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THE U.S. COMMERCIAL LAUNCH INDUSTRY: GOVERNMENT'S ROLE IN TECHNOLOGICAL DEVELOPMENT

by

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ABSTRACT

The U.S. space launch industry has been in transition from government contractor to a quasi-commercial state since 1984. Stiff competition from foreign launch providers for the launch contracts of commercial and some foreign government payloads has prompted calls for government action to ensure the competitiveness of this new Commercial Launch Industry.

With a long history as a government contractor, the U.S. launch industry has and continues to receive government support for technological development. As this new commercial industry comes to life, government efforts to enhance industry competitiveness through technological development must be scrutinized.

This thesis examines whether the government should take action to develop or influence the development of technologies specifically to enhance the competitiveness of the Commercial Launch Industry, and if so, what those actions should be. The role of government is analyzed by exploring the reasons for maintaining a competitive commercial launch industry, the economic rationales for government intervention, and the technologies to improve competitiveness. The results of these analyses are then incorporated with the realities of government operation to develop appropriate and feasible recommendations.

The primary conclusion of this thesis is that the greatest opportunities, and most appropriate actions, for government to enhance the competitiveness of the Commercial Launch Industry with improved technology lie, not in government development of new technologies, but in its role as customer for launch vehicles, catalyst of private innovation, and provider of infrastructure.

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ACRONYMS AND ABBREVIATIONS

ALS	Advanced Launch System
ALTP	Advanced Launch Technology Program
CLI	Commercial Launch Industry
CSTI	Civilian Space Technology Initiative
DOD	Department of Defense
DOT	Department of Transportation
ELV	Expendable Launch Vehicle
ESA	European Space Agency
ESMC	Eastern Space and Missile Center
GEO	Geosynchronous Orbit
GLOW	Gross Lift-off Weight
GTO	Geosynchronous Transfer Orbit
LEO	Low Earth Orbit
LOX-H2	Liquid Oxygen-Liquid Hydrogen
NASA	National Aeronautics and Space Administration
NASP	National Aerospace Plane
OCST	Office of Commercial Space Transportation
R&D	Research and Development
SDI	Strategic Defense Initiative
SSME	Space Shuttle Main Engines

1.0 INTRODUCTION

Since 1984 the United States space launch industry has evolved from government contractor to a quasi-commercial state. In the past, all payloads launched into space by the United States used launch vehicles procured from the manufacturer by the government. With the advent of the Space Shuttle the government moved away from using expendable launch vehicles leaving manufacturers of those vehicles without much demand for their product. Legislation was enacted allowing the manufacturers to market launch services directly to private and foreign government customers, but with the Space Shuttle offering low launch prices not many customers were found. The ***Challenger*** accident changed that by prompting an Executive Order restricting Shuttle launches of non-government payloads to those requiring its unique capabilities.

Now the U.S. Commercial Launch Industry is competing head to head with foreign launch providers for commercial and some foreign government payloads. Thus far the competition has been rather one sided with the new kids on the block, the Europeans, winning most commercial launch contracts. This has prompted calls for government action to ensure the competitiveness of the U.S. Commercial Launch Industry. Yet, as this new Commercial Launch Industry comes to life, the role of government should be scrutinized to determine where government action impedes growth, and where government support is no longer appropriate.

While many areas of government-business relations in the Commercial Launch Industry merit exploration, those which result in a direct subsidization should be given particular attention. With a long history as a government contractor, the U.S. space launch industry has, and continues, to receive government support for technological development. The Commercial Space Launch Act Amendments of 1988 stated that "the U.S. Commercial Launch Industry must be competitive in the international marketplace" and pledged to achieve this goal, in part, through continued research and development of launch technology.[1]

The objective of this thesis is to determine whether the government should take actions to develop, or influence the development, of technologies specifically to enhance the competitiveness of the Commercial Launch Industry (CLI), and if so, what those actions should be. The assessment of the role of government in

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[1] PL100-657 Sec. 2 (3)

technological development for the Commercial Launch Industry is carried out by answering the following questions:

What are the reasons for maintaining a competitive Commercial Launch Industry? International trade, the potential for government cost reductions, national security and national prestige all represent possible reasons for maintaining the competitiveness of the CLI. But is a competitive Commercial Launch Industry needed to maintain national security or prestige? And can the government obtain cost reductions from a competitive CLI beyond those which might be obtained through government procurement? The answers to these questions form the essential framework within which the role of government must be evaluated. Different motivations for maintaining a competitive CLI will necessarily yield different sets of reasonable alternatives for government action.

What are the economic rationales for government intervention? Under most circumstances a commercial industry would be left to operate without direct government intervention to enhance competitiveness allowing the free market to drive innovation. But imperfections such as the inability or unwillingness of the financial market to finance projects, the non-appropriability of the results of R&D, or government policies, may lead to barriers that hinder private development of technology. Since the question at hand is whether the government should take actions specifically to enhance the competitiveness of the CLI through technology development, and not whether broader macro-economic steps are needed for the nation's industries as a whole, the important factor is whether the CLI faces barriers which other industries do not. Other economic rationales for government support might be unfair competition from foreign launchers, or that the CLI somehow represents an "strategic" industry important for the future economic growth of the nation.

Can any areas of technological improvements be identified as key to enhancing industry competitiveness? The competitiveness of a launch company can be improved not only by reducing launch costs, but also by reducing the cost of risk management, the cost of financing the launch, and the potential for launch delays. Thus, the ability of technology to improve each of these areas must be explored. The common means for doing this is through the use of mathematical models which estimate the potential costs and benefits of a new technology. Unfortunately, for launch vehicle technologies such estimates are based on assumptions and guesses about the future which lead to inaccurate and highly variable results. In addition, any new technology might be used differently by each launch company since their vehicles and manufacturing processes are not identical leading to the need for different estimates for each company. As a result, such estimates must be used very carefully in the formulation of government policy. Over-reliance on these poor estimates could lead to improper conclusions. Therefore rather than attempting to explicitly quantify the costs and benefits from any new technology this thesis will identify those groups of technologies which are key to improving the competitiveness of the CLI. This will be achieved in part by identifying where costs come from and by exploring the known technical and economic trade-offs associated with proposed technologies. As will be seen, by doing so it is possible to identify one group of technologies as key to improving the competitiveness of the CLI through improvements to existing launch systems, and to show that the optimal design of new launch vehicles will be highly dependent on government needs. In addition, exploration of these trade-offs reveals important disparities in government and commercial needs.

Given the answers to the above questions, what government role would be appropriate and feasible? The government can influence technological development for the CLI in four broad ways: as a developer of new technologies, as a customer for launch vehicles, as a catalyst to private innovation, and by providing infrastructure such as launch sites. Coupling the lessons learned by answering the previous questions with the realities of government operation these roles can be evaluated to formulate appropriate and feasible government actions.

This thesis begins with a brief history of the Commercial Launch Industry, definitions of the terms "commercial" and "competitiveness", a look at the competitors and customers, and finally a survey of current government support for technological development. It then proceeds to explore each of the above questions in turn.

2.0 INDUSTRY OVERVIEW

2.1 BIRTH OF THE U.S. COMMERCIAL LAUNCH INDUSTRY

The Early Years.

In the late 1950's the United States and Soviet Union were racing to be the first country to place a man made satellite in orbit. The first proposal to the U.S. government to achieve this goal, called Project Orbiter, came from Army and Navy rocket scientists, led by Wernher Von Braun, who were working on ballistic missiles. They proposed to modify an Army Redstone ballistic missile and promised to achieve the feat within 90 days[1]. But the Eisenhower administration wanted to emphasize to the world the peaceful purpose of the mission and was reluctant to use defense technology to achieve the task. As a result the Eisenhower administration chose instead to pursue a project proposed by the Naval Research Laboratory called Vanguard. Unlike Project Orbiter, Vanguard was to be a new vehicle rather than a modification of a military missile.

On October 4, 1957 the launch of Sputnik shocked the United States and caused an acceleration in the effort to reach orbit. Even before Vanguard attempted its first launch, the Soviets launched Sputnik II. Then, on December 6, 1957 the U.S. attempted its first launch of the Vanguard launch vehicle. The launch failed completely with the vehicle losing thrust seconds into the flight. The Eisenhower Administration quickly discarded its desire to avoid the use of military technology and opted instead for the quickest means to a successful launch. On December 11, 1957 the Eisenhower administration gave Project Orbiter the go ahead to modify a Redstone missile into a launch vehicle which would be called Juno I. Fifty days later on February 1, 1958 the U.S. successfully launched the first U.S. satellite, Explorer I, on Juno I. The use of military technology to launch Explorer I set a precedent for the next thirty years of unmanned space launches.

The Government Plays Middle Man.

Eight months after the launch, on October 1, 1958, the National Aeronautics and Space Administration (NASA) was inaugurated as the government agency in

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[1] Space Technology, Gatland, Harmony Books, New York, 1981, p. 24.

charge of civilian space activities. Wernher Von Braun and his team of engineers soon left the Army to work in this new agency. NASA was given the task of "...development and operation of vehicles capable of carrying instruments, equipment, supplies, and living organisms into space".[2] Yet, in spite of this charge, nearly all expendable launch vehicles (ELVs) used by NASA throughout the years had their birth in military missile programs. The one exception lies in the Saturn rockets, which were specifically designed to carry men to the moon. The three primary U.S. ELVs uesed today (Atlas, Titan, and Delta), all had their birth in missile programs.

Soon after the launch of Explorer I, NASA began to make arrangements to provide launch services for foreign and commercial users. In 1962, a mere four years after Explorer I, NASA launched the first commercial communications satellite, Telstar, for Bell Labs. The procedure for carrying out launches of non-government satellites remained essentially the same for the next twenty years. Under such arrangements, the commercial or foreign user contracted with NASA which procured an ELV from the manufacturer. The manufacture of the launch vehicle was subject to stringent oversight by the government to ensure that the ELV met specifications. NASA then supervised the launch of the ELV and the payload. The word "supervised" should be stressed because in most cases the number of private contractors on site during the launch outnumbered government employees. The charge to the outside user for this launch service was the cost of the ELV and the government's total incremental costs. NASA launched all commercial and foreign government satellites under these arrangements until the Space Shuttle became operational.

The Shuttle Era.

With the advent of the Shuttle, NASA drastically changed its pricing policy. No longer did the agency charge the total incremental cost of each launch. Rather, NASA reasoned that since the shuttle was reusable, and predicted that incremental costs would drop in the future, charges should be based on an estimated twelve year average cost. NASA believed that a pricing policy based on current cost would be an unacceptable commercial and foreign user price.[3] This was probably due to the

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[2] NASA Act of 1958, sec. 102(c)(3), 42 U.S.C. 2451.

[3] *International Cooperation and Competition in Civilian Space Activities*, Office of Technology assessment, OTA-ISC-239, July 1985, p. 131.

fact that charging actual incremental cost would have made the shuttle more expensive than the ELVs previously being used.

As the shuttle program progressed, NASA and the Air Force announced their intent to cease procurement of ELVs. This created an increased demand for Shuttle services which coupled with the inability of the program to meet its launch rate goals caused a large payload backlog. This backlog was ideal for the Europeans who were completing the test flights of their new ELV "Ariane". Once operational, a quasi-private marketing company called Arianespace began to offer the Ariane launch vehicle on a commercial basis. The glut of commercial and foreign government payloads awaiting launch provided many potential customers. In addition to Ariane, China and the Soviet Union began efforts to sell launch services to communications satellite companies and foreign governments.

However, NASA's Shuttle pricing policy made it nearly impossible for the small American firms to enter the market, and many claim it forced the Europeans to subsidize the launches of Ariane by as much as 25%-30% in order to remain competitive.[4] With NASA's pricing policy a Shuttle launch of a satellite could cost half as much as launching on a U.S. ELV. But the delay to launch on the Shuttle was just too great. For a commercial satellite owner every extra month the payload stayed on Earth cost millions of dollars in lost revenue. As a result, once again the U.S. was shocked by news from Europe -- three U.S. commercial satellites were going to be launched on Ariane.

Soon after, the Reagan Administration and Congress moved to enact legislation in an effort to remedy the situation. The proposed solution -- commercialization of the ELV industry. In 1984 two pieces of legislation intended to speed the commercialization of the expendable launch industry were signed into law: The 1984 NASA Act Amendment, and The Commercial Space Launch Act.

The Commercial Space Launch Act designated the Department of Transportation (DOT) to regulate the industry. In turn, DOT created the Office of Commercial Space Transportation (OCST) to carry out this task. This office proceeded to publish a full set of regulations (14 CFR Ch. III 400-415). These included licensing procedures, rules for the use of government facilities, and penalties for failure to comply. While the creation of this legal framework was

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[4] *International Cooperation and Competition in Civilian Space Activities*, Office of Technology assessment, OTA-ISC-239, July 1985, p. 133.

essential for the operation of the U.S. industry, alone it was insufficient to prompt commercial launches.

Congress realized that something needed to be done about NASA's pricing policy and role as a launch provider so the NASA Act was amended. With regards to the commercial launch industry, the NASA Act Amendment contained pricing requirements which attempted to alleviate the difficulty private launch companies were having competing with low NASA Shuttle prices. Congress attempted to establish a "stable and fair pricing policy"[5] by requiring NASA to recover full additive cost which was defined as the average direct and indirect costs of providing additional flights "...beyond the costs associated with those flights necessary to meet the...needs of the U.S. Government".[6] Unfortunately, this left a giant loop-hole for NASA. Because the Shuttle was required for government launches anyway, NASA was not required to charge for any of the cost of the Shuttle itself. Rather, the amendment only required NASA to charge for the operational and integration costs of launching the payload. As a result, these guidelines proved to be ineffective and prices for Shuttle services continued to be below full recovery cost[7] causing stagnation of the Commercial Launch Industry (CLI) before it ever got started. The *Challenger* accident caused this to change.

Challenger.

The loss of *Challenger* left the U.S. with a large backlog of payloads and no quick means for putting them in orbit. As a result of the move to the Shuttle as the nation's primary launch vehicle, the ELV manufacturers had begun to close down their production facilities. The U.S. was left with a few ELV's from earlier contracts and a dismantled ability to produce more. Failures of Delta, Titan and Ariane ELV's several months after *Challenger* and an Atlas Failure ten months later served to exacerbate an already difficult situation.

The government soon realized that putting all of its eggs in the Shuttle was never a good idea. The nation's space program was paralyzed. To ease this paralysis President Reagan signed an executive order more crucial to the commercial launch industry than all of the legislation of 1984. The order "directed that the Space Shuttle would no longer provide launch services for commercial and foreign

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[5] 42 USC 2466

[6] 42 USC 2466 (b) (2)

[7] *Space Commerce: An Industry Assessment*, US Department of Commerce, May 1988, p. 6.

payloads that did not require its unique capabilities".[8] Also, it directed "the U.S. government to purchase commercial space transportation services to meet its requirements to the fullest extent feasible".[9] With the stroke of a pen President Reagan eliminated competition from the Shuttle. Unfortunately, the launch company's assembly lines were in the process of being moth balled.

The Air Force Comes To The Rescue

Commercial demand for launch vehicles alone could not have justified the significant cost of restarting the ELV production lines. Large orders for ELVs through the Air Force's new Medium Launch Vehicle (MLV), MLV II, and Titan IV programs, were the only reason launch companies could afford the cost of restarting production.[10] It was probably no accident that each of the three major launch companies (General Dynamics, McDonnell Douglas, and Martin Marietta) won one of these contracts. As a result the three large ELV manufacturers were able to begin production of their launch vehicles and enter the commercial market.

The Insurance Hurdle

The U.S. CLI slowly came to life, but significant problems still confronted the industry. One problem which received an enormous amount of attention was the inability to obtain adequate third party liability insurance coverage. In the past when NASA performed the launches, launch companies did not have to obtain third party liability insurance and NASA indemnified satellite owners for claims over $500 million. Now that launches were being done privately, the companies needed to obtain protection against possible claims from the general public and the government itself. Third party liability posed a problem because the potential exists for enormous claims if a launch vehicle were to go astray into a populated area. However, the problem was not that premiums for such insurance were too high, but rather that there was a lack of financing available in the insurance industry to offer these potentially enormous policies. Few insurance companies were willing or capable of selling policies to cover the possibility of such large catastrophic third party claims. Thus, commercial launch companies had no choice

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[8] President's Directive on National Space Policy, 2/11/88.

[9] Ibid.

[10] "Space Commercialization Myth and Reality", Albert Wheelon, unpublished manuscript, 1/25/89, p. 4.

but to forgo insurance and take the risk. This was not only undesirable for the company, but was also unacceptable for the well-being of the general public.

To remedy the insurance problem, and other problems related to use of government facilities which had arisen, Congress enacted the Commercial Space Launch Acts Amendments of 1988. This law returned third party liability to the state which existed when NASA provided launch services for commercial payloads by requiring launch providers to obtain $500 million in third party liability or the maximum amount available at reasonable prices. The Deptartment of Transportation was designated to determine what constitutes a reasonable price. Above this amount, the government indemnifies the launch company.

Commercial Launch.

The first U.S. commercial launch which placed a satellite into orbit occurred on August 27, 1989 as a McDonnell Douglas carried a British broadcasting satellite into orbit. Unlike the launches done through NASA in previous years, this launch and all commercial launches are arranged directly between the ELV manufacturer and the customer without direct government oversight of the commercial ELV's production. Negotiations take place on price, schedule, insurance arrangements, and financing. However, the employees involved in the launch itself have not changed much because contractors had always manned NASA launches under the agencies supervision. The government's role in the commercial launch process is one of maintaining the public utility of launch facilities, offering them for a fee, and regulating the industry to insure public safety. Over the next four years The Office of Commercial Space Transportation has 30 firm commercial launches on its manifest.[11]

2.2 DEFINING "COMMERCIAL"

The word "commercial" might be the most abused word in public policy today. It has been used to describe a slew of projects and companies which fall in a grey area where many would be hesitant to call them commercial. The Commercial Launch Industry (CLI) certainly resides in this category. A whole paper could be written on the denotation and connotation of the word "commercial", but for the purpose of this thesis, delving into semantics would serve little purpose. Rather, it is only necessary to have a common understanding of how the term will be used.

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[11] "U.S. Enters Commercial Launch Arena", *AW&ST*, 9/4/89, p. 24.

In the CLI distinctions must be made between a commercial launch company, commercial payloads, and commercial launches. For the purpose of this study, a commercial payload is any payload financed by a non-government entity. A commercial launch company is any private company which builds (or procures from sub-contractors) launch vehicles and markets their services for commercial launches. A commercial launch occurs when a commercial launch company launches any payload (whether government of privately owned) with the payload owner contracting for the service of a launch, but carrying out no direct oversight of the manufacture or launch of the vehicle except for matters related to the integration of the payload with the vehicle. Commercial launches can be contrasted with government procurement of a launch vehicle where the government oversees manufacture and launch of the vehicle through design specifications, inspection, reporting, and documentation requirements.

U.S. government payloads can be launched domestically on a commercial (without direct oversight) or non-commercial (with oversight) basis. Within the definition presented here, just because a company launches some vehicles commercially and provides others for government procured launches, does not preclude the company from being a commercial launch company. As long as a private company markets its launch vehicle for commercial launches it will be called a commercial launch company. Commercial and foreign government payloads could be launched by a commercial launch company or by a government agency. Thus, six types of launch arrangements can occur:

1. Commercial Launches of Commercial Payloads.
2. Commercial Launches of Foreign Government Payloads.
3. Commercial Launches of Government Payloads.
4. Government Launches of Commercial Payloads.
5. Government Launches of Foreign Government Payloads.
6. Government Launches of Government Payloads.

2.3 DEFINING "COMPETITIVENESS"

Another word prone to be used ambiguously is "competitiveness". One reason for the ambiguity lies in the various levels at which efforts are made to describe competitiveness. Company, industry, and national competitiveness are often considered to be one in the same when in fact they may not be. The competitiveness of an individual company depends strictly on its ability to get customers to purchase its products or services over another provider. For an individual company selling to customers in the same country this is directly related to items such as price, quality, guarantees etc.. The competitiveness of an entire industry takes the overall ability of the individual companies to compete with foreign firms. Within an industry some companies will inevitably be more competitive than others.

On a national level, government efforts to increase industry competitiveness could have the net effect of decreasing the economic well being of the nation. For example, devalueing the nation's currency would make domestic products cheaper to other countries resulting in increased industry competitiveness. However, this would reduce the buying power, and thus the standard of living, of the country.[12] Thus, government efforts to increase industry competitiveness should focus on the net economic value to society of any actions, and not just the competitiveness of industry.

2.4 COMPETITORS

The U.S government no longer holds a monopoly on launches of western spacecraft. Now companies within the U.S. are privately offering launch services and face stiff competition from other nations.

United States

The U.S. CLI is dominated by the three companies which have roots in the early days of NASA and Intercontinental Ballistic Missile (ICBM) Programs. These companies are General Dynamics, Martin Marietta, and McDonnell Douglas. While several small start-up companies have begun offering launch services, no other U.S. companies presently have the capability to place a payload over 500 kg into orbit. Nor do any of the young start-up firms have the thirty years of demonstrated experience and success of the big three. Table 2-1 summarizes the payload capability, and approximate price of existing U.S. commercial ELVs. In addition to these companies, NASA still provides transportation for many U.S. government satellites and experiments on the Shuttle and its Scout ELV.

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[12] *Using Federal R&D to Promote Commercial Innovation*, Congressional Budget Office, 4/88, p.2.

TABLE 2-1
U.S. COMMERCIALLY AVAILABLE LAUNCH VEHICLES (1989)

	Company	ELV	Payload Capability (kg)	Approximate Cost/Launch ($M)
Large ELVs:	General Dynamics	Atlas I	2250 (GTO)	55-65
	McDonnel Douglas	Delta II (6925)	1450 (GTO)	40-50
	Martin Marietta	Titan III	5000 (GTO)	100-120
Small ELVs:	Orbital Sciences	Pegasus	400 (LEO)	6-8
	Space Services	Conestoga I	275 (LEO)	Never Launched
		Starfire I	300 (Suborbital)	1+

NASA

While NASA no longer offers commercial launches, it continues to launch many payloads which could conceivably be launched by commercial ELVs. Even though the Department of Defense has moved away from using the Shuttle, some military payloads will still be launched by NASA. In addition, NASA continues to launch almost all of its own satellites and scientific missions on the Shuttle. Many small experiments which are flown on the Shuttle and on NASA's remaining small Scout ELVs could conceivably be launched on small ELVs. NASA's supply of Scout ELVs will not be exhausted until about 1993.[13]

General Dynamics

General Dynamics won the contract for the Air Force's Medium Launch Vehicle II which will result in an upgraded version of the company's Atlas/Centaur rocket to an Atlas II. At 2680 kg to Geosynchronous Transfer Orbit (GTO) the Atlas II's payload capability will be 20% greater than Atlas/Centaur. The Air Force has ordered four Atlas II's with options for seven more at a total cost of $600 million.[14] The company will be offering both the Atlas II and the Atlas/Centaur (dubbed Atlas I) on a commercial basis and presently has seven firm launch contracts. The first commercial launch is slated for November of 1990.

