauthorized activities. In essence, IAEA aims to use these measures to prevent the diversion of nuclear material for illegitimate use dur-

[1] International Atomic Energy Agency, *The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons*, INFCIRC/153, p. 9. See also E. V. Weinstock and A. Fainberg, "Verifying a Fissile-Material Production Freeze in Declared Facilities, with Special Emphasis on Remote Monitoring," in Kosta Tsipis, David Hafemeister, and Penny Janeway (eds.), *Arms Control Verification*, Pergamon-Brassey's, McLean, Virginia, 1986, pp. 311–312.

ing the period of compliance. Breakout, however, is a key concern. Whether the international community can obtain a timely warning before a violator attains a nuclear weapons capability depends on the types of nuclear material and facilities available to the violator at breakout. For example, safeguarding a nuclear research reactor using highly enriched uranium (HEU), an enrichment plant, or a plutonium (Pu) reprocessing plant in a proliferator's own country is ineffective with respect to the timely warning criterion, since a proliferator can obtain weapons-ready nuclear material quickly (in days to weeks) after a breakout.[2] On the other hand, a regime that prohibits the use of the above highly sensitive nuclear materials and facilities in the proliferator's territories and needs only to safeguard its power plants and research reactors that use low-enriched fissile materials could be quite effective, as far as civilian nuclear power is concerned. Another key concern is enforcement, both during the period of compliance and after a declared breakout.

How relevant are the IAEA nuclear safeguards to SLV safeguards? First, the same methods of material accountancy, containment and surveillance, can be applied to control SLV parts, finished goods, and production and launch facilities. An international agency could probably prevent the diversion of SLV parts or systems for illegitimate use during the period of compliance just as well as IAEA could for nuclear materials. The problems are, again, breakout and enforcement. In addition, there is a new problem: continuous technology transfer to undesirable yet legitimate activities while complying. How can one prevent the transfer from SLVs to ballistic missiles? In the next section, we will discuss both the old and the new problems.

DIFFICULTIES IN SAFEGUARDING SLVs

Let us first recall that in the NPT, each nonnuclear-weapon state (1) agrees not to manufacture or acquire nuclear weapons or other nuclear explosive devices and (2) agrees to place all nuclear activities and facilities under safeguards. Most importantly, the drafters rec-

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[2]The products of enrichment and plutonium separation plants are called strategic special nuclear material (SSNM), which is a pure compound of either plutonium or uranium with a uranium-235 or uranium-233 enrichment greater than 20 percent. These pure compounds are in the form of plutonium and uranium oxides, nitrates, and fluorides, which generally have to be reworked in order to become ready for use in nuclear weapons. The process for conversion to plutonium and uranium metal (weapons-ready nuclear material) is, however, well known and documented, and can be done quickly on the order of days to weeks, if the rework facilities are available. Albert Wohlstetter et al., *Swords From Plowshares*, University of Chicago Press, Chicago, 1979, pp. 153 and 181–182.

ognized the impossibility of banning military nuclear explosions but not peaceful nuclear explosions, and NPT explicitly bans the development of nuclear explosion for peaceful purposes. If one were to generalize the NPT to a missile safeguard regime, SLVs, being ballistic missiles for peaceful purposes, would have to be banned. Let us, however, examine whether there is any possible way to safeguard SLVs.

India and Israel have successfully launched satellites. Other space-launch-aspiring countries, which either have an active space launch development program or recently had, at least once, seriously considered pursuing one, include Argentina, Brazil, Indonesia, Iraq, Pakistan, South Africa, South Korea, and Taiwan.[3] Nearly all these countries have active ballistic missile programs. In fact, the first stages of India's space launcher SLV-3 and its 2500 km ballistic missile Agni have been reported by both Indian and foreign sources to be identical.[4] Ballistic missiles can use a space launcher's propulsion, guidance, structure, stage separation, and other mechanisms, as well as its manufacturing and launch equipment. The differences are in reentry vehicles, guidance instructions and, of course, payload types. Can one use these differences to promote space launch activities and restrict ballistic missile programs at the same time?

A likely scheme for safeguarding SLVs would include two basic elements. First, all critical SLV parts, systems, and production, storage, and launch facilities would be placed under an IAEA-like supervision. The second element would start with the intent of no acquisition or development of (surface-to-surface) ballistic missiles that are capable of delivering at least a stipulated payload beyond a stipulated range.[5] The MTCR uses a 500 kg payload and a 300 km range capability as the cutoff criteria for export control of its Category I items. But in a missile safeguard regime, a key provision would probably not allow flight tests of ballistic missiles beyond a stipulated range regardless of payload weight. Otherwise, a country could gain much experience about high-speed reentry and system testing, and there would be no more critical technology to stop a country, at declared or undeclared breakout, going from light-payload to heavy-payload, long-range mis-

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[3]W. Seth Carus, *Ballistic Missiles in the Third World*, Praeger, New York, 1990, p. 24.