The Atlas I rocket (Figure 2-1) is the result of numerous redesigns over the past thirty years of an Atlas ICBM first launched in 1957. Of the three large launch

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[13] "Pegasus Air-Launched Test Vehicle is Rolled Out", *AW&ST*, 8/14/89, p. 40.

[14] "Space Commerce: An Industry Assessment", U.S. Department of Commerce, 5/88, p. 12.

TYPICAL ATLAS CENTAUR VEHICLE

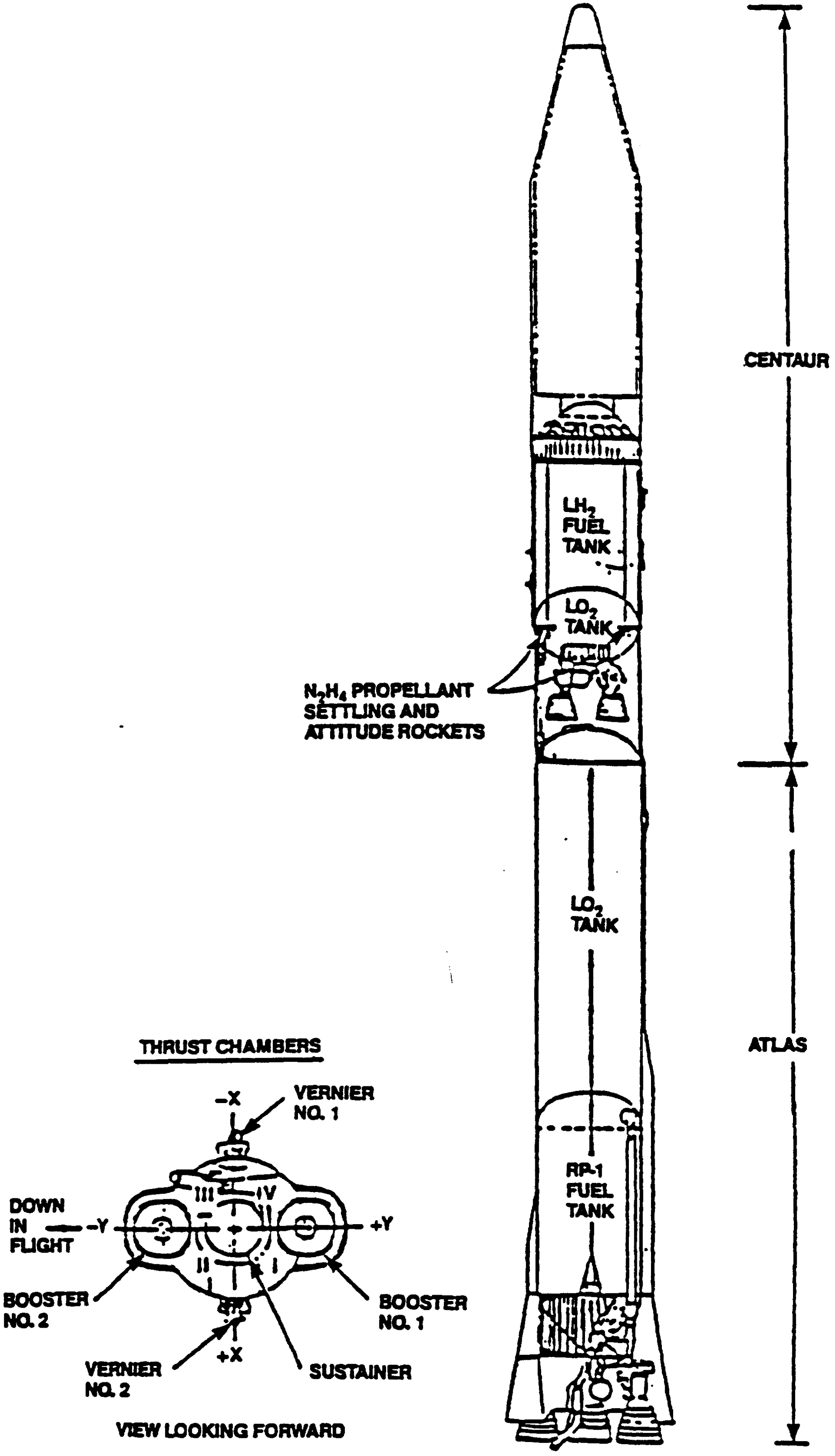

FIGURE 2-1

vehicles offered by U.S. companies, Atlas I is the only one which does not use any solid rockets. Its first stage uses non-cryogenic liquid fuel, and its highly efficient Centaur upper stage uses liquid oxygen and liquid hydrogen. The company may expand the series to include an Atlas IIA and possibly an Atlas IIAS each with a greater launch capability than its predecessor.

McDonnell Douglas

McDonnell Douglas' Delta rocket of today bears little resemblance to its ancestor the Thor ICBM. The Delta rocket has undergone over a dozen major redesigns since its first flight. As with all previous redesigns, the new Delta II 6925 (Figure 2-2) came about as a result of a government program. In this case it was the Air Force's requirement for a Medium Launch Vehicle with a slightly higher payload capability than the Delta 3920 (Delta II's predecessor) to launch its stock of 28 Global Positioning Satellites. The contract for these ELV's is worth almost a billion dollars.[15] The Delta II 6925 can boost 1450 kg to GTO and is being offered as the company's commercial ELV.

The Delta II(6925) consists of nine Castor Solid rocket strap-ons, a cryogenic liquid first stage, and non-cryogenic liquid second and third stages. The company manufactures the ELV's at a brand new facility in Pueblo Colorado made possible by the large government MLV contract. Future plans may include a Delta II (7925) with a 25% increase in payload capability over the Delta II (6925) to 1820 kg to GTO.

McDonnell Douglas has the distinction of being the first U.S. company to place a satellite in orbit on a commercial basis. The company has eight firm contracts for future commercial launches and seven more reservations for possible launches.

Martin Marietta

Martin Marietta has historically been the primary supplier of launch vehicles to the Department of Defense (DOD). Since DOD payloads tend to be very large, Martin's Titan series of ELV's have always had high payload capabilities, and presently Martin builds the two largest U.S. ELV's the Titan III with a capability of 5000 kg to GTO, and Titan IV with a capability of 4550 kg directly to Geosynchronous Orbit. However, unlike the other two large launch service providers, Martin does not plan to offer all of its ELV models on a commercial basis retaining the Titan IV

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[15] *Space Commerce: An Industry Assessment*, Department of Commerce, 1987, p.13.

TYPICAL DELTA VEHICLE

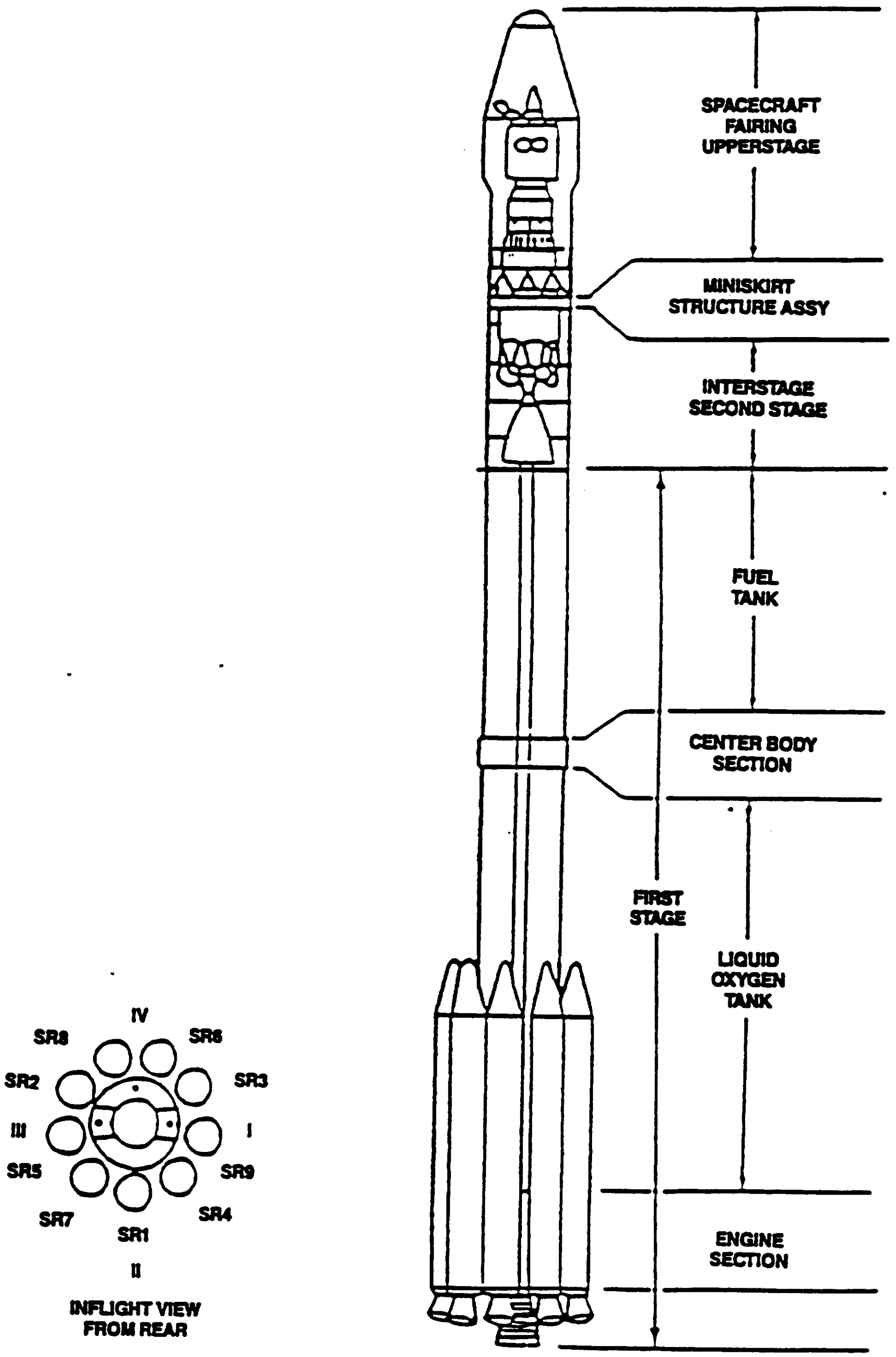

FIGURE 2-2

for the Air Force which has contracted for 23 vehicles at a cost of $10 billion.[16] While Martin Marietta's commercial launch vehicle, the Titan III, did not result directly from a government contract, it is built on the same assembly line, and uses many of the same employees as the Titan IV.[17] Thus, Air Force procurement of the Titan IV has a direct benefit to Martin's commercial launch program.

Titan III (Figure 2-3) uses two large solid rocket motors and two stages of non-cryogenic liquid rockets. Because of its high payload capability, Titan III will often be used to launch two satellites simultaneously into the same orbit. Currently Martin has four firm launch contracts and launched its first two payloads on a single launch in December of 1989. Martin's second commercial launch attempt resulted in a failure from improper wiring of the upper stage. Technical difficulties being experienced with Titan III coupled with sluggish sales may result in a decision by Marting to exist from the commercial launch business.[18] Another possible factor contributing to such a decision is the miniscule size of Martin's commercial contracts compared to the billions being brought in by the Air Force's Titan IV contract. Titan III may simply be more trouble than it is worth.

Other Companies

Through the 1980s many small commercial launch companies have been started and many have failed. The most recent is the American Rocket Company which has exited the commercial launch business after its first launch attempt in October of 1989 burned on the launch pad. Today essentially four start-up companies remain. These are E'Prime, Orbital Sciences, Space Services, and LTV. Each of these companies are competing for small payloads going to Low Earth Orbit (LEO) and suborbital experimental payloads, although several have plans for larger ELVs in the future.

E'Prime is proposing a family of four ELVs derived from MX missile technology with payload capability ranging from 450 to 3600 kg to Geosynchronous Transfer Orbit (GTO). The company has signed a commercialization agreement with the Air Force for the use of the MX technology, but at present the company has no firm launch contracts.

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[16] "Space Commerce: An Industry Assessment", U.S. Department of Commerce, 5/88, p. 12.

[17] "Commercial Titan Launch Vehicle Places Two Communication Satellites Into Orbit", AW&ST, 1/8/90, p. 43.

[18] *Space News*, "Future Clouded for Commercial Titan", 3/26/90, p.4.

TYPICAL TITAN VEHICLE

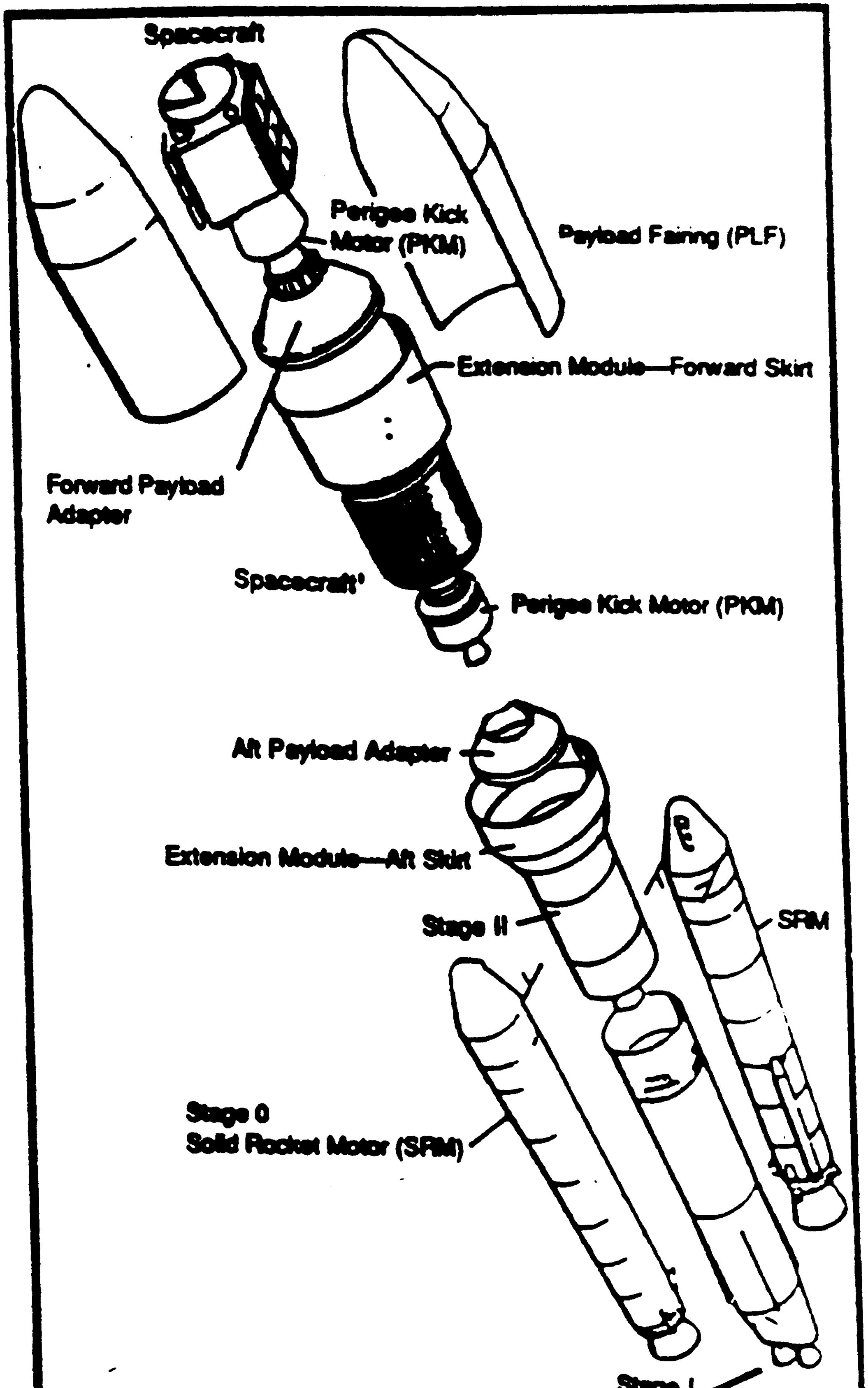

FIGURE 2-3

Orbital sciences is offering an innovative winged launch vehicle which is carried to high altitude by a B-52 and then released to fly into orbit. Payload capability is limited to about 500 kg to LEO. The Defense Advanced Research Projects Agency (DARPA) is presently the only customer having contracted for two $6 million dollar launches. The first launch occured in April of 1990 and was a resounding success

In September of 1982, Space Services became the first company to carry out a privately funded and operated launch. The company's Conestoga I ELV carried a small experimental payload on a suborbital trajectory on that day. A second suborbital launch attempted in November of 1989 resulted in a failure. The company plans two more launches in 1990. Space Services hopes to offer a series of Conestoga rockets which will be constructed by using increasing numbers of Castor solid rockets.

LTV manufactures the Scout rocket for the government. While the company has not officially begun to compete for new government contracts it has expressed a desire to do so.

Foreign -- Europe, China, and The Soviet Union

Along with the advent of the Space Shuttle came a shift in the U.S. dominance of commercial and foreign government payload launches to the European. But even the Europeans are beginning to face stiff competition from the Soviets and Chinese who, in their search for hard currency, are offering cut-rate launch prices (Table 2-2).

Arianespace

Measured by number of firm contracts, Arianespace is the largest launcher of commercial satellites in the world. Arianespace carried out its first launch in 1980 and has had 28 out of 32 successful launches through early 1990. Two of these failures occurred when the U.S. was experiencing its string of failures in the *Challenger* aftermath. As a result of the Ariane failures, Airianespace did not launch a vehicle for eighteen months contributing to the western backlog of payloads. Currently the company has 36 firm contracts worth $2.4 billion.[19] At present Arianespace represents the primary foreign competitor to U.S. commercial launch companies.

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[19] Arianespace, Press Release 89/13, p. 1.

Arianespace is a quasi-private company with 50 shareholders in eleven European countries. While a number of these shareholders are private companies, a significant portion of the company (and some argue majority) is held by various government agencies. The role of Arianespace is to market, procure, and launch the Ariane launch vehicles.

Currently Arianespace offers a series of six ELVs ranging in payload capability from 1900 kg to 4200 kg to Geosynchronous Transfer Orbit (GTO). Each increase in payload capability is achieved by strapping on additional solid and/or liquid rocket boosters (Figure 2-4). Arianespace launches its ELVs from a facility owned by the European Space Agency (Europe's equivalent to NASA), in Køurøu, French Guiana. This launch site is well suited for launching commercial payloads into GTO because it lies close to the equator where launch vehicles obtain a greater benefit from the Earths rotation.

TABLE 2-2

FOREIGN COMMERCIALLY AVAILABLE LAUNCH VEHICLES (1989)

Country/ Region	ELV	Payload Capability (kg)	Approximate Cost($M)
China	Long March 3	1400 (GTO)	20-30
Europe	Ariane 40	1900 (GTO)	55-105
	Ariane 42P	2600 (GTO)	
	Ariane 42L	3000 (GTO)	
	Ariane 44P	3200 (GTO)	
	Ariane 44LP	3700 (GTO)	
	Ariane 44L	4200 (GTO)	
Soviet Union	Proton	2100 (GTO)	30-50

China

The Chinese government has been aggressively marketing the launch services of their Long March ELVs to foreign customers. To do this the government has set up the China Great Wall Industrial Corporation. The Long March vehicles have proven enticing to satellite owners because of the cut-rate prices being offered by the Chinese government. These prices have been as much as 66% less

ARIANE LAUNCH VEHICLES

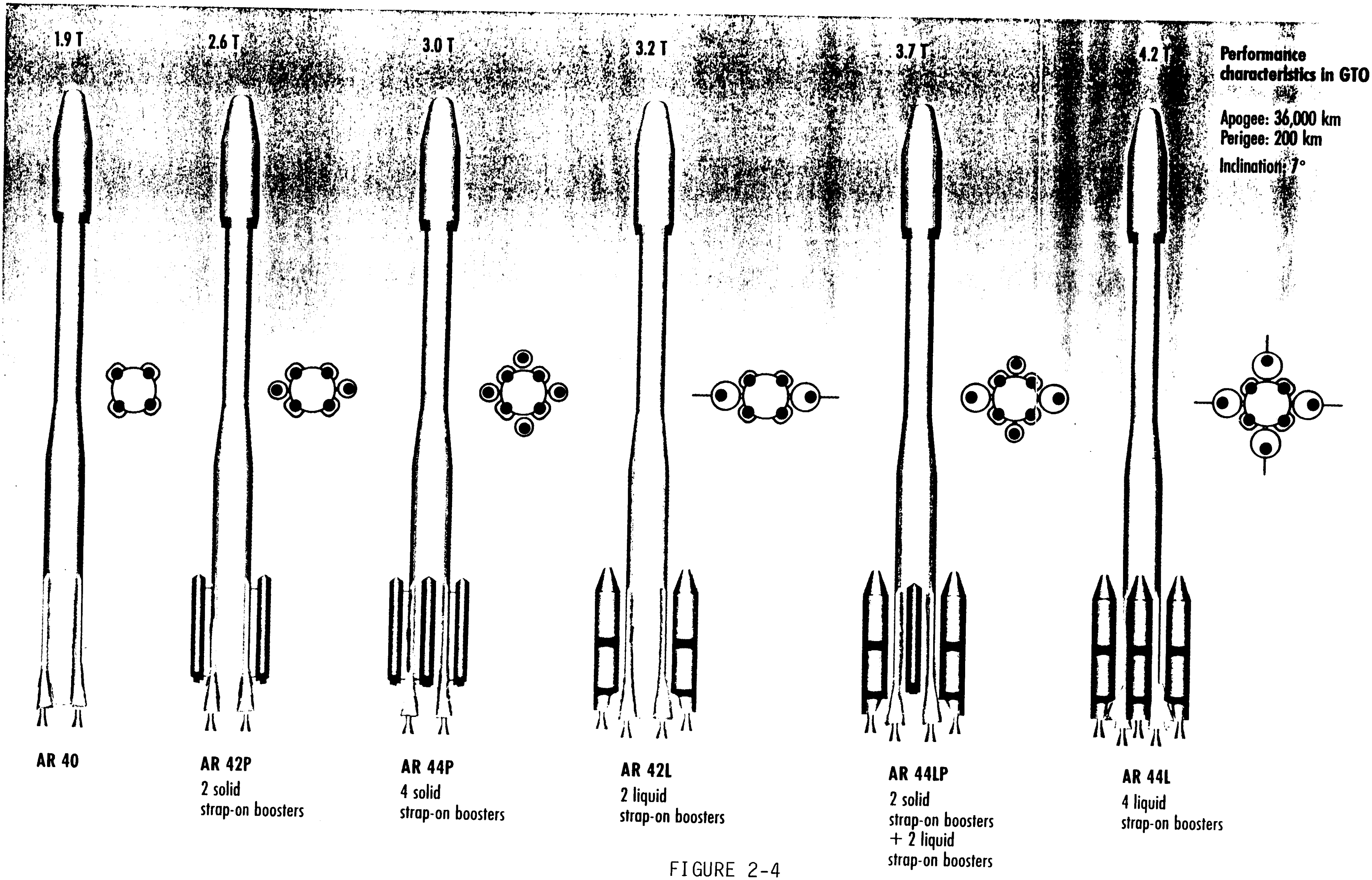

FIGURE 2-4

than U.S. prices.[20] China has entered into several agreements for satellite launches. The U.S. government has been reluctant to issue export licenses for U.S. manufactured satellites. However, after much debate, in 1988 the Reagan administration approved export licenses for three Hughes satellites. These licenses were subsequently suspended for several months as a result of the Tienamen Square incident, but have since been reinstated. In April of 1990, China successfully launched the first of these satellites.

The Chinese also market sub-orbital flights for micro-gravity experiments. France has contracted for two missions, one of which was successfully completed in 1987. A West German consortium also flew some micro-gravity experiments aboard a Chinese mission in 1988.

Soviet Union

The Soviet Union markets its launch services in the U.S. through a Texas based company called Space Commerce Corporation. The low prices being offered by the Soviet government have created a large interest in their launch services. However, the U.S. government has yet to approve any export licenses for satellite launches by the Soviets. In fact, a recent amendment to the 1990 appropriations bill prohibits such launches unless the President certifies that such a launch is in the "national interest". Recently the Soviet Union began an effort to circumvent U.S. government opposition by offering to sell Zenit boosters to Australia which would then launch them from their proposed Cape York facility. Congress immediately passed legislation setting rigid pricing guidelines for any such launches. The Soviets have numerous ELVs, but have primarily been marketing their Proton launch vehicle to foreigners. Presently the Soviets have no firm contracts for foreign satellite launches.

The U.S. restriction on satellite launches does not appear however to extend to micro-gravity experiments. A collection of such experiments designed by Payload Systems Inc. of Massachusetts will be delivered to the Soviet space station MIR in early 1990. They will then be returned to the Earth two months later. Thus far, Payload Systems is the only U.S. company that has been granted an export license by the Commerce Department.

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[20] "U.S. Approval of Chinese Launches Determined by Value of Satellites", *AW&ST*, 10/7/88, p. 25.

Other Nations

The Japanese government is completing development of their new H-2 launch vehicle which will have a payload capability of 4000 kilograms to GTO. The first launch of the H-2 is presently scheduled for 1993. Once the H-2 is operational, it is likely that the Japanese government will offer it on a commercial basis. However, before the H-2 is complete, the Japanese will not be able to enter the commercial market because their current launch vehicle, the H-1 was built using U.S. Delta technology under a licensing agreement which prohibits the use of the vehicle for commercial launches.

The Indian government has a small launch vehicle which might be offered for sub-orbital flights, and the Brazilians are in the process of developing a launch vehicle. At present, however, neither India or Brazil have offered their launch vehicles on a commercial basis.

2.5 CUSTOMERS -- THE BIG ONE, THE OTHER ONE, AND THE ETHEREAL ONE

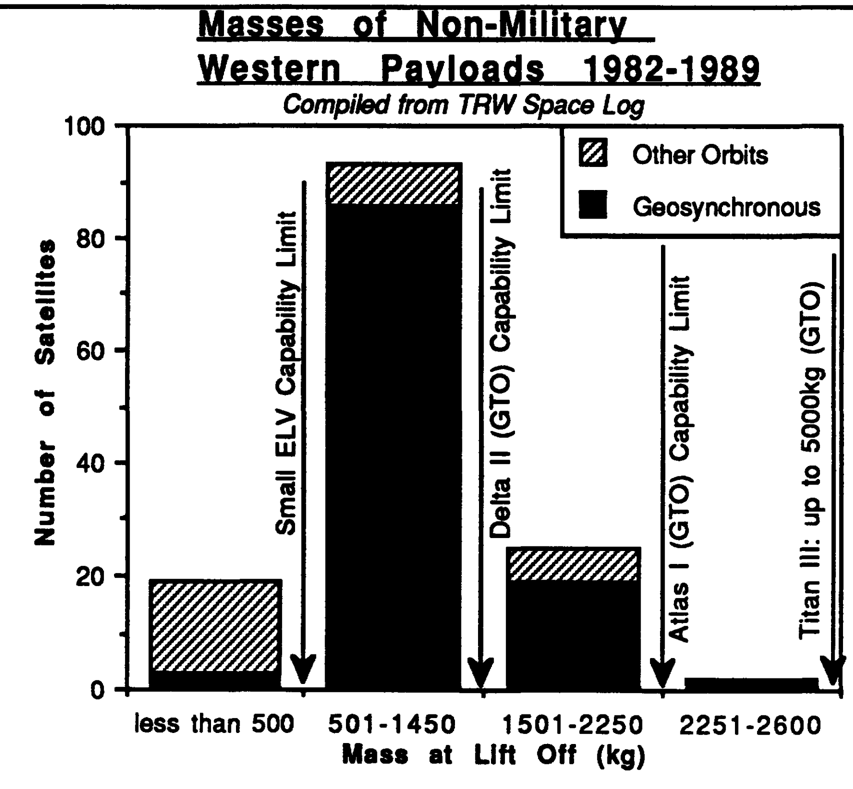
Launch vehicle payloads can be broken down into two broad categories. First are large satellites placed into a sustainable orbit. Next are very small satellites launched into low orbits, and experimental payloads which require low-gravity or high altitudes and are launched on sub-orbital trajectories.

Large Satellites

The majority of space launches are intended to place a satellite into orbit. In the U.S. this is presently being done by the three big launch companies and the Space Shuttle. Satellite construction can be financed by the commercial sector, foreign governments, or the U.S. government. Excluding military payloads (for which data is classified), the vast majority of satellites over the past eight years have had masses ranging from 500-1500 kilograms and have been launched into a Geosynchronous orbit (Figure 2-5) where they stay over the same point on the Earth while orbiting. While most of these satellites could have been launched by any of the three large U.S. launch vehicles, military payloads used for reconnaissance can be much larger with launch masses reaching 40,000 kilograms and can often only be launched on Titan or the Shuttle.

In the short term the future demand for satellite launches can be predicted with fairly good accuracy because it takes several years to design, build and launch most satellites.[21] Thus, the satellites in production today will constitute most of the launch demand for the next two or three years. However, predicting long-term demand in excess of those satellites already planned is very difficult to do accurately and previous estimates have been atrociously poor. For example, in 1979 NASA, using a model prepared by Battelle, predicted the equivalent of 44 shuttle flights for 1985, but in 1985 only 12.5 equivalent shuttle flights occurred.[22] The further into the future the prediction goes, the worse it will inevitably be.

Every commercial satellite placed in orbit has been a communications satellite, and most foreign government satellites placed into orbit by the U.S. have been for communications. Through the 1970's and early 80's demand for satellite communications grew steadily. However, the advent of fiber optics in the mid 1980's has begun to make a dent in the demand for satellite communications.[23] For point to point communication, such as between two telephone switching centers,


Masses of Non-Military Western Payloads 1982-1989

Compiled from TRW Space Log

FIGURE 2-5

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[21] "Launcher supply Expected to Exceed Payload Demand in 1990s", *Space News*, 2/19/90, p. 28.

[22] *Setting Space Transportation Policy for the 1990s*, Congressional Budget Office, 10/86, p. 10.

[23] *Space Commerce: An Industry Assessment*, Department of Commerce, 5/88, p. 43.

fiber optic cables represent an economical alternative to satellites. While demand for some other types of satellite communications, such as direct broadcast and mobile service, continue to grow they may not make up for the losses in point to point demand. The number of communications satellites in construction and awaiting launch over the next few years seem to confirm this as they decrease steadily from 1990 to 1992 (Figure 2-6). Granted a few more satellites might still be built over the next few years, but it seems extremely unlikely that the number to be launched in 1992 would grow by enough to surpass 1990 levels. Thus, commercial satellite and foreign launch demand will remain constant or decrease over the next few years.

On the other hand, U.S. government demand for ELVs will increase in 1990 and remain steady over the next few years. The Air Force is planning seven Delta, six Titan IV, and two Atlas launches, over the next several years for a total of fifteen launches per year. In addition, the Navy, Department of Commerce, and NASA, will be launching a total of two to three payloads per year on ELVs. As a result, in 1990 over 70% of U.S. ELV launches will be for government payloads.[24] In 1991 this fraction will very likely become even higher since the number of commercial and foreign government payloads will decline. Even if U.S. companies captured all of the uncommitted payloads for 1991 (an extremely unlikely possibility), government satellites would still account for well over 60% of U.S. satellite launched on ELVs. Thus, the U.S. government will continue to dominate the demand for U.S. ELVs over the next several years.

Presently no other viable market appears to exist for commercial satellites other than communications. For a while remote sensing appeared like it may be a promising new commercial use of satellites. But efforts to commercialize the remote sensing services of LANDSAT were a resounding failure, and presently no private company has plans to construct a remote sensing satellite.[25] As a result of the lack of other markets, communications satellites will continue to constitute the vast majority, if not all, of commercial satellite demand for the foreseeable future.

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[24] Compiled from company manifests.

[25] *Space Commerce: An Industry Assessment*, Department of Commerce, 5/88, p. 60 and p. 71.

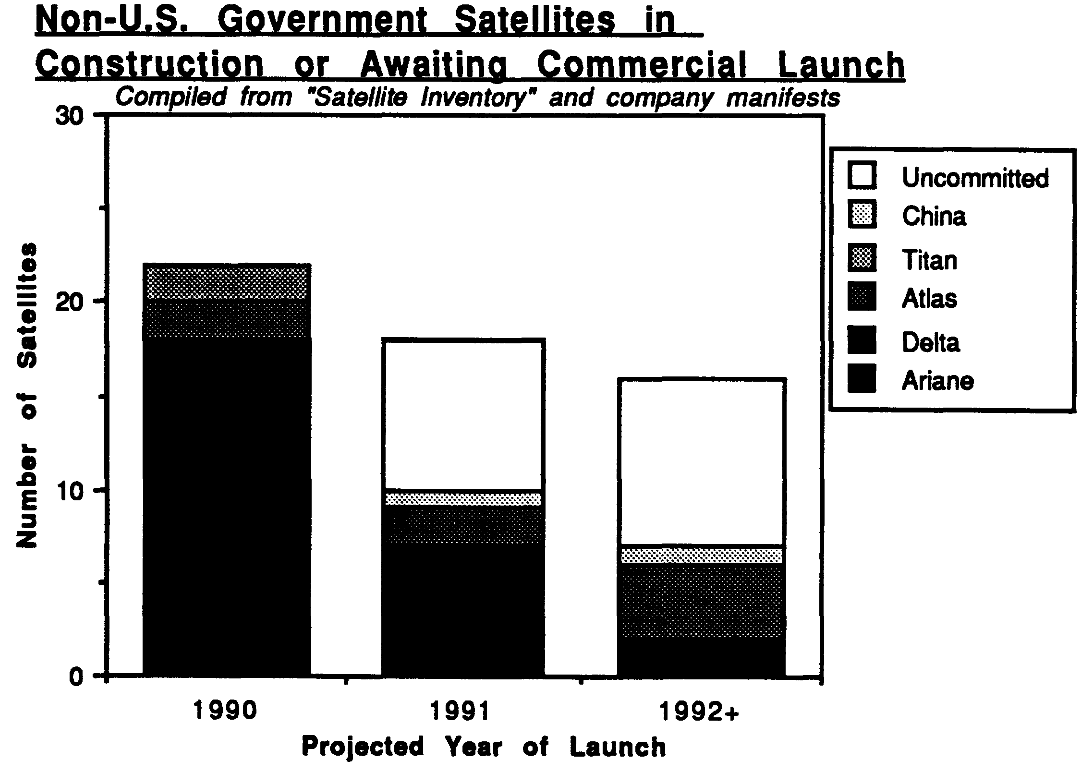

FIGURE 2-6

As previously mentioned, in the long-run it is very difficult to say exactly what launch demand will be like. However, even Battelle's model, which made the ridiculously high prediction for NASA, predicts that the number of communications satellites requiring commercial launches through 1999 will be at most 20 per year (Figure 2-7) which is less than the number being launched in 1990 and only four more than those presently planned for 1991. Launch and satellite industry experts themselves believe that demand will remain flat in the years to come.[26] If Arianespace continues to capture 50% of this market, then only 10 satellites will be launched commercially by U.S. companies each year -- the same number planned for 1990. Even if the three large U.S. companies and Arianespace each launched equal portions of future demand (an unlikely scenario considering other competitors are attempting to enter the launch market), at present government launch rates the U.S. government would still account for well over 50% of domestic demand.

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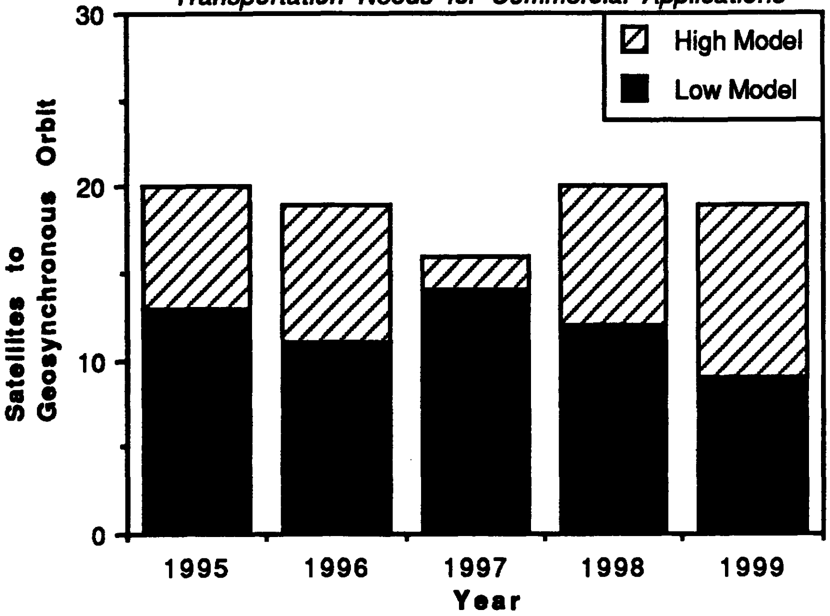
[26] "1990s Promise to Trim Ranks of Launch Firms", *Space News*, 2/19/90, p. 6.



Battelle Model Long-Term Commercial Launch Demand Estimates

SOURCE: Brackeen, "The Future Space Transportation Needs for Commercial Applications"

FIGURE 2-7

Long-term government demand will be determined by policy decisions made in the future. For example, SDI would require an enormous number of ELV launches. Also, if the Space Station is built, it will require a majority of the Shuttle flights for assembly and resupply. This will push other planned government satellites onto ELVs. Government programs will almost certainly account for the majority of U.S. ELV demand over the next several years, and as the dominant customer, will definitely have the single greatest influence on long term domestic launch demand.

Small and Sub-orbital Payloads -- A Commercial Facade

The government operated Scout is the only small U.S. ELV to have placed a payload into orbit. The satellites launched by Scouts have all been government financed and commercially no firm plans exist for small satellites. The greatest demand for the small launch vehicles currently being offered by several small entrepreneurial firms has been for sub-orbital flights. These payloads have primarily been experiments requiring a low-gravity environment or high altitudes. All of the experiments which have been launched on small ELVs, and all those planned, have been financed directly or indirectly by the U.S. government.[27]

Commercial demand for sub-orbital flights is almost non-existent. The use of the microgravity environment for materials processing has received much attention, and has been touted as a future area of commercial growth, but private financial commitments have been very small. Many point to McDonnell Douglas' microgravity experiments which were flown on the Space Shuttle, and claim that this indicates the potential of future commercial demand. However, the drug processing experiments flown by McDonnell Douglas, and other private microgravity ventures, have been heavily subsidized through NASA Joint Endeavor Agreements or Centers for the Commercial Development of Space.[28] McDonnell Douglas received a free flight on the Shuttle for its experiments.[29] Even with such subsidization, in recent years many companies, including McDonnell Douglas, have discontinued their microgravity experiments.[30]

The cost of space flight makes the economic viability of any space processed material unlikely. One expert estimates that for a space processed material to be economical it would have to sell for more than $100,000 per kilogram, or nearly ten times the cost of gold.[31] Because of this, and the highly uncertain prospect that microgravity research will result in a marketable material, future commercial investment in sub-orbital experimental flights is unlikely to be significant without government subsidization.[32]

Near-term government demand for small ELVs will be five to six per year.[33] However, as mentioned in section 2.3, the government still has a stock of Scout launch vehicles that it intends to use, and which will not be exhausted until about 1993. This will put a dent in demand for commercially available small ELVs over the next few years. The long-term government and commercial demand for small ELVs will be highly dependent on government policy. Government programs such as

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[27] Personal Communication, Eric Gabler, Department of Transportation, 1/15/90.

[28] *Space Commerce: An Industry Assessment*, Department of Commerce, 5/88, p. 101.

[29] *Space Commerce: An Industry Assessment*, Department of Commerce, 5/88, p. 101.

[30] *Space Commerce: An Industry Assessment*, Department of Commerce, 5/88, p. 99. and "Small Launchers to Vie for CCDS Science Payloads", *Space News*, 2/12/90, p.1.

[31] "Space-Born Materials: How Practical Are They?", Sheahen, *Materials Engineering*, 8/87, p. 27.

[32] "Government Interest in Small Launchers Grows", *Space News*, 2/19/90, p. 7.

[33] "Pegasus Air-Launched Test Vehicle is Rolled Out" *AW&ST*, 8/14/89, p. 40.

DOD's Lightsat communications satellites, or tests for SDI, would greatly increase future demand.

Thus, future demand for domestic small ELVs will continue to be driven by government programs and government subsidization of private payloads.

2.6 CURRENT GOVERNMENT SUPPORT

With their historical role as government programs, launch vehicles, and their associated infrastructure, continue to receive government support for technological development. This section briefly examines the current government technology development efforts both in the United States and abroad.

United States

Before the creation of the CLI in the United States, the government financed all research and development towards technological advances for launch vehicles and their infrastructure. Now commercial launch companies are beginning to commit some of their own funds to improve their vehicles and facilities. However, the U.S. government still foots the bill for the vast majority of R&D for existing and new launch vehicles. It does this through improvements to government owned launch facilities, procurement of ELVs, and leading edge technology programs. Currently there are three primary government initiatives to advance launch vehicle technology. These are, the National Aerospace Plane, the Advanced Launch Vehicle (ALS), and Civilian Space Technology Initiative (CSTI),

National Aerospace Plane (NASP)

The NASP program is an effort to develop a completely new means of high speed propulsion using air-breathing hypersonic "scramjet" engines. Multiple missions have been proposed for NASP including high speed civilian transport, strategic defense, manned space flight, and placing payloads in orbit at significantly reduced cost. Regardless of the mission, NASP will face enormous technical challenges in the areas of propulsion, fuels, materials, and computational fluid dynamics. Currently, the program envisions a manned vehicle that would take off from a conventional runway, accelerate to speeds up to Mach 25, and have the capability to fly into orbit. The present effort is geared towards developing a single experimental vehicle designated the X-30 in the mid 1990's. Through 1989 total program funding will be over $800 million. The 1989 funding for the program is $316 million with NASA contributing $88 million and DOD $228 million.[34] Estimates for the total cost to develop the experimental vehicle have ranged from $3 billion to over $17 billion[35], and estimates of the cost per flight from $1 million to $9 million.[36] Current plans envision a vehicle with a payload capability of about 9000 kg to Low Earth Orbit (LEO).

Advanced Launch System (ALS)

ALS was born as a result of the need to place the large volume of payloads required for the Strategic Defense Initiative (SDI) into orbit at a reasonable expense. Jointly managed by DOD and NASA, the original goal of ALS was to reduce launch cost by a factor of ten to about $600 per kilogram to LEO. Several contractor concept definition studies suggested vehicles with enormous payload capabilities ranging from 23,000 to 90,000 kilograms to LEO. Most of the concepts also called for partially reusable launch vehicles with unmanned fly-back boosters. However, the various studies differed in their dependence on new materials and advanced propulsion technologies. Some argued that cheaper materials and rockets offset the drawback of increased weight or lower efficiency while others argued the exact opposite. Estimates of the cost to develop ALS ranged from $3 billion to $15 billion dollars.[37]

As a result of SDI budget cuts in 1989, the ALS program was changed from an effort to build a new launch vehicle to a technology development program (which some are now calling the Advanced Launch Technology Program or ALTP). Funding for ALS in 1990 will be $120 million which is about 40% less than the amount originally planned by the Air Force.[38] With shrinking SDI budgets the Air Force has been looking to relinquish its role as the lead agency in the project making it clear (if there was ever any doubt) that SDI was the driving force behind ALS. At present it is not clear whether NASA will take over as the lead agency or if the program will fade out of existence. However, if NASA takes over as the lead agency, indications are that the focus will shift to producing a large highly

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[34] *Round Trip To Orbit*, OTA-ISC-419, 8/89, p. 75.

[35] "The Aerospace Plane: Technological Feasibility and Policy Implications", Korthals-Altes, MIT-PSTIS, Report #15, 5/86.

[36] *Round Trip To Orbit*, OTA-ISC-419, 8/89, p. 68.

[37] "USAF Cuts Vehicle Design Work on ALS", *AW&ST*, 12/18/89, p. 112.

[38] "USAF Cuts Vehicle Design Work on ALS", *AW&ST*, 12/18/89, p. 112.

efficient rocket engine prototype.[39] Such an engine might be used on a large ELV for voyages to the Moon or Mars which NASA envisions.

Civilian Space Technology Initiative (CSTI)

CSTI is a NASA effort to enable less costly space transportation and operations by funding research which leads to demonstrations of actual hardware. Funding for the program in 1989 was $122 million.[40] About 30% of CSTI funds are designated for propulsion technology.[41] These efforts focus on developing a large scale advanced cryogenic liquid propulsion booster engine very much like the one being discussed by NASA for the new ALTP program. A portion of the funds for propulsion research are also being used to develop a liquid booster to replace the solid rocket boosters on the Shuttle.[42] Other areas of research in decreasing order of funding, include automation & robotics, structures, information systems, vehicle concept development, and power generation. However, work in these areas focuses almost exclusively on manned projects centered around the proposed Space Station.[43]

Procurement -- The R&D Workhorse

Historically improvements to todays ELVs have resulted primarily from small incremental changes achieved through government production contracts and not through leading edge of technology development programs. The large ELVs of today bear little resemblance to their predecessors. For example, the Delta ELV has undergone over a dozen major changes during its thirty year history. Such changes resulted directly from government requirements for slightly improved (generally larger payload capability) launch vehicles.