[4]Gary Milhollin, "India's Missiles—With a Little Help From Our Friends," *The Bulletin of the Atomic Scientists*, November 1989, p. 35.

[5]In addition to safeguarding SLVs, ballistic missiles below a stipulated range would have to be safeguarded against being used in the development of longer-range missiles. This study focuses on the difficulties of safeguarding SLVs.

siles. Further, within the stipulated range there will be a certain payload/range limit schedule, and countries under safeguard cannot acquire or develop (including flight test) missiles with a payload/range exceeding those limits.

The safeguard scheme can be very stringent, depending on the stipulated range. One such case would have a range not to exceed, say, 60 km but would still allow the use of most of the unguided battlefield rockets. Obviously, the more stringent the restraint, the more unlikely countries would be to agree to it. A more likely case would have a range of 300 km or 1000 km. In any case, the problem remains that there will be technology transfers to missiles up to the cutoff range.

Take the case of a 300 km cutoff. The safeguard planners of such a regime could argue that missiles with less than that range are already in great abundance in many countries and that it is too late to limit their spread. They could further argue that 300 km missiles have too short a reach to be effective as either terror or military weapons. Then they reason that if SLV assistance can be used to lure countries into forgoing the development and possession of ballistic missiles with a range over 300 km, the bargain would be a beneficial one.

A closer look, however, reveals serious defects in such an argument, as well as in the above SLV safeguard scheme. During the period of compliance, SLV activities will serve as a conduit for the flow of guidance, propulsion, and structure technologies and flight-testing experience to the improvement of military shorter-range (<300 km) missiles (see Table 3.1). High-speed reentry can be tested through the retrieval of experiments, such as microgravity, from sounding rocket flights. Moreover, SLV stages can be flight tested individually or in pairs (instead of a full three or four stages) in a flight profile not exceeding a horizontal distance of 300 km. A lofted profile could be used for a full system's test of less than 300 km, and yet the system could have the potential for distance well beyond 300 km. After breakout, the additional time needed to attain a longer-range (≥300 km) missile capability could be as short as several months, as in the Iraqi case to be discussed shortly. Even in the most optimistic cases where the time is measured in years, one still wonders whether we would want to trade our SLV assistance for other countries' temporary refrain from a longer-range missile development. SLVs could be the only avenue not closed out by export control for obtaining such missile technologies as stage separation and system integration. SLV assistance might supply an otherwise unavailable education on missile technologies.

Table 3.1

Difficulties in Safeguarding a Space Launch Program

	Nuclear Safeguard Regime	Space Launcher Safeguard Regime
During period of full compliance	Bans peaceful nuclear explosions. No weapon-ready nuclear materials.	Allows "peaceful" ballistic missile. Continuous transfer to concurrent ballistic missile programs.
After breakout, time to attain dangerous capability	Pu extracted in 18 to 24 months; longer for HEU.	Longer-range ballistic missiles in several months to 5 years.

To study how SLV technologies are usable in ballistic missiles, we need to review their characteristics. Scud and Scud-modified missiles are the best representation of the current generation of ballistic missiles in the Third World. They use liquid propellants. Their fueling operation is time-consuming and can serve as a warning signal to the enemy to mount counter or defensive actions. Their primarily 1950s–1960s mechanical inertial guidance sensors produce an accuracy of only about one-third of one percent of range, or 1000 meters at 300 km.[6] This inaccuracy makes these missiles mostly militarily ineffective, except when mated with nuclear, biological, or chemical weapons. Their structures use standard missile airframe materials, such as aluminum and steel, which make the missiles heavy and less mobile.

Although major launch-providing countries use liquid propellants for their higher specific impulse (Isp), countries such as Brazil currently use only solid propellants for their space launch vehicles. The same solid propulsion technology applied to ballistic missiles will result in much faster launch response, because fueling immediately before launch would not be necessary. Moreover, the multistage technology essential to SLV could be used to develop multistage ballistic missiles, which will be lighter and more mobile than single-stage missiles. Gerald Frost calculated that a single-stage, solid-fueled, and mobile missile with a liftoff mass of 8850 kg can deliver a 500 kg warhead to 675 km away.[7] If a two-stage design were used, a solid-fueled missile with the same liftoff mass can deliver the same warhead to a distance of 1000 km. The numerical increment might not seem large, but the

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[6]Personal communication with Gerald Frost, RAND, August 1991.