The most significant recent government support for commercial launch vehicle and infrastructure technology was the procurement of the medium launch vehicle (MLV), the MLV II, and the Titan IV by the Air Force. As discussed in section 2.1, without these large DOD contracts to restart production lines it would have been difficult for U.S. companies to enter the commercial launch market. In

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[39] "USAF Cuts Vehicle Design Work on ALS", *AW&ST*, 12/18/89, p. 112.

[40] NASA, Office of Aeronautics and Space Technology, Congressional Budget, 1/2/90.

[41] *Launch Options For the Future*, OTA, p. 56.

[42] "Civilian Space Technology Initiative: A First Step", NASA, TM-100944, 1988, p. 7.

[43] "Civilian Space Technology Initiative: A First Step", NASA, TM-100944, 1988 and *Launch Options For the Future*, OTA, p. 56.

addition, these contracts financed increases in payload capability for the major launch company's ELVs. Similarly, government orders for the small ELVs currently being offered on a commercial basis are the only reason these companies could finance their R&D and why these companies still exist today.

Launch Facilities

The government owns, manages, and maintains the launch facilities for all commercially available U.S. ELVs. As a result, improvements to those facilities have historically been government financed.

Europe

Aside from than U.S. companies, the only launch company not completely government owned and operated is Arianespace which procures, markets and launches Europe's Ariane launch vehicles. The Ariane ELVs were developed by the European Space Agency (ESA) which is jointly financed by a group of 15 European governments. ESA not only performed the R&D for the launch vehicles, but also funded the initial demonstration launches before turning the vehicles over to Arianespace for commercial use. In many ways this has mirrored what happened with the commercial ELVs in the United States where the government paid for ELV development and recently turned them over for commercial use. However, ESA does not finance small incremental changes considered to have little or no risk, such as the recent expansion of the Ariane 44's lift capability. Nor does ESA directly fund incremental improvements in manufacturing facilities of Arianespace contractors although some improvements which benefit Arianespace come about as the result of other ESA contracts.[44] Similar to the situation in the U.S., the Ariane launch facilities in French Guyana are government owned (by ESA) and any improvements to them are funded by the European governments. In all cases, the cost of implementing any new technology developed by ESA resides with Arianespace. Thus, while ESA develops new technologies, Arianespace must still pay to purchase them.

Currently ESA is designing the Ariane 5 launch vehicle which will have a payload capability of 5800 to 6800 kilograms to GTO. One of the primary missions envisioned for Ariane 5 is the launching of the Hermes space shuttle which is also

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[44] Personal Communication, Mr. Weinreich, Arianespace, 1/10/90.

under development. However, Arianespace also plans to offer Ariane 5 as a commercial launch vehicle. The first launch of Ariane 5 is presently scheduled for 1995. In 1988, ESA funding for space transportation systems, including the development of Ariane 5, was about $700 million.[45]

Other Countries

In the case of all other countries which currently sell launch services for commercial and foreign government satellites, or which may offer them in the near future, the launch vehicles are procured and launched by government agencies. Thus, research, development and implementation costs of all technological improvements are funded by the government. Efforts are underway in Japan, China, and the Soviet Union to improve existing launch vehicles and facilities, and to design new launch systems.

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[45] *ESA Annual Report '88*, Europe and Space Agency, 1988, p. 210.

3.0 POSSIBLE MOTIVATIONS FOR MAINTAINING A COMPETITIVE INDUSTRY

If the government is going to take actions specifically to enhance the competitiveness of the CLI, then the industry should hold some importance for the nation. What does the nation have to gain from a competitive CLI? Answering this question is essential because different motivations will yield different sets of reasonable alternatives for government action. For instance, if the primary motivation for building a new launch vehicle was to provide transportation to Mars, it would look very different than one built to reduce launch costs. Arguments which have been used in support of government action for the CLI have covered all the bases including national security, national prestige, government cost reductions, and international trade. The objective of this chapter is to evaluated each of these in turn to determine their credibility as reasons for maintaining the competitiveness of the CLI and in doing so provide a framework for evaluating any government action.

3.1 NATIONAL PRESTIGE

The space program has historically had high visibility and has been a source of national prestige. The first launch of U.S. satellites by a foreign entity, Arianespace, presented a blow to that prestige as the nation and Congress realized that America no longer held a monopoly in the western space launch business. But it was the U.S. government which held that monopoly, and not a commercial industry. The bruise to national prestige resulted primarily because the launch industry was still being looked at in the light of a national space program. In a competitive commercial environment, the other company will win sometimes. If the nation is to have a commercial launch industry this must be accepted.

In formulating government policy for the commercial launch industry, a differentiation must be made between the political goal of national prestige and the economic goal of competitiveness. In general, the political objective of national prestige is achieved through engineering successes, such as placing a man on the moon. Commercial success, on the other hand, relies on making a profit. While national prestige may be an acceptable motivation for developing new technologies, it is a weak one, and in many cases one incompatible with enhancing the competitiveness of an industry.[1] For example, development of a supersonic transport by France brought national prestige to the country but it has proven to be a poor commercial airplane. Since national prestige in space is driven by engineering success rather than profit, such prestige can be more efficiently obtained through a government program (where profit is irrelevant) than through the private sector. Improving the competitiveness of the CLI may increase the market share of U.S. companies but its impact on national prestige would not even approach that obtained through an Apollo, Space Shuttle, or Space Station program. If launching western payloads is critical to national prestige then the U.S. could return to subsidized government launches and recapture much more of the market than will be possible with a CLI.

3.2 NATIONAL SECURITY

In the aftermath of the Challenger accident the government quickly realized that it was a poor idea to place all of its faith in one launch vehicle. As a result a "mixed fleet" strategy, using the shuttle and ELVs, was adopted. With the commercialization of the launch industry, some have argued that a competitive CLI is important for ensuring access to space. This is just not the case. Even if the U.S. CLI went out of business (i.e., did not offer any commercial launch services) this would not mean the U.S. would lose its ability to build ELVs -- government procurement of ELVs alone could maintain a viable industry. This was clearly demonstrated following the *Challenger* accident when large orders from the Air Force were the only reason launch companies were able to afford the cost of restarting previously closed production lines.[2] If DOD needs to place a payload in orbit and wishes to do so on an ELV then it can procure the ELV as it has done in the past whether a CLI exists or not. Thus, a competitive CLI is not required to ensure that ELVs are available for national security needs.

Another national security issue which has been raised is the potential for technology transfer to non-western nations from launches of U.S. satellites by those nations. Ostensibly such technology transfer would occur because the launching nation would be able to inspect the payload during integration with the ELV. Special security measures were included in the recent Chinese licensing

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[1] "The Government's Role in the Commercialization of New Technologies: Lessons for Space Policy", Rose, *Economics and Technology in U.S. Space Policy Symposium*, 6.86, p.97.

[2] "Space Commercialization Myth and Reality", Albert Wheelon, unpublished manuscript, 1/25/89, p. 4.

to improve competitiveness, then the situation is really no different than that which existed before the creation of the CLI when government financed all improvements to launch vehicle technology. Whether government invests to reduce the cost of ELV's it procures or those it purchases commercially, the end result for government costs would be the same. The government would only save additional money from new technology if the competitive environment drove industry to invest some of its own funds towards technological improvements. Government efforts to enhance industry competitiveness through technological development would not necessarily result in increased private contributions for similar measures. In fact, government funding to improve launch vehicle technology could have the opposite effect by reducing the incentive for companies to invest on their own (see Chapter 4.0).

Yet, ensuring the competitiveness, and thus the existence, of a CLI still might save the government money by providing a means to avoid the inefficiencies in government procurement of ELVs. This savings would come from reduced oversight, and increased incentive within the industry to reduce cost. There is strong evidence that companies under government contract to build an ELV have little incentive to reduce cost because "their profit/cash flow is reduced when they perform under budget."[5] In addition, the government requires expensive documentation for oversight. All of these factors drive costs above those that might be commercially available. Experts estimate that the government could save 10%-20% of the total cost of a launch by purchasing commercial launch services rather than procuring ELVs.[6]

The government could, in theory, obtain similar cost savings simply by procuring ELVs in a "commercial" manner (i.e., without extensive oversight). The CLI merely provides an avenue by which the government can do so, but the existence of a commercial launch industry is by no means required to obtain such cost savings. Nor does the existence of a CLI guarantee that government will take advantage of the opportunity for reduced costs. The Air Force, which accounts for the bulk of large government payloads, has contracted for very few commercial launches and this trend is likely to continue. The Assistant Secretary of the Air Force recently stated that "the Air Force would like to provide all launch services

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[5] *Reducing Launch Operations Costs*, OTA-TM-ISC-28, 9/88, p. 20.

[6] Personal Communication, Ed Blond, Aerospace Corporation, 11/15.

[for Air Force Payloads] and will continue to attempt to do that".[7] Ostensibly this is because of the unique technical and security requirements for Air Force payloads.

Even for supposedly commercial launches of government payloads evidence exists that much oversight will continue to be required negating potential cost savings. For example, an upcoming commercial Titan III launch of a NASA payload will cost $40 million (or 35%) more than a typical Titan III launch as a direct result of government requirements and oversight.[8] Thus, the mere existence of a CLI does not guarantee that government will take advantage of this avenue for reducing costs. With or without a CLI, if the government continues to require extensive production oversight it will pay the cost of that oversight.

3.4 INTERNATIONAL TRADE

The large U.S. trade deficit has been a drag on the economy and a focus of much attention. With commercial launch prices ranging from $40 to $120 million[9] for all but the smallest of payloads, launching satellites is big business. In 1990 alone 24 satellites are slated to be launched commercially at a value of about $1.3 billion.[10] Prior to 1984 the U.S. enjoyed a monopoly over the launches of western payloads. Even though the U.S. Government carried out all of the launches during the monopoly years, payments for the service fully benefited the American economy because the government paid launch facility workers and bought U.S. ELVs with the funds. But, ever since 1984 the U.S. market share has been steadily decreasing primarily as a result of competition from Arianespace. Of the 24 commercial satellites to be launched in 1990 only nine will be launched by U.S. companies.[11] While the launch manifests for 1991 and beyond are not firm yet, preliminary indications show little improvement for the U.S. industry over the next few years.

With the high cost of launches, overseas launch competition can have a significant impact on the trade deficit. To put this impact in perspective, Senator Bensten noted that "every three satellite launches lost by U.S. companies is equal to

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[7] "Pentagon Plans for Heavy Use of Current Rocket Fleet", *Space News*, 2/19/90, p. 26.

[8] "Briefs", *Space News*, 1/15/90, p. 30.

[9] "Price Estimates of Launch Vehicles", Office of Commercial Space Transportation, data sheet, 5/89.

[10] Ibid., also company commercial launch manifests.

[11] Ibid.

10,000 imported cars".[12] Ariane's launch service contracts for 1990 represent lost business opportunities for the U.S. worth approximately $750 million.[13] Improved technology could allow the U.S. CLI to better compete with its primary competitor Arianespace resulting in improved sales of domestic commercial launch services. However, improved technology is unlikely to allow U.S. companies to compete with the subsidized and therefore extremely inexpensive prices being offered by China and the Soviet Union anytime soon, if ever. Since nearly all commercial launches place U.S. manufactured satellites into orbit, present U.S. trade restrictions will prevent extensive competition from these nations. But for the Soviet Union such restrictions may soon become difficult to maintain due to the changes occurring within the nation. If restrictions are lifted then the U.S. government would need to reach some sort of a pricing agreement with the Soviets to enable the U.S. CLI to compete.

3.5 SUMMARY

The clearest motivation for a government effort to enhance the competitiveness of the CLI through technological development are the potential economic benefits of increased domestic launch contracts. If government foots the entire bill for new technologies, the net result for government costs will be no different than if a Commercial Launch Industry did not exist. The government would save additional money from new technologies for the CLI only if industry invests some of its own funds for technological development. The existence of a CLI also provides an avenue by which the government can purchase launch services without extensive oversight resulting in considerable cost savings. But with or without a CLI if the government requires extensive oversight it will pay the price for it. The government could, in theory, obtain similar savings even without a CLI simply by procuring launch vehicles in a "commercial" manner. Finally, neither national security nor national prestige provide a sound basis for government action to maintain a competitive CLI through technological development.

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[12] "Companies Submit Commercial ELV Requests", *AW&ST*, 3/16/87, p.26.

[13] "Price Estimates of Launch Vehicles", Office of Commercial Space Transportation, data sheet, and Arianespace manifest.

4.0 ECONOMIC RATIONALES FOR GOVERNMENT INTERVENTION

Under most circumstances a commercial industry would be left to operate without direct government intervention to enhance its competitiveness allowing the free market to drive innovation. But having been born as a government program, and having government as a primary customer, the CLI is far from your typical commercial industry. The unique nature of the industry lead many to argue that the market fails to provide the environment necessary to ensure efficient allocation of resources, or that the potential benefits to society are greater than private benefits leading to under investment from a societal point of view. Due to these market failures it is argued that the government must take action. These arguments inevitably fall into one of three categories. First, economic barriers exist to private development of technology. Second, the CLI represents a "strategic" industry necessary for future economic growth. And finally, the CLI faces government financed foreign competition.

4.1 BARRIERS TO PRIVATE DEVELOPMENT

Private industry bases any decision to research or develop a technology on the potential profitability of the venture in comparison to other alternatives for investment. The potential profitability of any investment in technology is influenced by the expected return on investment, the technical and market risk associated with that expectation, and the cost of capital to finance the venture. Each of these elements factors into a company's decision and each influences the other. For example, ventures which are perceived as high risk will generally have high capital costs and thus will require large returns on investment.

Just because industry elects not to develop a technology does not automatically imply that some sort of barrier exists. Often a technology may just be a bad investment with little potential for a profitable return. A barrier to private development of a technology may exist when either the expected profit, the risk, or the capital cost, is skewed as a result of factors external to the market for the technology or flaws in the market itself. Such a distortion decreases the overall potential profitability of a technology reducing or eliminating the incentive for private investment. Since the question at hand is whether the government should take actions specifically to enhance the competitiveness of the CLI through technological development, and not whether broader macro-economic steps are needed for the nation's industries as a whole, the important factor is whether the CLI faces barriers which other industries do not. For the CLI, financial market failure and non-appropriability of the products of R&D are often fingered as the primary causes of such distortions. In reality they present much less of a barrier than two other areas which are frequently overlooked: government policies & programs, and industry segmentation.

Financial Market Failure

Financial market failure occurs when financing is unavailable for a project even though it appears to exhibit the potential for returns commensurate with the risk. It is often argued that the high risk, extremely long lead times, and enormous investments, associated with space ventures incapacitates the financial market's ability to supply financing for projects even if they appear commercially viable.

Does technological development for the commercial launch industry exhibit high risk, long lead times and large investments? Incremental improvements to existing launch vehicles or facilities rarely exhibit all of these features and often exhibit none of them. Historically, most incremental improvements have involved implementation of existing or slightly improved technology with little technical risk, and relatively short lead times. For example, the recent MLV contracts, while government financed, resulted in improved Delta and Atlas ELVs in just a few years. More exotic improvements to existing launch vehicles, such as development of a highly efficient engine, would be more likely to exhibit high cost, high risk and long lead time. Likewise, development of an entirely new launch vehicle would tend to exhibit such features. In general, the greater the level of technical improvement desired, the greater the risk, cost, and lead time will be.

Does the financial market refrain from financing projects which are high risk, long lead time or high cost? Numerous examples exist of projects exhibiting these features which have been privately financed. In the 1960's IBM virtually bet the company by risking billions of dollars on development of its highly innovative System 360 design.[1] Every year pharmaceutical firms invest roughly

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[1] "The Government's Role in the Commercialization of New Technologies: Lessons For Space Policy", Rose, *Economics and Technology in U.S. Space Policy Symposium*, 6/86, p. 99.

$1 billion on R&D for new drugs with distant and uncertain returns.[2] Examples even exist within the aerospace industry. In the early 1950's Boeing invested a quarter of the company's net worth to develop the 707 aircraft prototype[3] and has spent billions since to develop other commercial aircraft. Hughes spent over $75 million (1990 $'s) to develop its commercial 376 satellite series with highly uncertain returns.[4] Over the next five years Hughes plans to invest more than $1 billion on satellite equipment.[5] Even small companies such as Orbital Sciences, which has spent $50 million to develop its Pegasus vehicle, have found it possible to obtain funding.[6] Chemical processing plants, baseload electric generating units, off-shore oil platforms, and recent investments in biotechnology all demonstrate the financial market's ability to finance projects exhibiting high risk, long lead, high cost, or all three. No evidence was found which would indicate that the financial market systematically fails to finance such projects whether space related or otherwise.[7]

This is not to say that the financial market will finance all development of technologies. Rather, it will provide capital for those technologies which appear to have returns commensurate with their risk and with other alternatives for investment. Exotic technologies which appear feasible may be passed over by the financial market because they do not appear profitable. This does not represent a failure of the financial market, in fact it shows that the market is working properly by allocating resources to the projects which are most profitable.[8]

Whether financing can be obtained at reasonable interest rates is another question. Much has been written about the high cost of capital which may be preventing private investment in the United States. But there is no indication that

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[2] "The Government's Role in the Commercialization of New Technologies: Lessons For Space Policy", Rose, *Economics and Technology in U.S. Space Policy Symposium*, 6/86, p. 99.

[3] *Civil Tiltrotor Industrial Base Impact Study*, U.S. Department of Transportation, DOT-TSC-VR806-PM-88-4, 4/88, p. 39.

[4] Personal Communication, Bud Wheelon, Former CEO Hughes, 1/25/1990.

[5] "Hughes Expansion Has Billion Dollar Price Tag", *Space News*, 12/11/89, p. 42.

[6] "Pegasus Air-Launched Test Vehicle is Rolled Out", *AW&ST*, 8/14/89, p. 36.

[7] See Leyard, "Economic Issues in the Development of New Technology: The Role of Government in Satellite Communications RD&A", *Symposium on Space Communications R&D*, National Research Council, 3/88, p. 143. and "The Government's Role in the Commercialization of New Technologies: Lessons For Space Policy", Rose, *Economics and Technology in U.S. Space Policy Symposium*, 6/86.

[8] Leyard, "Economic Issues in the Development of New Technology: The Role of Government in Satellite Communications RD&A", *Symposium on Space Communications R&D*, National Research Council, 3/88, p. 143.

the financial market systematically increases interest rates for space projects simply because they are space projects. In general, if space projects experience higher interest rates, it is because the project involves high risk, and not because the financial market has failed. If there is a problem of high capital cost then the problem generically effects all industries, and will require macro-economic actions which are not specific to the CLI.

Thus, even though more exotic launch vehicle technologies may exhibit high risk, long lead time, and high cost, it does not appear that this presents a barrier to private development when those projects offer returns commensurate with their risk and other alternatives for investment. Failure of the financial market to provide capital for a launch vehicle technology would be a good indication that the technology does not represent a profitable venture, and not that the financial market has somehow failed.

Non-Appropriability

Appropriability affords a company exclusive or nearly exclusive use of any beneficial result of R&D for some length of time. Non-appropriable R&D is unattractive to private firms because other companies could benefit from any beneficial results without having to pay for the R&D. The more basic the research the more distant and unclear the application to a commercial technology will be making it difficult to secure exclusive use of the results. At the other extreme, development of highly applied technology used in a commercial product would be easily appropriable through patents or trade secrets. In general, the more applied the R&D the more appropriable the result.[9]

For the CLI most incremental technology development would be highly applied and therefore highly appropriable. Incremental improvements to existing ELVs could not only be patented but in many cases would be so specific to the launch vehicle that other companies couldn't use them if they wanted to. Appropriability of technology does not appear to have hindered development of new small launch vehicles by numerous companies. For example, Orbital Sciences independently developed an innovative winged launch vehicle. Nor has it kept larger launch companies from making some investments in technical

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[9] "US Government Support for Civilian Technology: Economic Theory Versus Political Reality", Eads, Research Policy, 2/74, p. 13.

improvements such as General Dynamics' recent investment to improve the insulation on its Atlas ELV.[10]

The situation would be different for development of highly advanced, or "leading edge", technologies. Such technologies would likely require extensive basic R&D. For example, development of the National Aerospace Plane is demanding extensive basic R&D in materials, combustion, and aerodynamics. While the technology of the vehicle itself could be easily appropriated through patents or trade secrets, the basic research performed to gain the knowledge necessary to build it could not. However, the difficulty associated with appropriating the results of basic R&D are not unique to the CLI. As with all industries the more basic the R&D the less appropriable the result will likely be.

Government Policies & Programs

For large ELVs, government policies & programs represent one of the primary barriers to private development of technology. One way in which the government deters private investment in technology development is through the seemingly harmless act of purchasing launch vehicles. When the government procures launch vehicles it monitors quality and cost through stringent reporting requirements. Since commercial launches use the same vehicles (or same assembly line in the case of Titan) and facilities as government launches, commercial launch vehicles are subject to those regulations established for government procured vehicles.[11] Along with these regulations comes requirements for extensive documentation and reporting of changes in technology or procedures which must be approved by the government. This increases the time required to implement a new technology or procedure and incurs additional cost to the company. This problem is particularly pertinent to launch operations because the government owns the launch facilities. Not only are companies constrained by government procedures, but they have even less control over the technical characteristics of the facilities themselves. The Office of Technology Assessment noted that unless the government encourages investment in launch facilities and operations "by removing unnecessary barriers of documentation and reporting and rewarding innovation, launch firms

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[10] "Commercial Atlas Launch Systems", Matsumori, 39th IAF Conference, 10/88, p. 3.
[11] "Energizing the Space Launch Industry", Berkowitz, *Issues in Science and Technology Policy*, Winter 1989, p. 80.

are unlikely to assume such risks on their own."[12] The complications and added costs incurred from government oversight make companies reluctant to deviate from the present status quo.

In addition to the barriers created by government reporting and documentation requirements, the method by which government establishes the price it will pay for launch vehicles can create economic penalties to innovation. The normal incentive for a company to reduce cost comes from the ability to sell a product at reduced price (to obtain more customers) and/or increased profit margin. But when government procures large launch vehicles, companies often have little inducement to develop technology to reduce cost because they cannot expect significantly increased numbers of government payloads if prices are lowered or obtain increased profit. Reducing prices to the government would have little impact on the number of launch vehicles it purchased because government needs are controlled primarily by politics and policy. Since the large U.S. launch vehicles have discrete and unique payload capabilities most government payloads are confined to the use of an individual ELV (see section 2.4). This means that the government cannot competitively procure launch services for the majority of its payloads. In a non-competitive procurement the government allows the company to make a reasonable percentage profit beyond costs. If the company reduces cost then the government often demands reductions in price. Even after a contract is signed the government may renegotiate in order to capture any cost savings for itself.[13] As a result, government contractors have found that efforts to reduce cost can actually result in decreased profit on the project because the same percentage profit on lower costs yields lower profit.[14] Some recent government procurement contracts for launch vehicles have made efforts to be more innovative in providing incentives for companies to reduce costs. But as the Vice President of General Dynamics Commercial Launch Services noted, "...cultural and institutional changes are far from total in their acceptance and implementation."[15]

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[12] *Reducing Launch Operations Costs*, OTA-TM-ISC-28, 9/88, p. 80.