[7]Personal communication with Gerald Frost, RAND, August 1991.

change in military and strategic effectiveness brought about by increasing the range from 675 to 1000 km and by keeping the missile mobile could be highly significant. SLV activities also provide experience in the use of lighter and more heat-resistant materials for missile structures. The attributes of quick response and mobility will make the sort of search-and-destroy operations against mobile launchers used in the Gulf War even less effective.

Some planners have turned the above argument on its head. Since liquid propulsion is less suitable for ballistic missiles, they argue that liquid propulsion technology should be exportable to nations with emerging space launch programs. We disagree. By saving the costs and circumventing the technical difficulties in developing a liquid engine indigenously, a country might decide to continue its regular launcher program, which otherwise might have been terminated. In spite of foreign assistance, the continuation would likely lead to a larger loss than would result from pursuing the small launchers alone. The more comprehensive the space launch activities and the larger the losses, the stronger the incentives to spread the cost by developing ballistic missiles for export. Also, although solid propulsion is more suitable for military ballistic missiles, liquid-fueled missiles are not harmless. After all, many missiles are liquid-fueled, and they include Scud, modified Scuds, Lance, China's CSS-2, and India's Prithvi. Moreover, liquid-fueled SLVs, as well as solid-fueled SLVs, can be converted to intercontinental-range ballistic missiles. Even if they are at fixed locations and vulnerable to attack, they can still be used in a preemptive mode to threaten any nation anywhere on the globe. The threat is particularly serious if these missiles are equipped with weapons of mass destruction.

As for the transfer of guidance technology from SLVs to ballistic missiles, the utility could be seriously underestimated. It is generally said that ballistic missiles require a more accurate guidance and navigation system than SLVs do. Positional errors generated by an SLV can be corrected, by the kick motor or by the satellite's on-board propulsion system. Sometimes correction is not even necessary, since even an error substantially greater than 1000 meters does not affect many satellites' mission performance. In contrast, a ballistic missile's effectiveness depends sensitively on its circular error probable (CEP). Although booster burnout velocity errors could be corrected during reentry, doing so would generally require a costly and sophisticated maneuvering reentry vehicle with terminal sensors or receivers. Underestimation of the utility of SLV guidance in ballistic missiles comes from overlooking two factors.

First, a new lower-cost guidance system might happen to provide better accuracy as well. This more accurate guidance would find its way to ballistic missiles. Major launch providers are considering the use of GPS in their launch vehicles for lowering cost while also improving accuracy.[8] In an SLV safeguard regime, it could be unfair for anyone to argue that other countries cannot use GPS or other highly accurate guidance systems in SLVs while the major launch providers can. Countries under SLV safeguards would counter that such restraints are designed to make their launch systems noncompetitive.

Second, the accuracy of developing countries' ballistic missiles is far below the accuracy of their counterparts in the United States, CIS, and other developed countries. A 300 km Scud missile with a CEP of 1000 meters is some 300 times less accurate than a 10,000 km ICBM with a CEP of 100 meters.[9] An SLV guidance system could be much inferior to a U.S. ballistic missile guidance system and thus useless to U.S. missile development. But that same SLV guidance system could be superior to a Third World country's current missile guidance system and useful to its ballistic missile development. For example, a GPS-equipped ballistic missile of the range of Scud could have a CEP of a few hundred meters, and the use of GPS would eliminate the need to launch from presurveyed sites.[10] An accuracy of a few hundred meters is better than the 1000 meter CEP of Scud.

Therefore, SLV technologies can be used to make missiles more accurate and mobile and, in other words, more potent and difficult to counter.

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[8]A global positioning system (GPS) receiver was installed on the second Pegasus launcher as a redundant source of navigational information, while the inertial measurement unit (IMU) continued to be the primary source. Antonio Elias, the chief Pegasus engineer at Orbital Sciences Corporation (OSC), said that GPS receivers are more rugged and inexpensive than IMUs, and OSC intends to make GPS Pegasus' primary navigation instrument. "Latest Winged Booster Features Liquid Propulsion Unit, GPS Navigation," *Aviation Week and Space Technology*, July 22, 1991, p. 25.

[9]Minuteman II has a range of 12,500 km and a CEP of 200 meters; Minuteman III, 13,000 km and 120 meters respectively; Peacekeeper, 9600 km and 90 meters. Duncan Lennox (ed.), *Jane's Strategic Weapon Systems*, 1990.