[13] "Economic Issues In The Development of New Technology: The Role of Government in Satellite Communications RD&A", Ledyard, *Proceedings of a symposium on Space Communications R&D*, National Research Council, 3/88, p. 152.

[14] *Reducing Launch Operations Costs*, OTA-TM-ISC-28, 9/88, p. 20.

[15] Dunbar, Dennis, Vice President, General Dynamics, Space, Science and Technology Subcommittee Hearing, 11/9/89.

The new launch companies offering small ELVs do not face many of the disincentives experienced by large launch companies from government procurement of ELVs. For these companies government is the only customer, and for the most part, when government purchases launch services from them it carries out much less oversight than with large ELVs. This results primarily because the payloads being launched on these ELVs are almost always inexpensive experimental payloads rather than expensive satellites fulfilling a defense or NASA mission. In addition, several companies are offering small ELVs with similar payload capabilities, so the government has the ability to competitively procure vehicles creating competition among the companies for these contracts.[16]

Another way the government deters private investment in launch vehicle technology is by spending money on R&D. Aerospace firms receive 80% of all government R&D funding that goes to industry.[17] As was discussed in section 2.6 the government has historically provided all R&D for launch vehicle technology, and continues to spend large sums of money. Over the years the well established launch companies have grown accustomed to this government support for their industry. When government invests in R&D for space technology the company has a virtually guaranteed profit margin. As a result, the corporate culture in the space industry tends to be extremely risk averse with respect to private spending for R&D of new technologies.[18] Why should a company risk its own capital when it can lobby government to obtain a contract which yields a comfortable return on investment with no risk? By offering a low-risk path, government support of R&D in the space industry acts to deter private investment even into technologies which appear to offer returns commensurate with their risk.[19]

It appears then that government policies and programs represent significant barriers to private development of technologies for the CLI. Yet, the deterrent created does not call for direct government support of R&D. In fact, such support represents one of the primary ways government creates a disincentive for private investment.

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[16] See"U.S. Government Ready to Place Orders for Small Launchers",*Space News*,3/12/90, p 8.

[17] *Using Federal R&D to Promote Commercial Innovation*, Congressional Budget Office, 4/88, p. 41.

[18] Personal Communication, Bud Wheelon, Former CEO Hughes, 1/25/1990.

[19] See James Bennett, Vice President AMROCK, *Space, Science and Technology Subcommittee Hearing*, 11/9/89, p. 6.

Industry Segmentation

Competition among firms offering similar products or services drives much of the private innovation which occurs in a free market economy. It would seem then that having multiple launch companies within the U.S. would provide added impetus for private development of launch vehicle technologies. For the small launch companies offering launch vehicles with similar payload capabilities, competition for government contracts appears to be working very effectively in driving private innovation. These companies have individually invested to develop the small launch vehicles they are offering. Unfortunately, the launch vehicles being offered by the large launch companies each have different payload capabilities (see section 2.4). This prevents extensive competition between these companies because many payloads can only be launched efficiently on one of the vehicles (it would be uneconomical to fly a small satellite individually on a large ELV). In fact, the only competition which could reasonably occur between U.S. companies comes from the ability of Titan III (the largest commercial ELV) to launch two smaller payloads, each of which might be launched individually on a smaller ELV. But as was mentioned in section 2.4, Martin Marietta, which makes Titan III, has won very few commercial launch contracts and may be withdrawing from the commercial business. If this occurs then the small amount of competition between large U.S. launch companies for commercial contracts will virtually disappear.

The main driving force behind any private innovation in the large U.S. launch companies lies in foreign competition. Arianespace, the U.S. industry's primary competitor, offers a series of launch vehicles with capabilities spanning those offered by the three large U.S. launch companies and can effectively compete for almost all satellite launch contracts. Segmentation of the U.S. industry narrows the potential market for each individual company. This reduces the benefit any individual company would obtain from a new technology because any investment must be recovered through cost savings on future launches, or an increase in the number of launch contracts won. As a result, some technologies for improving launch vehicles and facilities which might be economical at higher launch rates will be passed over by the U.S. companies. If a single large U.S. launch company existed which offered a full range of payload capabilities, it could economically invest greater amounts in new technology since it could expect higher launch rates and thus a more rapid return on its investment. In addition, a single company would have almost as much incentive to invest in new technology as the three current U.S. companies which do not compete extensively with one another. Thus, the segmentation of the large launch vehicle industry reduces the economic viability of private investments in new technology, but yields little of the increased incentive for investment which would normally come from increased competition.

Conclusions

Appropriability and the ability to obtain financing represent no more of a barrier to private investment for the CLI than in other industries. The real barrier to private development lies in the procurement practices and R&D funded efforts of the government. For large ELVs, contracts from the government can cause a disincentive to reduce cost while oversight and reporting requirements make changes in technology difficult. In addition, the segmentation of the large launch vehicle industry decreases the potential return to individual launch companies from any investment in new technology, without significantly increasing the incentive for investment which would normally come from competition.

4.2 THE STRATEGIC INDUSTRY ARGUMENT

The prospect that an industry is somehow "strategic" to the future economic well being of the nation has often been used by proponents of government support for industry specific technology development. The concept of strategic industries is itself highly controversial, and various definitions of what constitutes a strategic industry have been put forth. In general the definitions all encompass the concept that a strategic industry yields economic benefits to the nation beyond those generated by other industries with similar levels of activity.[20] A strategic industry does this through technological advances which create opportunities for innovation in related industries and which in turn generate further economic benefits. Due to the benefits generated external to the industry itself it is argued that government support is warranted. Assuming one accepts the theory it must be asked whether it is likely that the CLI represents a strategic industry?

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[20] *Federal Financial Support for High-Technology Industries*, Congressional Budget Office, 6/85, p. 3.

While the CLI is only a few years old, the launch industry itself has been around for thirty years. As a result, the service that it offers is far from new to the market place. A truly strategic industry would spawn other new industries and innovations in existing industries. Yet, over thirty years only one commercial industry has sprung up as a direct result of the ability to place payloads in orbit -- communications satellites. This can be compared with integrated circuits, which are commonly used as an example of a strategic industry, and the innumerable products which they have made possible.

Some argue that significant reductions in launch costs would spawn many new space industries. Yet, even if the cost of launch services dropped significantly, today it would still be difficult to find many commercial uses for operations in space beyond communications (see section 2.5). Some commercial navigation or remote sensing might become feasible, but the demise of the commercialization of Landsat, which was put in service at government expense, makes one skeptical about the latter. Low gravity materials processing has received much attention, but there has yet to be a break through which resulted in a material or processing technique which has a commercial application. While there can be no way to tell with certainty what would happen if launch prices decreased dramatically it appears that opportunities for vast expansion of commercial activities in space are presently quite limited.

It might be argued that the innovations in other industries which have resulted from the launch industry are not directly related to the act of placing a payload in orbit, but rather to innovations which were required to achieve the task. This is the "spin-off" argument. Certainly some spin-off has occurred as does from any industry and especially one which has been supported by billions of dollars in government funds. But the amount of spin-off is generally over stated. Most technologies developed for launch vehicles are highly specific and have no use in other industries. Only the more generic technologies such as materials or automation would generally find use outside the launch industry. Yet, the space industry often lags behind in the application of just such technologies.[21] The reason for this is linked to the need for high reliabilities which results in the desire to use proven technology which meets previous specifications. Due to this the launch industry might be better described as "high spec" than "high tech".

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[21] *Launch Options For the Future*, Office of Technology Assessment, OTA-ISC-383, 7/88, p. 13.

Given the questionable ability of the launch industry to spawn innovations in other industries, and the presently limited opportunities for expanded commercial uses of the space environment, the strategic nature of the industry must be doubted. Certainly other industries more clearly demonstrate the attributes of a strategic industry than the CLI. Thus, even if one accepts the controversial notion of strategic industries, justifying government support of the CLI on this basis would be dubious at best.

4.3 GOVERNMENT FINANCED COMPETITION

The U.S. CLI faces the spectre of government supported competition from every country with launch capabilities. Foreign government support ranges from financing of R&D for new technologies to complete government ownership and operation (see section 2.6). Given a similar situation in most other industries the U.S. response would be to attempt a resolution through trade negotiations. But the tradition of government support for technological development in the launch industry has kept the focus on R&D efforts. While some trade discussions on commercial launch vehicle pricing have taken place between the U.S. and Europe, the topic of government support for technology development in the industry has yet to be raised. In reality, even if the point were raised it would likely be dead on arrival because commercial launch providers are so closely linked to national space and defense programs. Some of the foreign competitors are essentially the governments of non-market countries themselves. As a result, foreign competitors will almost certainly continue to receive government support for development of new launch vehicle technologies for the foreseeable future.

Whether foreign government support for R&D of commercial technologies justifies similar actions within the U.S. remains an area of debate among economists.[22] However, even if one accepts that some support is justified on this basis, it does not justify unlimited expenditures. Would it be worthwhile to spend billions of dollars just to ensure a few millions in additional domestic launch contracts? If national prestige, or national security depended on the expenditure then it may, but the only reasonable motivations which have been identified for taking action to increase the competitiveness of the CLI are economic. While

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[22] See Leyard, "Economic Issues in the Development of New Technology: The Role of Government in Satellite Communications RD&A", *Symposium on Space Communications R&D*, National Research Council, 3/88.

expenditures might increase industry competitiveness, and thus the number of commercial launch contracts won by U.S. companies, at some point the additional contracts would cost the nation more than they are worth. Just because a foreign government elects to spend billions of dollars to develop new launch vehicle technology, would not automatically mean that it is in the interest of the U.S. to follow suit. In fact it may be more in the economic interest of the nation to simply take advantage of inexpensive subsidized foreign technology rather than matching the large subsidies.

The exact amount which might be reasonably spent on new technology would be nearly impossible to calculate accurately due to considerable uncertainty in the impact any technology would have on U.S. market share, uncertainties in future demand, and disagreement among economists on how to gauge the effect of such government expenditures on the economy. Writing on the topic one economist noted that "At best the numbers calculated will be statistics which bear minimal relationship to the real facts; at worst the numbers will be misleading."[23] However, realization that such a limit exists should temper any proposed government spending on launch vehicle technology for the CLI.

4.4 SUMMARY

For the large launch companies the primary barriers to the private development of launch vehicle technology are government policies and programs, and the segmentation of the U.S. industry. Government procurement can provide a disincentive to reduce cost, and oversight requirements can restrict the ability of companies to implement new technologies. The segmentation of the large launch vehicle industry presents a barrier to private development of technology by reducing the economic viability of private investments in new technology, without yielding the increased incentive for investment which would normally come from increased competition among multiple companies. Government R&D programs themselves also provide a disincentive to private investment by providing a low risk path to development of new technology.

Even if one accepts the controversial notion of strategic industries the CLI represents an unlikely candidate for such a distinction. Justifying government

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[23] Leyard, "Economic Issues in the Development of New Technology: The Role of Government in Satellite Communications RD&A", *Symposium on Space Communications R&D*, National Research Council, 3/88, p. 140.

spending on this basis would be dubious at best. Government support for foreign launch providers may represent a reasonable economic rationale for government efforts to improve launch vehicle technology, but any spending on this basis must be tempered by the realization that excessive government expenditures could reduce the net benefit to the nation of increased commercial launches.

5.0 ENHANCING THE COMPETITIVENESS OF EXISTING LAUNCH SYSTEMS

Whether a technology will enhance the competitiveness of a company depends not only on the economic benefit obtained, but also on how much it would cost the company. For a commercial launch company the sunk cost of developing and manufacturing (or purchasing) a technology must be amortized over the ensuing launch vehicles and recovered in the form of cost savings or increased customers from reduced prices. The higher the launch rate, the greater the benefit from a new technology will be each year. Low launch rates would require larger savings on each ELV to make an investment in a new technology profitable. However, if government covers some of the cost, then a technology can be beneficial with smaller cost savings. Thus, the net benefit to a company of a technological improvement depends on the cost of obtaining the technology, the economic benefit from it per ELV, the realized launch rate, and the level of government support.

Ideally, the costs and benefits associated with a proposed technology would be quantified to guide government policy. But estimates of the net benefit which might be obtained from new launch vehicle technologies are extremely inaccurate and highly variable. For example, development cost estimates for ALS and NASP have ranged from $3 billion to over $15 billion.[1] Estimated operating costs for NASP have ranged from $1 million to $9 million per launch.[2] Previous estimates of the potential benefits from various sub-system level launch vehicle technologies are no different, often varying by more than an order of magnitude.[3] The poor nature of all these estimates results from the "subjective and unreliable" methods used for estimating the cost to develop a new technology,[4] and the equally poor predictions of long term launch demand which were discussed in section 2.5. Technological risk, or the chance that the development or application of a technology will fail to meet it specified technical goals, also contributes to the uncertainty of such

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[1] "USAF Cuts Vehicle Design Work", *AW&ST*, 12/18/89, p. 112. and "The Aerospace Plane: Technological Feasibility and Policy Implications", Korthals-Altes, MIT-PSTIS, Report #15, 5/86.

[2] *Round Trip To Orbit*, OTA-ISC-419, 8/89, p. 68. and "The Aerospace Plane: Technological Feasibility and Policy Implications", Korthals-Altes, MIT-PSTIS, Report #15, 5/86.

[3] See the various Space Transportation Architecture Studies and *Reducing Launch Operations Costs*, OTA-TM-ISC-28, p. 70.

[4] *Launch Options for the Future*, OTA-ISC-383, 7/88, p.14.

estimates. In general, the more exotic the proposed technology, the worse the estimates become.

The Office of Technology Assessment has noted that "The Aerospace field is rife with examples of technologies that took much longer to develop and implement and cost much more than originally anticipated...."[5] In fact, in two of OTA's recent launch vehicle studies, one of the primary findings was that better cost estimating methodologies need to be developed.[6] Until better methods are developed, attempting to quantify the potential costs and benefits from new launch vehicle technologies would only lead to inaccurate and misleading results. Over dependence on such poor estimates in developing government policy would likely lead to improper conclusions.

Rather than attempting to explicitly quantify the costs and benefits from any new technology, this chapter will identify those technologies which are key to improving the competitiveness of the CLI. This will be achieved in part by exploring where costs come from and by identifying the known technical and economic trade-offs associated with proposed technologies. The emphasis will be on identifying what is known and accepting what remains uncertain. Previous estimates of the net benefit which might be obtained from proposed technologies will only be used with extreme caution and, when possible, on an ordinal (i.e., comparison) rather than cardinal (i.e., absolute) basis to avoid erroneous conclusions about what the actual net benefit may be.

Before evaluating any technologies, it must be realized that competitiveness entails more than just the price of a launch. Competitiveness can also be increased by reducing the cost of risk management (such as insurance), the potential for launch delays, and the cost of financing the launch.[7] The first three items might potentially benefit from improved technology. However, the cost of financing a launch is controlled almost exclusively by the world money market, and is independent of factors related to the launch.[8] Improvements in technology would have little or no impact on financing costs for commercial launches. Thus, it would not make sense to explore the financial market in the context of this thesis.

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[5] *Launch Options For the Future*, OTA-ISC-383, 7/88, p. 47.

[6] *Reducing Launch Operations Costs*, OTA-ISC-TM-28, 9/88 and *Launch Options For the Future*, OTA-ISC-383, 7/88.

[7] "The Selection of a Launch Vehicle", Greenberg and Christensen, 25th Space Congress.

[8] "Space Transportation--The Commercial Users Perspective", Simanis, AIAA 88-3492, p.2.

The remaining three areas are explored in the following sections where it is shown that one group of technologies holds the key to reducing launch costs, and that important disparities exist between the needs of government and the commercial launch industry. The next chapter then turns to entirely new launch systems.

5.1 LAUNCH PRICE

The terms "launch price" and "launch cost" have been used in many different contexts to mean many different things. No "right" definition of these terms exists per se, but it is important to have a clear and common understanding of how these terms will be used. In this study "launch cost" is the total cost to the commercial launch company of manufacturing and launching an ELV. It does not include the cost of items such as insurance, financing, or launch delays. "Launch price" is simply the launch cost plus the profit margin added by the commercial launch company.

When comparing prices of different launch vehicles the total cost or price of a launch has little meaning because larger ELVs will inevitably cost more. As in other transportation industries where cargo rather than people are being transported, the useful basis for comparison is the specific price (i.e., price per unit mass). In addition, the destination of the cargo influences price since some destinations are further away or more difficult to reach. As noted in Chapter 2, commercial payloads predominantly go to geosynchronous orbit (GEO). However, when a satellite goes to GEO, the ELV usually only takes it a portion of the way to its destination to what is called a geosynchronous transfer orbit (GTO). From that point the satellite's own rockets propel it to its final destination. Thus, for satellites going to GEO, transportation costs are usually compared on the basis of dollars per kilogram to GTO. In cases where comparisons between launch vehicles incapable of reaching GTO are needed, the cost per kilogram to low earth orbit (LEO) is most often used.

To create reductions in launch price <u>through technological development</u>, specific launch cost must be reduced. Neglecting for the moment the cost of obtaining and utilizing a new technology, the <u>specific</u> launch cost of existing ELVs can be lowered by reducing the cost to manufacture and launch the ELV, or by improving performance. Improvements in performance can take three forms. First, the mass of ELV hardware can be reduced. Second, booster engine efficiency can be increased. And third, for reasons that will be discussed later, sometimes simply increasing the ELV's size can yield benefits.

Reducing Manufacturing and Operations Cost

Any effort to reduce manufacturing and launch operations cost should begin by examining where cost comes from. Figure 5-1 shows the cost for three recent U.S. launch vehicles broken down into five categories. The cost data shown is the result of a compilation of government costs for ELV procurement and launch operations performed by the Aerospace Corporation in 1984. Aerospace Corporation also simultaneously performed a similar compilation of expected commercial launch costs. However, the commercial data is considered proprietary. Can this data be taken as representative of current launch systems? While none of the current commercially available ELVs are represented explicitly in this data, the current ELVs resulted from incremental modifications to them and are very similar in design to those shown in Figure 5-1. Also, the author of the report noted that many of the tasks falling into the categories of "Government Services" and "Other Government" would need to be performed by commercial launch companies anyway, and while commercial costs were estimated to be 10% to 20% lower, the savings were spread fairly evenly among the categories represented. The cost breakdown of the currently available U.S. commercial ELVs should therefore be comparable to the data presented.

Looking at Figure 5-1, manufacturing is the largest fraction of each launch vehicle's cost. Breaking manufacturing cost down further into labor cost and materials reveals that about 60% of manufacturing cost can be attributed to the cost of labor.[9] The reason for this high percentage lies in the fact that each ELV is virtually hand made.[10] The other costs shown in Figure 5-1 are also almost entirely labor related. As a result, the cost of labor represents about 70% of total launch cost. With such a large portion of launch costs coming from labor, technologies which reduce the number of man-hours required to manufacture and launch an ELV would appear to have the potential for reducing launch costs. Even a small percentage reduction in labor cost would outweigh much larger fractional cost reductions in other areas.

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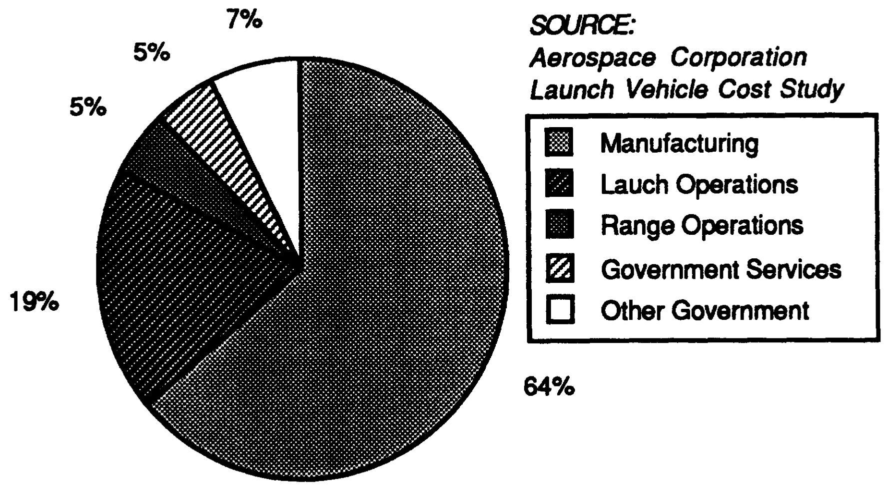
[9] Personal Communication, Ed Bock, General Dynamics, 11/17/89.

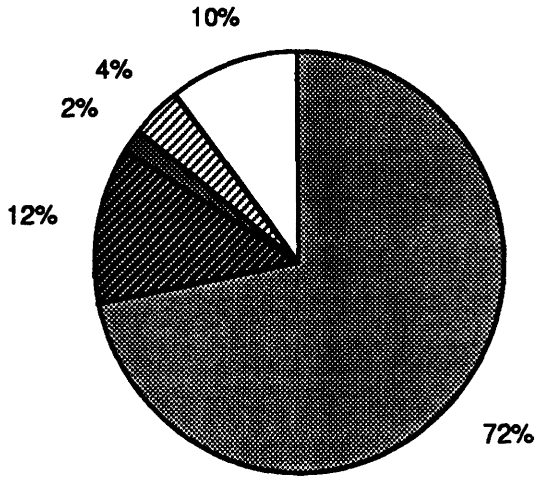
[10] "Big Dumb Boosters: A Low Cost Transportation Option?", OTA Background Paper, 2/89, p.25.

Cost Breakdown For Delta/PamD



SOURCE:
Aerospace Corporation
Launch Vehicle Cost Study

Cost Breakdown For Titan 34D/Transtage



Cost Breakdown For Atlas/Centaur

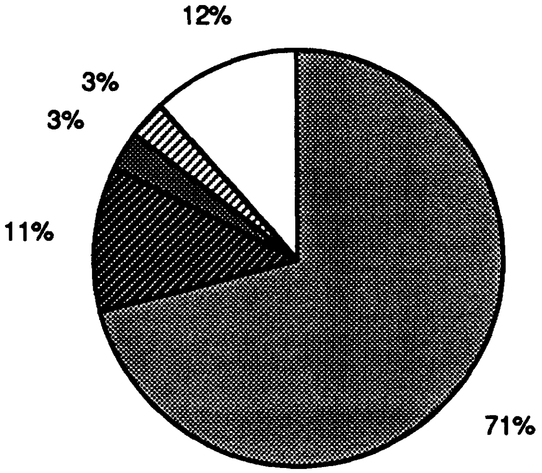


FIGURE 5-1

It is not surprising then that studies focused on reducing launch cost have consistently identified labor reducing technologies as the top prospects for the near term. The most extensive such studies have been the multi-million dollar Space Transportation Architecture Studies (STAS) performed by three separate contractors and the Air Force in the early 1980's. STAS was an effort to create a framework for meeting the nation's future space transportation needs at low cost. The STAS studies ranked technologies on the basis of reduction in life cycle cost or internal rate of return, both of which account for the full cost and benefits of the technology. All four studies identified various labor reducing technologies such as automation, and new information systems as the most promising technologies for reducing costs in the near term.[11] Some examples of the specific technologies explored include computer integrated manufacturing, expert systems, paperless management systems, and applications of existing and new automation equipment. Although the estimated net benefit of such technologies varied enormously among the various studies, technologies which reduced the cost of labor consistently ranked the highest.