[10]This assumes that only the coarse acquisition (C/A) or the lower accuracy mode of GPS (about 100 meters CEP) is used and that missiles do not have the expensive post-boost vehicles or maneuvering reentry vehicles. The guidance errors will then have to be corrected before the booster burnout, which occurs relatively early in the missile flight. The other sources of system CEP errors include uncertainty in fuel cutoff time, gyro drift, and missile reentry. Gregory S. Jones, *The Iraqi Ballistic Missile Program: The Gulf War and the Future of the Missile Threat*, American Institute for Strategic Cooperation, Marina del Rey, California, Summer 1992, p. 40; and personal communication on September 22, 1992.

WOULD FLIGHT TESTS PROVIDE TIMELY WARNING?

Missile safeguard planners would likely rely heavily on a no-flight-test provision for timely warning after the breakout. Let us first review how timely warning could be obtained in nuclear safeguards. In one effective regime, the use of HEU or Pu in research and power reactors and the availability of enrichment and reprocessing plants would be prohibited. Then, in the event of a breakout, a reprocessing facility would have to be constructed in order to extract Pu from highly radioactive spent fuel, and the warning time would be 18 to 24 months.[11]

Those who believe that HEU, separated plutonium, enrichment plants, and reprocessing plants in proliferators' territories could be safeguarded would probably not agree with us on the difficulties of safeguarding SLVs. To us, such a nuclear safeguard regime fails to meet the timely warning criterion. In SLV as in nuclear safeguards, attempting to guard items that cannot be guarded would legitimize and promote dangerous activities. The safeguard regime ends up speeding, rather than slowing, the spread. There is another illusion, namely, that civilian activities or facilities are always safe. They are not, and those with meager economic returns but dangerous applications should especially not be condoned or promoted.

The SLV components, production facilities, and launch complexes in an SLV safeguard regime are similar to the sensitive nuclear materials and enrichment and reprocessing plants in a nuclear safeguard regime. They may be even more similar to peaceful nuclear explosives, which cannot be safeguarded because of their virtual indistinguishability from the military article. It is difficult to control all these items to meet the goal of timely warning. Moreover, permitting shorter-range ballistic missiles in an SLV safeguard regime is similar to permitting small nuclear weapons in proliferators' hands in a nuclear safeguard regime. Obviously, the NPT drafters would never dream of making an exception for small nuclear weapons. Yet, the shorter-range missiles are very likely to be allowed in any SLV safeguard regime. The lack of full-scope safeguards, timely warning, and enforcement is the primary source of difficulty in designing an effective SLV safeguard system (see Table 3.2).

Now let us elaborate why SLV flight tests might not provide timely warning. There are three reasons. First, some countries, such as

[11] Wohlstetter, *Swords into Plowshares*, op. cit., p. 155.

Table 3.2

Difficulties in a Possible Space Launcher Safeguard Regime

- No full-scope safeguards
  - Continuous technology transfer to ballistic missile up to the stipulated range
  - Same production infrastructure
- Inadequate and ambiguous warning
  - As short as a few months for missiles with range of 300 to 1000 km, particularly if violator had prior operational or testing experience with such missiles
    - Al Husayn, a single-stage missile of 600 km, flight tested on August 3, 1987, then 189 launched seven months later
    - Longer-range missiles can be developed by bundling or stacking single stages
  - Even if the post-breakout development encounters problems in reentry, guidance, etc. (more likely for missiles well above 1000 km) and takes two to five years to succeed, the safeguard regime still provides an education on missile technology
- No enforcement
  - Politically enforcing the compliance with missile safeguards before and after the breakout would be even more difficult than doing so with nuclear safeguards

India, Iraq, and Israel have already tested ballistic missiles much beyond 300 km. Even if they would be willing to join the missile safeguard regime and destroy all missiles at or above 300 km,[12] after breakout they might not need any more flight test before they could quickly assemble and use missiles reaching beyond 300 km. The assembly would include bundling or stacking booster stages for longer range.

Second, even countries that have never tested a missile with range greater than 300 km could conduct such a test and use such missiles quickly. In fact, the first flight test of the 600 km Al-Husayn missile

[12] In the case of Iraq, it would be 150 km, as stipulated in UN Resolution 687.

occurred on August 3, 1987. Then, merely seven months later and from February 29 to April 20 (the War of the Cities), Iraq launched as many as 189 such missiles against Iran. Moreover, missiles can be used as terror weapons even before they attain high accuracy.