Do the conclusions reached in STAS apply to the CLI? STAS assumed a very high launch rate averaging almost 500,000 kg to orbit per year, and thus large total costs savings each year.[12] In the unusually busy year of 1985 the U.S. placed only 275,000 kg into orbit -- about half of what STAS has projected.[13] STAS also assumed that all investments would be made in a single launch system which would launch all payloads. In the CLI each company has its own manufacturing and launch facilities so each would require separate investments and each company only launches a portion of each years payloads so it would receive only a fraction of the annual benefit. As a result, it is reasonable to expect that at present launch rates the net benefit to any individual company would be significantly less than those estimated in STAS. However, since the reductions in the return on investment from the lower launch rate would be common to all of the technologies evaluated in STAS, the ranking of the technologies would remain unchanged.

While many of the technologies explored in STAS require further R&D before they could be used, some of the technologies which could reduce labor costs in the CLI are already in use in other industries.[14] Many aerospace experts argue that

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[11] Martin Marietta, General Dynamics, Boeing, and Air Force, STAS.
[12] Martin Marietta, STAS, X88-10258, p. 3-13.
[13] "Getting Into Space: Rockets and Shuttles", Wheelon, unpublished manuscript, 4/11/89, p. 9.
[14] *Launch Options For the Future*, OTA-ISC-383, 7/88, p. 13.

significant cost savings could be achieved simply by "modernizing manufacturing facilities".[15] Thus, the technological risk associated with some technologies for reducing labor cost is very low. Whether such technologies can actually reduce manufacturing and operations costs will be highly dependent on the cost of the technology to the company, and the launch rate. However, it seems reasonable to conclude that technologies which reduce labor costs, have the greatest potential for reducing manufacturing and operations costs.

Reducing ELV Hardware Mass

The specific launch cost of an ELV can also be reduced by reducing the mass of the launch vehicle's hardware allowing the vehicle to carry more payload instead. Even though ELV hardware constitutes only about 10% of the Gross Lift-Off Weight (the rest is almost entirely propellant), its mass can be 10 times greater than the payload.[16] Thus, even a small percentage reduction in hardware mass can have a significant impact on payload capability.

Current ELVs appear to have nearly reached the economic limit of reducing weight through design with current manufacturing techniques. Efforts to produce lighter weight hardware from standard materials requires labor intensive precision manufacturing as part thickness or size is reduced.[17] This may be why studies such as STAS have focused on weight reduction through use of advanced light weight materials. Some of the top advanced materials candidates currently under study include new aluminum alloys such as Aluminum-Lithium offering a 10% density reduction, and carbon composites such as graphite epoxy with up to 40% density reductions.[18]

On a dollar per kilogram basis advanced materials are much more expensive than their traditional counterparts sometimes costing as much as 300% more.[19] However, the value of increased payload capability is enormous. For example, the specific launch cost of an Atlas/Centaur is about $29,000 per kilogram to GTO, and thus an additional kilogram of payload capability would be worth $29,000. Current specific costs for the structural materials which would be the top candidates for

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[15] *Launch Options For the Future*, OTA-ISC-383, 7/88, p. 47.

[16] "Commercial Atlas Launch Systems", Matsumori, IAF 88-170, 10/8/88, p.5.

[17] "Big Dumb Boosters: A Low-Cost Space Transportation Option?", OTA Background Paper, 2/89, p. 13.

[18] General Dynamics, Martin Marietta, and Air Force STAS.

[19] *Advanced Materials By Design*, OTA-E-351, 6/88, p. 123.

replacement with advanced materials are well under $20 kg. Thus, if advanced materials could simply be substituted for their traditional counterpart the 300% increase in materials cost (about $60 per kg) would be insignificant when compared to the benefit. Even the modest 10% density reduction offered by Aluminum Lithium would yield a benefit of $2900 for each replaced kilogram of traditional material -- far greater than the increased materials cost.

The problem with advanced materials lies in the difficult and labor intensive task of fabricating with them. Most advanced materials require unconventional fastening and forming techniques. As a result, designing with advanced materials can sometimes lead to more complex parts. This complexity reduces the benefit of lower density by requiring a greater amount of material. Some attempts to use composites in the aerospace industry have actually resulted in heavier parts.[20] The complexity of design also increases the difficulty of fabrication. In the aerospace industry, composite structures are commonly fabricated by slow and labor intensive means.[21] As a result, labor costs for composites can be much greater than for standard materials. Most cost information on the use of advanced materials is proprietary, but one set of data from OTA showed that not only do materials costs increase by hundreds of percent, but so can labor costs.[22]

The economy derived from using advanced materials on launch vehicles depends much less on the cost of the material than on the ability to design and manufacture efficiently (i.e., with low labor cost) with them. For some materials overcoming the complications of fabricating with advanced materials would be aided by improvements in fastening and forming techniques. But in general, economical use of advanced materials will be driven by simpler designs and automation of repetitive or complex tasks to reduce the cost of labor required to manufacture with them.[23] It should be no surprise then that the STAS never ranked improvements in materials higher than technologies for reducing labor costs. Advanced materials will be unlikely to economically reduce ELV mass without measures to reducing the cost of fabricating with them.

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[20] "Economic Issues in Composites Manufacturing", McLane, American Society for Composites, 1988, p. 26.

[21] *Advanced Materials By Design*, OTA-E-351, 6/88, p. 79.

[22] *Advanced Materials By Design*, OTA-E-351, 6/88, p. 80.

[23] "Economic Issues in Composites Manufacturing", McLane, American Society for Composites, 1988, p. 27.

Improving Booster Engine Efficiency

A more efficient booster engine would allow the mass of propellant required at lift-off to be reduced. The engineering efficiency (i.e., efficiency which does not consider cost) of a rocket is generally measured by the specific impulse which is the thrust of the rocket divided by the weight flow rate of propellant. The highest specific impulse engines of current launch vehicles are those fueled with liquid hydrogen and liquid oxygen (LOX-H2) such as the Centaur upper stage, and the Space Shuttle Main Engines (SSME) while the lowest are solid boosters such as those used on Delta, Titan and the Shuttle.

Even though high specific impulse engines can increase the fraction of the gross lift-off weight dedicated to the payload, they may not improve the specific launch cost (i.e., $/kg). The ideal engine has high performance, high thrust-weight ratio, and is inexpensive. But high engine performance requires tight design margins, and more complex designs with more parts.[24] This drives up the cost and weight of the rocket engine. Thus, a trade-off exists between improvements in the engineering efficiency of rockets, and the cost of the rockets which causes the optimum engine to lie somewhere between those which are expensive with high efficiency, and inexpensive engines with low efficiency. Exactly where this optimum lies is currently a matter of debate (and would be different for different ELVs anyway), but regardless of the optimum, the high cost of the most efficient engines can be prohibitive for ELVs where they will literally be thrown away after one launch.

Why are higher specific impulse engines so much more complex and expensive? If we take the extreme comparison between solid and LOX-H2 rockets the reason becomes clear. Solid rockets are basically a fuel filled shell with a nozzle on the end, while LOX-H2 engines are intricate mechanical devices requiring plumbing, pumps, and many other parts. Engine complexity also increases when striving to improve the performance of liquid engines. Higher performance liquid engines generally operate at higher temperatures and pressures requiring tighter design specifications and the addition of complex mechanical systems such as turbopumps and cooling systems. High pressure pump fed engines, such as the shuttle main engines, may have 15000 parts compared to 100 for more simple pressure fed engines like the Transtage used to power to upper stages of Delta II and

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[24] "Space Transportation Booster Engine Selection", Meisl, AIAA 87-1852, p. 3.

Titan III.[25] The turbopump alone is made of hundreds of rapidly moving parts and can account for 20% of the engines costs.[26] Also, in higher performance liquid engines the fuel nearly always requires cryogenic cooling yielding more complex designs. The increased complexity of the engines translates directly into increased labor cost because, like the rest of the launch vehicle, the rockets are basically hand made.[27] In fact labor cost represent about 70% of liquid rocket production just as it did for the entire launch vehicle.[28]

Incremental improvements to existing launch vehicles could be made to improve the engineering efficiency of the rockets, but the majority of these improvements would require increased complexity resulting in increased manufacturing costs. In addition, some engineers believe current liquid rockets are approaching the peak of their development potential in terms of specific impulse.[29] Therefore, significant improvements in specific cost from improved rocket efficiency will require more efficient manufacturing processes. A recent article on prominent rocket engine company's R&D efforts (Rocketdyne), noted that "Instead of focusing on the engine, the thrust of the technical advances are aimed at increasing the efficiency of the manufacturing process."[30] Increasing manufacturing efficiency could be achieved through simpler designs, automation of some manufacturing processes, and use of some advanced information system technologies.[31] The economic viability of applying such technologies will be dependent on their cost and the launch rate, but without attention to reducing labor costs, higher efficiency rocket engines are unlikely to improve the specific launch cost of existing ELVs.

Increasing Payload Capability -- Bigger Isn't Always Better

Over the thirty year history of the launch industry the principal factor leading to reduced specific launch price has been the increasing size and resulting

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[25] "Big Dumb Boosters", OTA Background Paper, 2/89, p. 12.

[26] "Big Dumb Boosters", OTA Background Paper, 2/89, p. 11.

[27] "big Dumb Boosters", OTA Background Paper, 2/89, p. 25.

[28] "Life Cycle Cost Considerations for Launch Vehicle Liquid Propellant Rocket Engines", Meisl, AIAA 86-1408, p.5.

[29] "Propulsion for Economic Space Transportation Systems", Bond, *Aerospace*, 8/88, p. 9

[30] "Rocketdyne to Use Simple Designs", *AW&ST*, 6/12/89, p. 29.

[31] "Life Cycle Cost Considerations for Launch Vehicle Liquid Propellant Rocket Engines", Meisl, AIAA 86-1408, p. 8.

increase in payload capability of ELVs.[32] Figure 5-2 shows how larger ELVs yield reduced specific price if the entire capability is utilized. Why does larger payload capability yield reduced specific costs? First of all, no matter how large the ELV, some sub-systems will remain virtually the same size. For instance, the guidance system for a large ELV does not need to be much larger than that for a small ELV. Also, if the fuel tanks are made larger, then the ratio of surface area to volume decreases allowing the tank to carry more fuel per kilogram of tank mass. These have the net effect of increasing the fraction of the gross lift-off weight which can be dedicated to the payload.

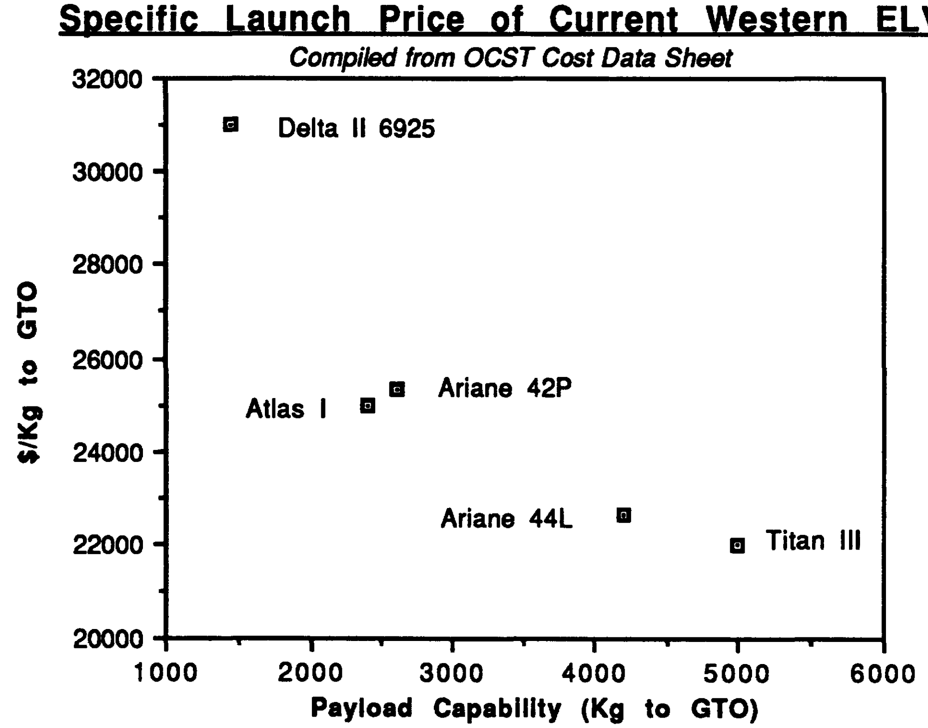

FIGURE 5-2

However, increasing the payload fraction of gross lift-off weight does not represent the only, nor the predominate factor leading to reduced specific cost. For example, the Ariane 44L has a greater payload capability and lower specific price than its predecessor the Ariane 3, but has a lower payload fraction of gross lift-off

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[32] *Handbook of Space Technology Status and Projections*, Hord, CRC Press, 1985, p. 6.

weight.[33] The other driver of reduced specific cost with increasing ELV size again lies in the cost of labor. Large ELVs benefit from economies of scale in production -- an ELV which is twice as large does not require twice the man-hours to manufacture. In addition, launch and range operations cost increase only slightly as the ELV size increases, but the launch places a greater payload into orbit.[34]

However, it must be remembered that the benefits afforded by increased ELV size can only be obtained if the payload capability is fully utilized. Thus, it only makes sense to increase capability if demand exists for larger payload capabilities, or if the payload increase is large enough to allow for the launch of multiple smaller satellites. In the past, increasing the size of ELVs has not been driven as much by the desire to reduce launch cost as by the government's desire to launch larger payloads into orbit (remember that launch vehicles used to be exclusively government programs). But commercial satellites have generally been built to conform to the size of existing payload capabilities of ELVs in order to utilize its full capability. As discussed in section 2.5, most commercial satellites have been built to fit in the smaller ELVs and the largest commercial ELVs (Titan III and Ariane 44L) have routinely launched dual payloads. Future commercial payloads may actually become smaller as demand for satellite communications decreases and as companies and governments opt for the increased reliability and flexibility of having several small satellites as opposed to a single large one. For instance, even though every previous Intelsat communications satellite has been larger than its predecessor, the newest Intelsat satellite is 25% lighter than its predecessor. Thus, larger payload capabilities would almost certainly require launching multiple commercial payloads.

Launching multiple payloads has several drawbacks. First, such launches are difficult to coordinating efficiently.[35] Also, launching multiple payloads leads to increased difficulty in obtaining inexpensive insurance because the potential loss is much higher.[36] Finally, if one payload experiences a problem then none of the payloads can be flown causing a delay and added costs for all users. The more payloads that are being flown, the more severe these problems become. Thus, when

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[33] "Cost Reduction Potential for Communications Satellite Systems and Services", Koelle, AIAA 88-0838, p. 467.

[34] "Space Launch Vehicle Costs", Blond and Knittle, Aerospace Corporation, ATR-84(4460-03)-IND, 7/84.

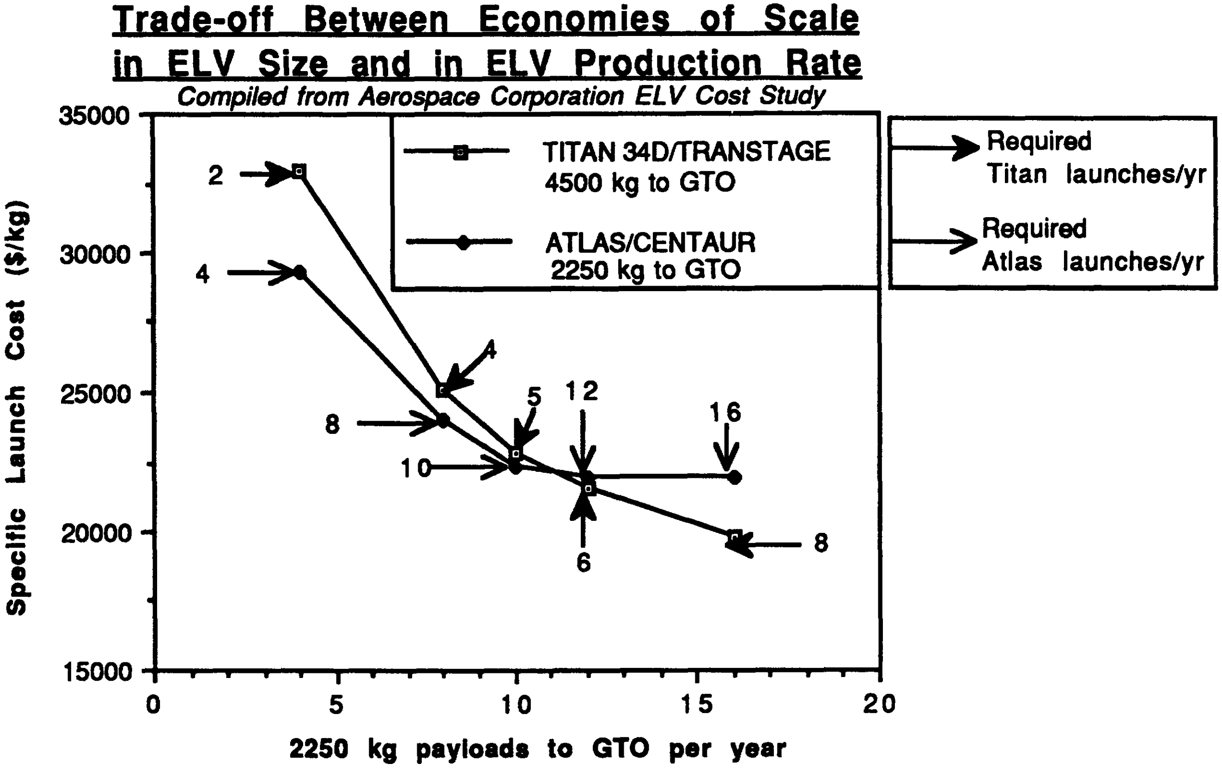
[35] *Launch Options For the Future*, OTA-ISC-383, 7/88, p. 39.

[36] *Launch Options For the Future*, OTA-ISC-383, 7/88, p. 39.

multiple payloads must be flown the decrease in specific price may not necessarily lead to increased competitiveness because other costs may be incurred.

In addition, because economies of scale are also obtained via higher production rates, a trade-off exists between ELV size and launch rate . As ELV size increases, and multiple payloads are flown on a single ELV, fewer launches will be needed each year. This leads to an increase in the unit cost of each ELV in part because fixed costs must be spread over fewer vehicles. In addition, less opportunity exists to benefit from the higher efficiency of high production rates such as increased opportunity for automation and increasing effectiveness of employees with repetition of tasks. If production rates drop too low, the benefit obtained from ELV size will be offset by the added cost of low production rates. Figure 5-3 demonstrates this trade-off using cost data from the Aerospace Corporation. As demonstrated in section 2.5 nearly all non-military satellites over the last several years have had launch masses below 2250 kg. A satellite with a launch mass of 2250 kg going to GTO could be launched individually on an Atlas/Centaur or together with another similar size payload on a Titan. Figure 5-3 shows the variation in specific launch cost for various numbers of such satellites to be launched annually. (One could also think of a 2250 kg payload as two individual 1225 kg payloads with no change in specific launch cost). When launching less than ten such payloads per year the smaller Atlas/Centaur rocket may actually be more cost effective than the larger Titan. Over the next several years General Dynamics will launch <u>at most</u> eight Atlas vehicles per year, and will likely launch less. Martin Marietta will be launching at most two and more likely one or none Titan IIIs in coming years. Launching all of these payloads on a larger ELV could actually result in increased specific cost. (This might also help explain why Martin Marietta, which makes Titan, is considering leaving the commercial launch business). Thus, with the current launch rates and sizes of most non-military payloads, bigger would not necessarily be better, and the optimal payload capability of future launch vehicles in terms of specific price will be highly dependent on the number and size of future payloads.

Ideally, the user would be able to select from a menu of launch vehicle to suit their needs and desires. This would allow them to select the simpler and more flexible individual launch, or a multiple launch at lower price. It would also allow them greater flexibility in selecting the size of their satellite. Currently Arianespace has its launch vehicles configured in just this way. The diversity of



Trade-off Between Economies of Scale in ELV Size and in ELV Production Rate

Compiled from Aerospace Corporation ELV Cost Study

FIGURE 5-3

launch capabilities offered by the three large U.S. companies as a group mimics closely the capabilities offered by Ariane. Significant increases in the payload capabilities of U.S. ELVs would narrow the variety of launch options offered by U.S. companies as a group unless the companies continued to offer the smaller predecessors of these new ELVs. Unfortunately, because U.S. ELVs were not originally designed to offer incremental payload capabilities, enlargement usually entails increasing tank and engine size rather than strapping on additional solids as is done on Ariane. Maintaining the capability of manufacturing the smaller predecessors is an expensive and complicated task because assembly lines must manufacture multiple sizes of parts. As a result, the launch companies cease production of the old ELV as demonstrated by the recent enlargements of the three major commercial ELVs and the corresponding discontinuation of their predecessor.

At present, each major U.S. launch company is filling a market niche resulting in a full range of launch options to be offered by U.S. companies as a group. Further incremental increases in launch capability would lead to a decrease in product diversity because the smaller ELVs would no longer be offered. In addition, unless launch rates or payload sizes increase significantly, larger ELVs may not result in decreased specific cost. Thus increasing ELV size would be unlikely to result in increased competitiveness of the U.S. CLI as a whole.

Conclusions

Reducing the specific launch cost of current ELVs will require efforts to reduce the labor intensiveness of manufacturing and launch operations. In order to make improvements in performance through higher efficiency rocket engines or advanced lightweight materials cost-effective, they will need to be coupled with efforts to prevent the increase in labor cost which normally accompanies their use. The technological means for reducing labor costs lie in simplified designs, automation, and advanced information systems. Since the cost-effectiveness of each specific technology will be dependent on its cost and launch rates, individual studies would be necessary for each specific technology, and for each proposed use, to determine which ones might have a potential net benefit. However, for the purpose of developing a broad based government policy for technological development in the CLI it is adequate to identify technologies which reduce labor cost as the key to reducing specific launch cost through incremental improvements to existing ELVs.