Third, the warning from a flight test could be too ambiguous for us to react decisively. Carus and Bermudez observed that "the [Al-Husayn] project was conducted with considerable secrecy, and even Western intelligence agencies were unaware of the project." They went on to observe that "intelligence agencies in the West dismissed as propaganda Iraq's claims in early 1987 to have successfully tested a 650 km range missile."[13]

On the other hand, the lead time for applying SLV technologies and components to develop a much longer-range ballistic missile, say well over 1000 km, could be considerably longer than the lead time for missiles with less range. The lead time depends sensitively on the violator's technological status at breakout (whether declared or undeclared) and the desired reliability for its missiles. Reentry at high speed and flight tests of the full missile system are two key elements in the post-breakout development program. During the period of compliance, a violator is likely to gain some important experience about reentry by experimenting with film-retrieval canisters and other recovery systems used in satellites and sounding rockets. Moreover, a range of reentry conditions can be simulated in wind-tunnel test facilities. Even with all these activities and tests, it is still conceivable that the lead time could still be from two to five years. Would this provide enough warning? The answer takes two parts.

First, shorter-range missiles, as discussed earlier, would not need a lead time as long as two to five years, and yet 600–1000 km missiles are very troublesome to regional stabilities and to America's and its allies' theater military operations.

Second, even if we could ignore these dangerous shorter-range missiles, or even if developing them also took as long as two to five years, the missile safeguard planners still need to consider whether trading SLV know-how for two to five years of lead time is worthwhile, especially if export controls can effectively slow the flow of missile technologies and components to the space-aspiring countries and leave SLVs as the only conduit for them to obtain the needed assistance. Moreover, the issue of enforcement or response is even more difficult

[13]W. Seth Carus and Joseph S. Bermudez, Jr., "Iraq's Al-Husayn Missile Programme," *Jane's Soviet Intelligence Review*, May 1990, p. 207.

in the missile safeguard regime than in the nuclear one. There may also be nothing to enforce, because an SLV program ensures the possession of ballistic missiles. The international community could perceive that violating or breaking out of the SLV safeguard regime for longer-range missile development is a much less severe event than violating the nuclear regime for nuclear weapon development. We should strive to change such a public perception. In the meantime, when a country under missile safeguards diverts components and technology to a longer-range missile program, either during the period of compliance or after a breakout, enforcing the safeguard rules or neutralizing what the violator has learned during the period of compliance would be difficult.

One might argue that although safeguards and inspections are not perfect, an IAEA-like agency for space launcher and ballistic missile activities is better than nothing. The problem is the illusion that such a safeguard regime would create. The MTCR members would then have to provide technical assistance to countries that are willing to join the regime. Some countries will join simply because they know the regime cannot stop them from transferring missile technology from space launchers to ballistic missiles. The creation of the regime would greatly reduce the likelihood of MTCR members joining forces in refraining from providing space launch assistance to others.

4. FINDINGS

This report found that it is difficult to design a space launcher safeguard regime that can stop technology transfers from space launchers to ballistic missiles both during the period of compliance and after the breakout. The study also found that the denial of technical assistance does not force nations with emerging space launch programs to forgo lucrative profit opportunities. After all, the space launch business is unlikely to be profitable to them even if they get help from major launch suppliers. Nations with emerging launchers lack adequate domestic demand and will be hard-pressed to keep up with launch technology advances. Moreover, for a given platform or weapon such as aircraft, artillery, and tanks, some countries want a combination of high-tech versions and low-tech versions. Countries such as Brazil aim for the low-tech markets. Launch services are not characterized by a high/low split. Countries with infant space launch programs would have to compete head-on with countries with well-developed programs. Finally, oversupply in launch services will continue.

If major nations refrained from licensing missile technologies to other countries, these other countries' space launch economics would be even worse, and perhaps even so miserable that they would terminate or not even start their space launch programs.

In view of the drastic changes in the national security environment and in space launch economics, nations that are pursuing or plan to pursue space launch development are well advised to reassess the chances and the significance of meeting their original objectives. Some will find that the economic payoffs have disappeared, and that a space launch venture is not the vehicle for technology spinoffs and national prestige. Especially for those nations that now plan to join MTCR and forgo missile export, they cannot count on exports to recover part of the developmental costs. If, after all these considerations, some still discover some merit in equipping themselves with ballistic missiles, they will have to develop them on their own and take whatever political costs follow. No matter how justifiable they believe their actions to be, others do not have an obligation to assist them, given the concerns about missile proliferation.

Space launch suppliers need not maintain the view that proliferation of space launch capabilities is irreversible. The miserable economics and the difficulties in obtaining technical assistance might kill many of them. That all the major launch suppliers are either members or abiders of MTCR provides an unprecedented opportunity to form a unified position and refrain from providing space launch and ballistic missile assistance to others. The United States and other MTCR members should not give up prematurely. They should discourage emerging national space launch development instead of hoping that it can be safeguarded. Otherwise, the MTCR members might end up promoting missile proliferation instead of slowing it.