5.2 RISK MANAGEMENT

Every rocket launch faces the specter of failure and the loss of millions of dollars invested in the ELV and payload. In addition to this loss, the potential exists for the launch vehicle to cause damage to the launch facility, and to persons and the property of uninvolved third parties. These financial liabilities contribute to the cost of every launch.

Failures can occur as a result of launch vehicle or payload malfunction, but only those caused by the launch vehicle will effect the competitiveness of the commercial launch company. Thus, for the purpose of this paper, "launch failure" is defined as failure to achieve the desired orbit or trajectory as a result of launch vehicle malfunction. This section identifies the key factors associated with improving competitiveness through technologies aimed at reducing the cost of risk management. In doing so some important disparities between government and commercial needs are discovered.

Methods for Managing Risk

Managing risk essentially means making a decision about the most economical way to cover the cost of potential financial losses. Individuals and companies practice risk management every time they decide whether or not to purchase an insurance policy. Satellite owners must make risk management decisions for each launch. For many years now some commercial satellite owners have purchased insurance to cover the hazards of launch including loss of payload, cost of re-launch, loss of expected revenues, and third party liability. Launch companies on the other hand have only had to concern themselves with launch insurance since the industry was commercialized. Before then, the government owned and operated the ELVs and the launch companies had no launch liability. With the commercialization of the launch industry, launch companies have had to obtain third party liability insurance, and in order to remain competitive, to offer innovative risk management packages to customers.

As was discussed in section 2.1, third party liability was the subject of much debate in Congress. The resulting legislation indemnifies third party liability for commercial launch companies for damages over $500 million or a less amount specified by the Secretary of Transportation. DOT requirements for the first commercial Delta and Titan launches were set at only $80 million.[37] Despite all of the attention it has received, third party liability insurance is only a small portion of the cost of risk management with premiums running well below 1% of the policy's value.[38] There has never been damage or injury to a third party as a result of a launch failure. Managing the potential loss of payload and launch vehicle are much more costly.

For many years insurance premiums to cover these losses ran about 5% of the policy's value. A spate of launch failures from 1984 to 1985 caused enormous losses in the insurance industry and premiums soared to above 25% of policy value.[39] As a result of these high insurance premiums, alternative means of managing risk have been sought. In some cases this has simply meant accepting the financial risk of a launch failure, sometimes referred to as self-insurance. For example, Intelsat, which has insured all previous launches of its satellites, elected to self-insure the launch of its first Intelsat VI satellite because of dissatisfaction with the high

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[37] "U.S. Sets Insurance Minimums for Commercial Space Launches", *AW&ST*, 1/30/87, p. 69.

[38] Personal Communication, Alden Richards, Johnson & Higgens Insurance Brokers, 10/26/89.

[39] "Insurance, Risk Sharing, and Incentives for Commercial Use of Space", Doherty, ***Explorations in Space Policy***, Resources for the Future & National Academy of Engineering, p. 81.

rates.[40] Another form of self-insurance has been started by some launch companies which, for an additional charge, offer free re-flights in the event of a failure. For example, General Dynamics offers this option for an additional 10% of launch price.[41] Arianespace has gone so far as to create a subsidiary company called S3R to provide launch insurance for its customers.

The cost of risk management, and the selection of the most economical means for doing so is based in part on the perceived likelihood of failure. But how is this perception formed?

Measuring Reliability -- Uncertainties in Uncertainties

The perceived risk associated with any launch comes from estimates of the vehicle's reliability. Estimates of reliabilities for launch vehicles can been obtained in several different ways. For existing launch vehicles with significant launch histories, the crudest and most common method involves simply dividing the number of successful launches by the number attempted. The problem with this method is that the large launch vehicles of today have evolved into very different machines from there ancestors of thirty years ago. Throughout this evolution the frequency of launch failures has decreased. The failure histories shown in Figures 5-4a thru 5-4c demonstrate this improvement. So the question then becomes how many, and which, of the launches does one use to determine the success rate? Different numbers of launches will yield very different reliability estimates.

No single means for selecting the number of launches to be used in estimating reliability is the "right" method. However, some are less arbitrary than others. The lower success rates experienced by launch vehicles during earlier launches resulted from the learning period during which the technology was still being perfected, and the higher success rates experienced by todays ELVs has resulted, in part, from changes that were made to correct for design flaws. Incorporating the learning period into the reliability estimate would arguably lead to estimates unrepresentative of current vehicles. The point at which learning ceased to contribute significantly to improved reliability might be approximated by

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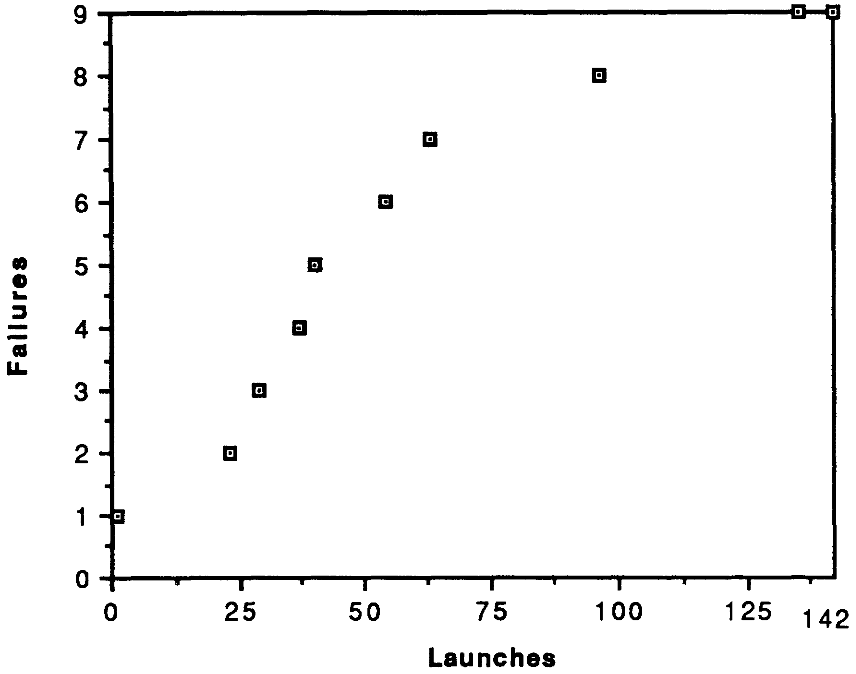
[40] "Intelsat Expected to Self-Insure February Titan Launch", *Space News*, 12/11/89, p. 18.
[41] "Commercial Atlas Users Conference", proceedings, 3/89, p. 557.

Delta Failure History

Compiled From TRW Space Log



Delta Historical Failure Rate

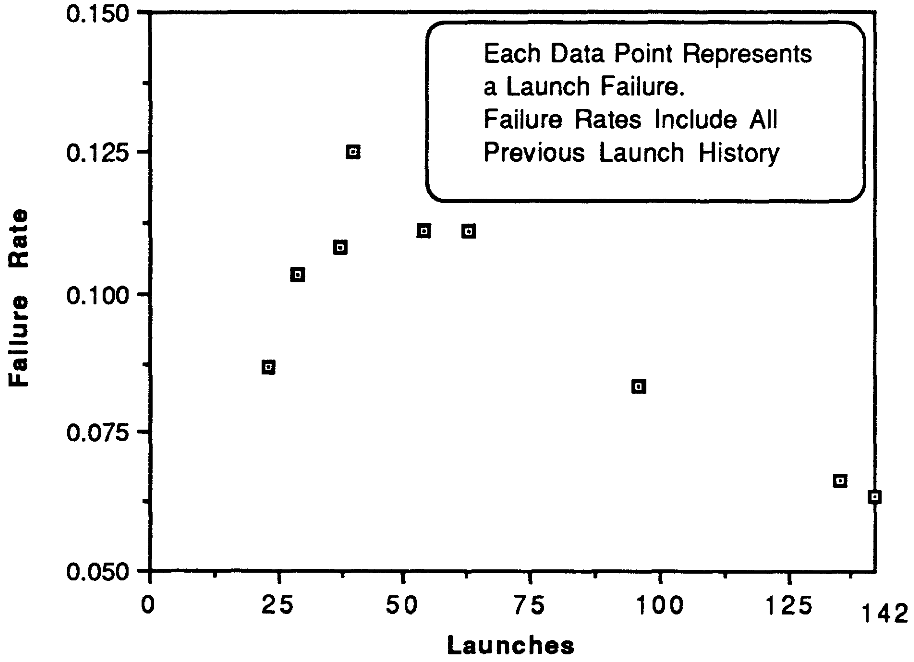
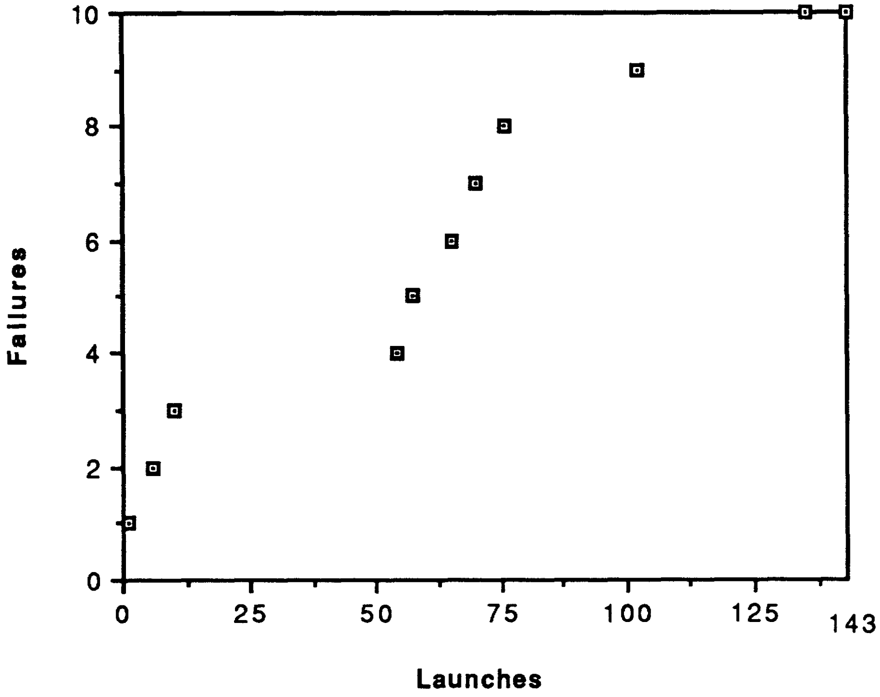


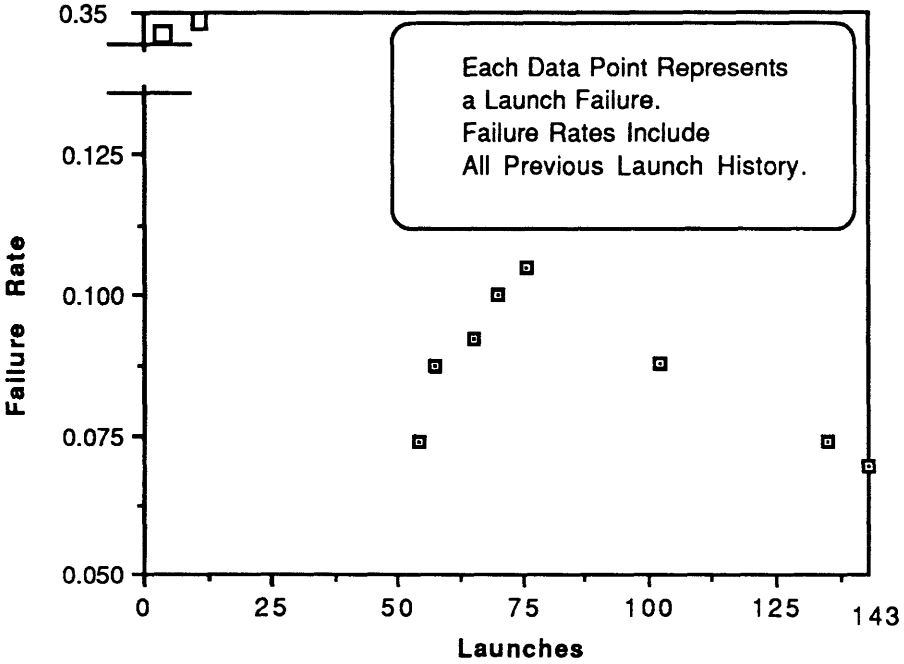
FIGURE 5-4A

Titan III/34D Failure History

Compiled From TRW Space Log



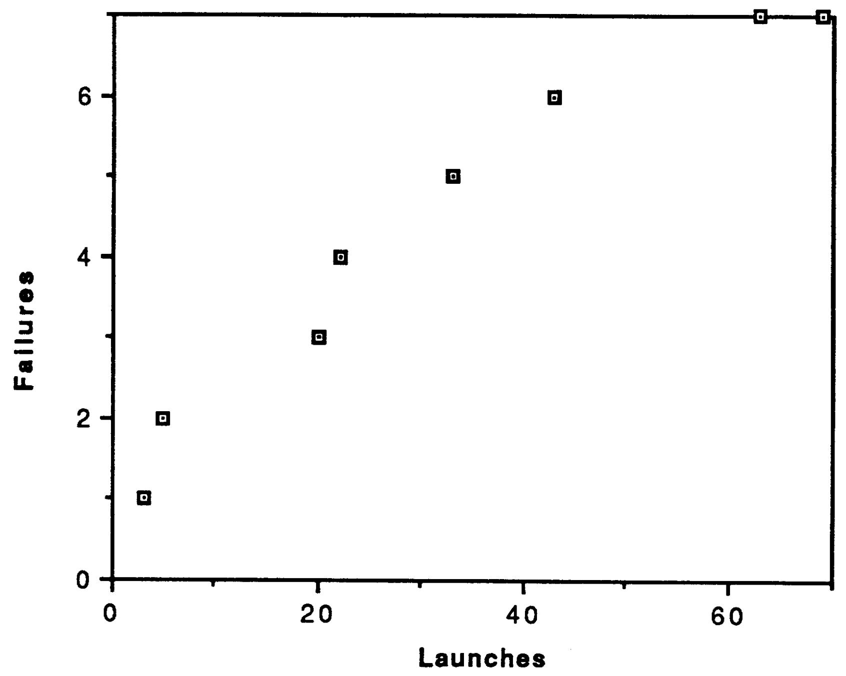
Titan Historical Failure Rate



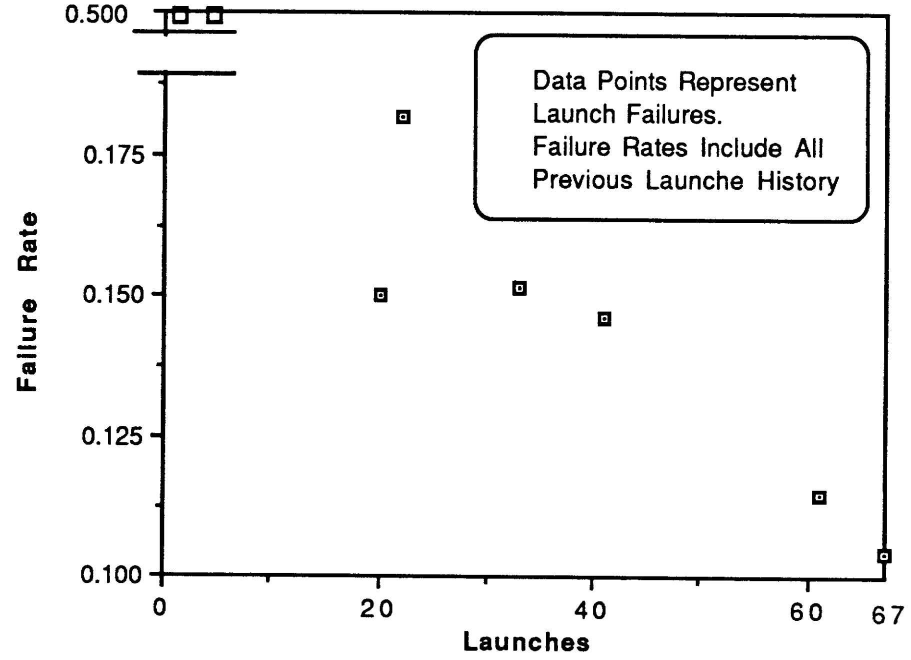
Each Data Point Represents
a Launch Failure.
Failure Rates Include
All Previous Launch History.

FIGURE 5-4B

Atlas/Centaur Failure History



Atlas/Centaur Historical Failure Rate



Data Points Represent Launch Failures.
Failure Rates Include All Previous Launche History

FIGURE 5-4C

breaking the launch failure histories into two linear parts as shown in Figure 5-5. The slope of the first line represents the approximate failure rate when learning was prevalent. The reliability estimate can then be made from the point of intersection of the two lines (the "break-point").

Once the number of launches to be used for the reliability estimate has been determined, a success rate can be found. However, with a limited number of launches it can not be said with 100% certainty that the failure rate represents the launch vehicle's reliability. For instance, if a new launch vehicle were to experience several successful launches with no failures, the success rate would be 100%, but the reliability would undoubtedly be less. Given a number of launches the best that can be done is to estimate the probability that the reliability lies within some range of values, or the probability that the reliability lies above some value. The former is formally called a "confidence interval", and the latter a "one-sided confidence interval". For reliabilities of launch vehicles, the one-sided confidence interval (i.e., the probability that the reliability is above some value) is of the greatest interest. Estimates of the success rate, and the one-sided 90%

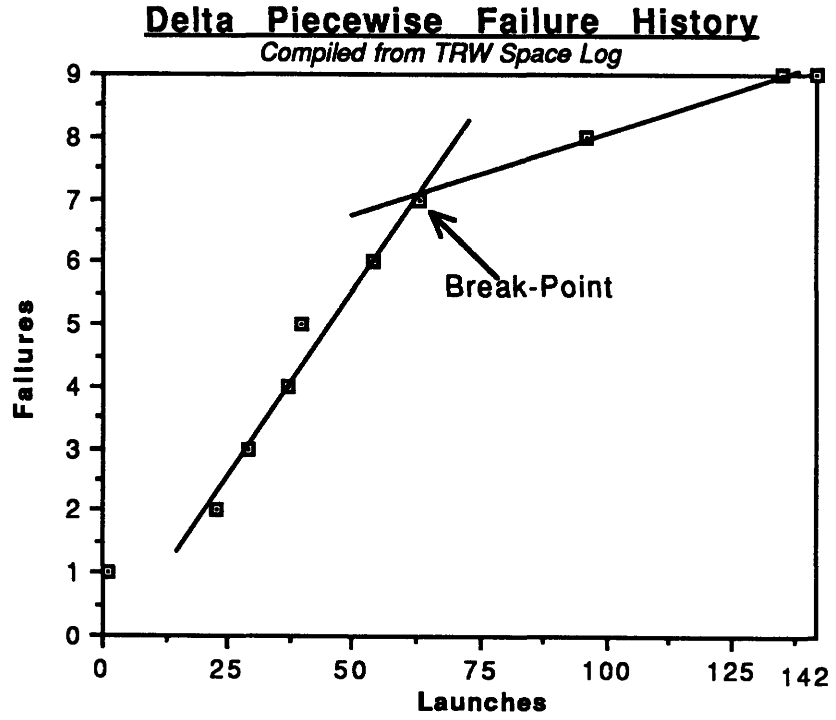


FIGURE 5-5

confidence interval (i.e., 90% probability that the reliability is above this value) taken after the break point, and over the full launch history, are shown in Table 5-1 for the three large U.S. ELVs. In addition, Table 5-1 contains reliability estimates for Ariane, Long March, and the Soviet Zenit. However, for these vehicles the launch histories are so short that they do not demonstrate a discernable break-point. As a result, estimates are made only over the full launch history (see Appendix A for derivation).

Another method for estimating reliability focuses on the launch vehicle subsystems rather than the entire vehicle and is the only method for estimating the reliability of a new vehicle which has not been launched. For each subsystem reliability estimates are made for each of the many individual parts or sub-assemblies. These estimates are based on the observation of failure modes in tests and any launches of previous vehicles which used that technology. For a completely new technology, the estimate can only be based on any tests that may

TABLE 5-1

Reliability Estimates of Large ELVs Based on Historical Data

ELV	Launches	Failures	Success Rate	Minimum Reliability at 90% Confidence
United States (From Break-Point)				
Atlas/Centaur	34	2	94.1%	85.4%
Delta	79	3	96.2%	91.7%
Titan III/34D	67	3	95.5%	90.3%
(Full Launch History)				
Atlas/Centaur	67	7	89.6%	83.2%
Delta	142	9	93.7%	90.3%
Titan III/34D	143	10	93.0%	89.4%
Foreign (Full Launch History)				
Ariane	32	4	87.5%	77.7%
Long March	21	2	90.5%	78.4%
Zenit	11	1	91.7%	70.6%

have been run on it, or in many cases simply on an engineers best guess based on experience with similar technology. Once the reliability of the subsystem parts have been estimated, the reliability of the entire subsystem can be determined, and then ultimately an estimate for the overall launch vehicle reliability.

Launch vehicle manufacturers often estimate reliability by subsystem. For existing ELVs with long launch histories this method may very well be the most comprehensive because it incorporates knowledge from tests, and knowledge from previous launches where similar subsystems or parts were used. Of course, such estimates are now considered proprietary because they have a direct impact on the company's competitiveness. While this method may yield fairly accurate results for launch vehicles with long launch histories, for completely new launch vehicles which use new technology such estimates are prone to large errors because extensive testing is very expensive, and therefore the estimates are usually made from a limited, or non-existent, test sample.

So what can be said about the reliability of current U.S. ELVs with long launch histories? While the exact reliability of launch vehicles can not be determined with certainty, statistically for any given launch history the failure rate represents the most likely actual reliability. And based on the historical data shown in Table 5-1 there is high confidence that the reliabilities of the large U.S. ELVs are higher than their foreign competitors, especially when the early launch history during which learning occurred is removed from the estimate.

Improving Launch Vehicle Reliability

Failures can occur as the result of a poor design, the poor quality of parts or fabrication, improper management decisions or an act of God. The *Challenger* accident is an excellent example of both poor design and improper management which led to launch failure. The lightning which struck a recent Atlas/Centaur launch is an example of an act of God, and parts which are not made to specification have caused failures in launch systems. Technological improvements do not hold much promise for reducing failures caused by God or managers. However, design and quality both can be improved with better technology.

As previously mentioned, over the years large launch vehicles have experienced significantly improved success rates. The higher failure rate experienced in earlier years resulted primarily from poor design. As greater knowledge of the launch system was obtained through additional launches, designs were improved. The newer launch vehicles being offered by small entrepreneurial firms will inevitably undergo a similar learning experience. For these vehicles most failures will likely result from design flaws, and improvements in reliability will come primarily from eliminating those flaws. Finding these design problems will require subsystem tests and actual launches.

For the large ELVs, the majority of design problems have already been resolved. As a result, most failures occur as the result of faulty parts or fabrication.[42] For example, the most recent Titan failure resulted from improper wiring and the most recent Ariane failure from a forgotten cloth in a water pipe.[43] The likelihood of a failure from faulty parts or fabrication can be reduced in two different ways. First, parts and subsystems can be tested more thoroughly before the launch to control quality. Technology can aid in quality control by developing more efficient and effective means for testing components. Second, parts can be manufactured and fabricated with greater consistency and accuracy. This can be done by requiring tighter design specifications. In addition, automation may be able to produce more exact and consistent work quality than a hand made part.

When it comes to the failure of a launch vehicle not all sub-systems are created equal. The propulsion system accounts for the vast majority of launch failures because this system has the most mechanical parts, the most moving parts, and experiences temperature and pressure extremes.[44] In addition, the rocket engines which will actually propel the ELV cannot be put through a test run because they weaken and in many cases destroy themselves in the process. The complexity of the propulsion system leads directly to decreased reliability. An excellent example of this is the up to ten times greater reliability demonstrated by relatively simple solid rocket engines as opposed to more complex liquid engines.[45] This suggests another means for improving the reliability of existing ELVs -- by decreasing, through simpler designs, the number of parts which can fail.

Thus, for newer launch vehicles improvements in reliability will result primarily from better understanding of the launch system which will be obtained from additional launches. Launch vehicles with proven designs could improve reliability through greater and more effective quality control, tighter design specifications, simpler designs, and possibly through the use of automation.

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[42] "Predicting launch vehicle failure", Leonard and Kisko, *Aerospace America*, 9/89, p. 36.

[43] *"Ariane Accident Cause Found"*, *Space News*, 4/6/90, p. 44.

[44] "Reliability and Cost Considerations in Launch Vehicles", Loftus, IAF 89-693, 10/89, p. 6.

[45] "Predicting launch vehicle failure", Leonard and Kisko, *Aerospace America*, 9/89, p. 38.

Interestingly, the latter two methods were also identified in section 5.1 as key means for reducing launch costs.

The Value of Improved Reliability

After the *Challenger* accident, reliability became quite a catch word. But whether reliability can improve the competitiveness of the CLI depends both on the cost to the company of the improvement, and on the benefits it obtains. The cost of improving reliability is extremely difficult to gauge, and cost estimates vary enormously.[46] In general however, the cost of improved reliability increases rapidly at extremely high reliabilities as more testing, and higher quality parts become necessary.[47] The benefit from improvements in reliability would be a decrease in the likelihood of failures and their associated cost. In theory an optimum reliability should exist above which the cost of reliability improvements exceed the benefits. But due to the high variability of cost estimates, and the fact that launch vehicle reliabilities can not be determined with certainty, attempting to explicitly identify this optimum would likely lead to improper conclusions for a government policy. However, some very important factors associated with the costs and benefits of improved reliability can be identified without relying on highly uncertain cost models.

Influencing Insurers and Customers

In order for improved reliability to enhance the competitiveness of a launch vehicle, customers and insurers must be convinced that an improvement has occurred. The reliability estimate used by customers and insurers comes not from the estimates made by launch company engineers, but from demonstrated successes of the launch vehicle.[48] For those launch vehicles with few or no demonstrated successes, such as the new small ELVs being offered in the U.S., obtaining insurance at any reasonable rate can be difficult. This reliance on demonstrated success results from the large asymmetry of information which exists -- launch companies know much more about their ELVs, and thus are able to apply both

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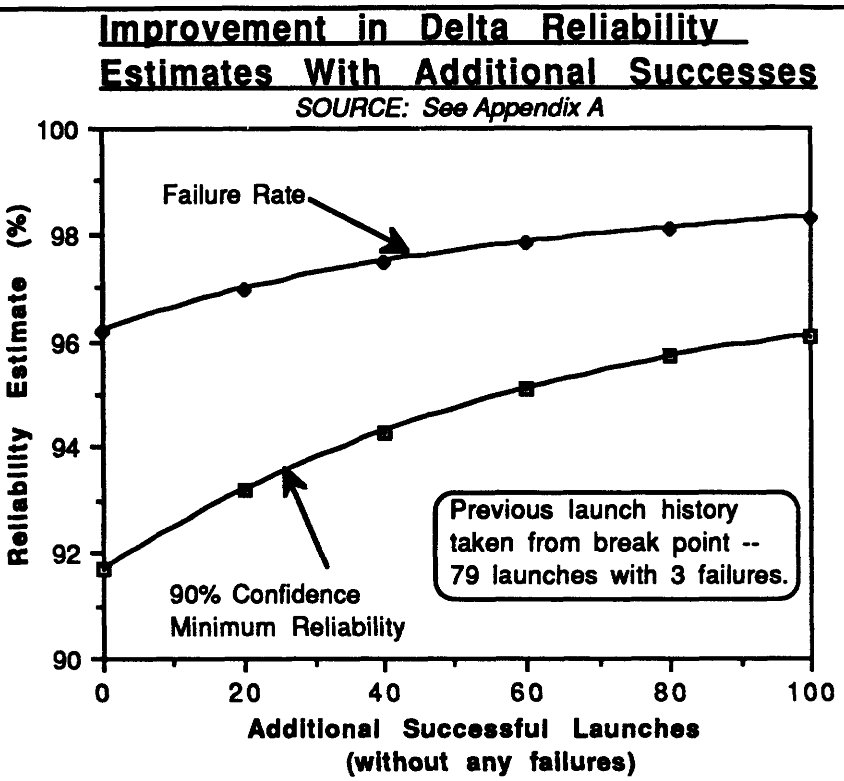
[46] See for example, *Reducing Launch Operations Costs*, OTA-ISC-28, 9/88, p. 27. and Martin Marietta STAS, X88-10254.

[47] *Reducing Launch Operations Costs*, OTA-ISC-28, 9/88, p. 27.

[48] "Insurance Risk Sharing, and Incentives", Doherty, *Explorations in Space Policy*, Resources of the Future & The National Academy of Engineering, 1987, p. 88.


Improvement in Delta Reliability Estimates With Additional Successes

SOURCE: See Appendix A

FIGURE 5-6

historical and subsystem information to more accurately estimate reliability, whereas insurers and customers do not have this option.[49] Therefore, for improved reliability to lead to reductions in insurance premiums, or to effect the decisions of customers, the launch company will have to demonstrate the improvement through successful launches.

For launch vehicles with long launch histories demonstrating improvements in already high reliabilities can take a long time. For example, one could imagine the difficulty in demonstrating a 99% reliability (1 failure out of 100 launches) in any reasonable amount of time at current launch rates of about 10 per year. Figure 5-6 shows hypothetical improvements in estimated reliability for the Delta ELV for a best case scenario of a string of successes. Each increase in estimated reliability takes more successes to demonstrate than the one before it. A two percent increase in the 90% confidence minimum reliability would take over 30 consecutive successes, or three years at present launch rates. To demonstrate a two percent increase in failure rate would take over 80 consecutive successes or eight years at present launch rates. If even one failure occurred the estimated reliability would decrease significantly, and the earlier this failure occurred the greater its impact

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[49] Insurance Risk Sharing, and Incentives", Doherty, *Explorations in Space Policy*, Resources of the Future & The National Academy of Engineering, 1987, p. 88.

would be. It could be reasonably argued that after several years of successes the previous launch history would be given less weight in the estimate. While this would increase the estimated failure rate, it could cause a decrease in the 90% confidence minimum reliability.

In addition to the drawback of having to demonstrate reliability to insurers, the estimated reliability is not the only, nor the predominate, factor in determining insurance premiums. For example, General Electric recently obtained identical insurance rates (16.5%) for two upcoming launches of identical satellites one of which will be launched on Ariane and the other on Delta, even though the Delta has demonstrated significantly higher reliability.[50] Similarly, Hughes obtained identical rates for upcoming launches of similar satellites on Ariane and Atlas vehicles, and Eutelsat which will be launching a satellite on each of these ELVs also obtained the same insurance rate for both launches.[51] Insurance is a commodity, and as such, market forces play the dominant role in determining insurance rates.[52] When the insurance market is "soft" more capacity exists to insure than demand for insurance, and as a result rates drop. When a "hard" market exists there is an under capacity of insurance and premiums will increase. After the large insurance claims of 1984 and 1985, available capital for covering launch insurance policies became scarce, dropping from a high of $300 million to $80 million.[53] This hard market caused rates to soar by as much as 600%,[54] even though the statistical reliability estimates of the ELVs which failed changed by only a small amount. One might speculate that the decrease in available capital was due to increased fears of insurance investors, but the enormous drop in capital could not be justified simply on the basis of reliability estimates. It was pure chance that those launch failures occurred so close to one another. If they would have been more evenly spread over time (say some earlier, some later) then insurance rates would not have soared so dramatically.

Thus, for launch vehicles which have demonstrated high reliabilities, such as the large U.S. ELVs, a significant amount time will be necessary to demonstrate improvements to insurers and customers through successful launches. This delays

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[50] "Satellite Launch Insurance Rates Lowest in Years at 16%", *Space News*, 3/12/90, p. 20.

[51] "Insurers Offer Stable Premiums Despite Recent Losses", *Space News*, 4/9/90, p. 6.

[52] Personal Communication, Alden Richards, Vice-President Johnson & Higgens Insurance Brokers, 10/26.

[53] "A Report on Spacecraft Insurance", Johnson & Higgins, 1987, p. 7.

[54] "A Report on Spacecraft Insurance", Johnson & Higgins, 1987, p. 7.

the potential benefit to the launch company from improving reliability. In addition, market forces are the predominant factor controlling insurance rates for ELVs with demonstrated high reliabilities, so improving reliability may only have a small impact on insurance rates. Finally, as was shown earlier, the large U.S. ELVs have demonstrated higher reliabilities than any of their competitors. All of these factors will tend to decrease the value to the launch company of improving reliability for commercial payloads.

Disparate Government and Commercial Needs

The theoretically optimum reliability of a launch vehicle would depend heavily on the value of the launch. The higher the value of the launch the greater the cost of failure and the more willing one would be to spend money in an attempt to increase reliability. The monetary value of an individual launch includes the launch cost, payload cost, and for a commercial satellite, the expected sales revenues. The cost of commercial satellites range from about $35 million to $95 million, and launch services run from about $50 million to $65 million. If the payload was lost, it might take from two to absolutely no more than four years to rebuild and launch a new satellite. In this case the cost of the delay in sales revenue could run from $15 to $40 million (assuming 15% discounting).[55] Thus the total cost of a typical commercial launch failure would range from about $100 million (35+50+15) to $200 million (95+65+40).

For many government payloads the total cost of a launch failure would be similar to costs for a commercial payloads. For example, the Air Force's twenty one Global Positioning satellites cost about $65 million each. However, the value of some government launches can be much greater than typical commercial launches. For instance, a typical photoreconnaissance satellite and Titan IV launch can cost well over $1 billion. In addition, some government payloads are one of a kind, or essential to a particular mission which may be important for the public welfare, the value of which can not be easily quantified. Such "critical" government payloads demand higher reliabilities than commercial payloads.

In an effort to achieve the highest reliability possible for critical payloads the government requires stringent quality control and tight specifications which incur additional costs. Since the same production lines are used for commercial and

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[55] "Scheduling Commercial Launch Operations at National Ranges", Department of Transportation, OCST, 5/89, p. 45.

government launches, all launch vehicles are subject to these additional costs.[56] Yet, for commercial payloads these additional costs may not be worthwhile. Because of the government oversight required to ensure the highest reliability possible for critical payloads, commercial launch companies are extremely limited in their ability to select the procedures or technologies which they believe would lead to the optimum reliability for commercial customers.[57] The Office of Technology Assessment noted that "Excessive Government oversight and reporting requirements generally develop incrementally as a response to real problems of quality control, a concern for safety, and the desire to complete high cost projects successfully. Over time these small increments of personnel or paper build to the point that they impede efficient operations, limit contractor flexibility, and add unnecessary costs."[58] From government's point of view such requirements are essential to ensure the highest reliabilities for critical payloads. From a commercial point of view their cost may not justify the increased reliability they might bring.

Small ELVs

A very different situation exists for the new entrepreneurial launch companies which have very limited or non-existent launch histories. First, the government and government financed payloads which presently represent all of the demand for their vehicles are not critical, in fact they are generally very inexpensive scientific payloads (see section 2.5). Therefore, since government is the only real customer, and the government payloads do not require the highest reliabilities possible, no conflict in desired reliability exists. Possibly as a direct result of this, the government has not carried out extensive oversight of most small launch vehicles obtained recently. However, these launch vehicles do not have demonstrated high reliability. Nor do these companies generally have the resources to self insure without risking the company's existence. One failure without insurance could be the end of the company as demonstrated by the demise of the American Rocket Company which exited the launch business after its launch failure. The lack of demonstrated success poses these companies with a dilemma.

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[56] "Energizing the Space Launch Industry", Berkowitz, *Issues in Science and Technology Policy*, Winter 1989, p. 80.

[57] See *Reducing Launch Operations Costs*, OTA-TM-ISC-28, 9/88, p. 80-81.

[58] *Reducing Launch Operations Costs*, OTA-TM-ISC-28, 9/88, p. 20.

They need successful launches to demonstrate reliability, and demonstrated reliability to make insurance available to them.

Conclusions

For the large ELVs with long launch histories, improvements in reliability could be achieved through greater quality control, tighter specification, more effective testing, automation, and simpler designs. However, improvements will only be worthwhile if the benefits exceeds the cost. Unfortunately, estimates of the cost to improve reliability are extremely uncertain so that attempting to identify an optimum reliability and technologies for achieving that reliability would very likely lead to improper conclusions for government policy.

What can be said with certainty is that the large U.S. ELVs have demonstrated higher reliabilities than their competitors. Also, any improvement in already high reliabilities for the large ELVs will take a long time to demonstrate to customers and insurers, delaying the benefit from any improvement. And even if improvements are made, they may have only a small impact on the insurance premiums paid by the company. Finally, a disparity exists between the extremely high reliability required for critical government payloads and the reliabilities required for commercial payloads. In order to achieve the highest possible reliability for critical payloads the government requires stringent quality control and tight design specifications which affect the cost of all launch vehicles. Due to this oversight, launch companies are extremely limited in their ability to select the procedures or technologies which they believe would lead to the optimum reliability for commercial launches.

The newer ELVs being offered by small launch companies do not experience the disparity in reliability requirements which large ELVs do because relatively inexpensive government and government financed experimental payloads presently represent the only demand. For these ELVs improvements in reliability will come primarily through additional launches which allow them to find and correct design flaws. In addition, because these ELVs have extremely limited launch histories, they need successful launches to demonstrate reliability to insurers in order to make insurance available to them.

5.3 LAUNCH DELAYS

Probably nowhere does the adage "time is money" ring more true than in the space industry. For the large U.S. ELVs, launch delays are both commonplace and costly. But while technology may be able to enhance competitiveness by reducing delays it is not a silver bullet capable of achieving the job alone. This section explores the cause of launch delays, and the key factors associated with reducing delays through technological development. Once again a disparity is found between government and commercial needs.

For all ELVs essentially two types of launch delays occur. First are those caused by pre-launch anomalies in the ELV or payload and then there are delays caused by the suspension of launches after a launch failure. Because very different situations exist for the large ELVs, and the smaller launch vehicles being offered by new entrepreneurial companies, the latter will be discussed separately at the end of the chapter.

Pre-Launch Anomalies of Large ELVs -- Regular Irregularities

Calling pre-launch complications "anomalies" is almost a misnomer because they are common occurrences. Anomalies result from complications in payload integration, or pre-launch test failures which require corrective action.[59] Large ELVs experience an average delay of 5 to 10 days from pre-launch anomalies on every launch.[60] These delays can be very costly to the launch company. As the launch approaches, the number of people dedicated to launch operations increases dramatically. During a delay this entire "standing army" must be paid at a cost of about $10,000 to $15,000 per hour of delay. So a typical five to ten day delay can cost between about $1 and $4 million.[61]

Ideally an economic analysis of various alternative technologies for reducing the delays from pre-launch anomalies would be performed in an effort to steer government policy. But as discussed at the beginning of the chapter, models estimating the economic returns from proposed technologies have proven to be extremely poor. This is especially true with respect to launch operations where the Office of Technology Assessment (OTA) noted that much of the data needed to build and verify such models has yet to be gathered. OTA found existing cost models

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[59] *Scheduling Commercial Launch Operations at National Ranges*, Office of Commercial Space Transportation, 5/89, p. 15.

[60] "Compiled Launch Slip Data", Lt. Col. Jerry Johnson, ETR.

[61] Personal Communication, Mike Holguin, General Dynamics, 11/90.

"grossly inadequate in estimating [launch] operations costs".[62] The Space Transportation Architecture Study (STAS) looked at many different technologies for enhancing present launch operations. (See section 5.1 for a complete discussion of STAS) However, bearing out the concerns of OTA, the estimated rate of return which might be obtained from investments in various technologies varied significantly between the different contractors performing studies.[63] More importantly, the order in which these technologies were ranked also varied, making them extremely suspect. Thus, once again, it would be imprudent to attempt to explicitly quantify the potential economic benefits associated with different technology options. However, some important factors associated with efforts to reduce delays from pre-launch anomalies with improvements in technology can be identified without relying on such cost models.

A Complex Process Requiring Available Technologies

One might think that after thirty years of space launches integrating the payload to the launch vehicle would be old hat. Regrettably todays ELVs suffer from the legacy left by their birth as missiles which were not originally designed to be easily integrated to payloads, or to be easily serviced. The operability, or ease by which routine assembly and testing is performed, of today's ELVs is extremely poor. As a result, assembling, testing, and servicing todays ELVs is complicated and time consuming. For example, a Titan ELV will spend an average of 5 to 9 months at the launch site, and 8 to 9 weeks actually on the launch pad.[64] The complexity of launch operations leads directly to increased likelihood of pre-launch anomalies and the associated delays.

The technologies which have been explored for improving operability included simplified designs, improved information systems, and increased use of automation.[65] In other words, the same general groups of technologies identified for reducing launch cost in section 5.1. Because launch vehicles and their ground facilities are highly interdependent and integrated, many efforts to improve operability will require coordinated improvements to both launch facilities and

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[62] *Reducing Launch Operations Costs*, OTA-TM-ISC-28, 9/88, p. 79.

[63] Martin Marietta, General Dynamics, and Air Force, Space Transportation Architecture Studies.

[64] *Reducing Launch Operations Costs*, OTA-TM-ISC-28, 9/88, p.35.

[65] *Reducing Launch Operations Costs*, OTA-TM-ISC-28, 9/88

launch vehicles.[66] However, improvements will not, in general, require extremely advanced technologies. Rather, just like the technologies identified in section 5.1, many of the technologies under consideration for improving operability already exist today or are under development.[67]

Disparate Government and Commercial Needs

An inherent conflict exists between the desire to obtain extremely high reliabilities and the desire to increase the efficiency of launch operations. Striving for extremely high reliabilities requires greater pre-launch tests and tighter standards which inevitably leads to lengthier launch operations, and added delays caused by the need to correct the additional anomalies discovered. As discussed in section 5.2, the government has much greater incentive than commercial companies to ensure the highest reliability possible because some of its payloads are extremely expensive or one of a kind. As a result, the government places enormous emphasis on pre-launch testing and quality control. When launch failures occur, the response of government has often been to further increase pre-launch requirements. The value of such increases depends directly on the perceived value of higher reliability. For example, after a Titan launch failure of 1985, the Air Force initiated new pre-launch non-destructive testing of Titan solid rocket motors which added time a cost to launch operations. Use of these tests revealed a number of minor imperfections in Titan solid rocket motors, which were corrected. Air Force personnel would likely claim that the added cost of the tests was justified to ensure mission success. However, the anomalies were so small that company engineers doubted they would have caused a launch failure,[68] making one wonder whether a company launching much less expensive commercial payloads, and desiring to launch on time to save money, would find the tests worthwhile.

For commercial launches, the launch company does have greater flexibility over choosing the pre-launch testing and quality control procedures it will use. For instance, Martin Marietta could elect not to test its Titan solid motors so stringently for commercial launches. However, the selection of new technologies for improving operability will be highly influenced by the value of achieving

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[66] *Reducing Launch Operations Costs*, OTA-TM-ISC-28, 9/88, p. 6.
[67] *Reducing Launch Operations Costs*, OTA-TM-ISC-28, 9/88, p. 4.
[68] *Reducing Launch Operations Costs*, OTA-TM-ISC-28, 9/88, p. 27.

extremely high reliabilities. While the government found it necessary to invest in the new test equipment for the Titan solid motors, Martin Marietta may have chose instead to develop a technology to improve efficiency. The value of reliability will drive many of the decisions made about technologies for improving operability, including such items as the amount of built in test equipment desired, the need for fault tolerance, and the desirability of automating various operations procedures. If the selection of technologies for improving operability is driven by government needs, the resulting improvements may not be the most beneficial for improving the competitiveness of the CLI because government will place a higher value on reliability and a corresponding lower value on operational efficiency, than a commercial company likely would.

The Problems of Common Facilities Operating Near Capacity

Every scheduled commercial launch of a large ELV will take place at the Air Force's Eastern Space and Missile Center (ESMC) in Florida, where launch facilities exist for the Atlas, Delta, and Titan vehicles. These facilities are also used for government launches of these ELVs. Each launch vehicle uses separate and unique integration facilities and launch pads. However, certain resources such as tracking and some communications are common not only to all the launch facilities at ESMC, but also to neighboring Kennedy Space Center where the Shuttle is launched. After the launch of any vehicle, these common resources must be reconfigured before launch of a different vehicle can occur.

At present launch rates, all ESMC launch facilities operate very near capacity leaving little buffer between launches for potential delays.[69] As a result, ESMC launch facilities almost operate on a "one slip all slip" basis whereby the delay of one launch vehicle can cause delays for vehicles on other pads waiting to use the facilities common to all of ESMC.[70] For example, the delay of the Space Shuttle launch of the Hubble Space Telescope also caused a three day delay for an awaiting commercial Delta launch at ESMC.[71] Thus, the limitations of present launch facilities common to all vehicles can cause delays from pre-launch anomalies of one vehicle to affect other vehicles awaiting launch.

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[69] *Scheduling Commercial Launch Operations at National Ranges*, Office of Commercial Space Transportation, 5/89, p. iv. and "Launch Options for the Future", OTA-ISC-383, 7/88, p. 20.

[70] Personal Communication, Mike Vanscoy, McDonnell Douglas, 1/30/90.

[71] "Hubble Holds up Delta-2 Launch", *Space News*, 4/9/90, p. 2.

Post-Launch Stand Downs of Large ELVs -- The Policy of Delay

After a launch failure a suspension of launch activity for the vehicle which failed routinely occurs. The suspension after a failure, called the "stand down" period, is created by a decision to determine the cause of failure, and correct the problem, before proceeding with other launches. Stand downs from ELV launch failures have historically averaged from four to five months.[72] With launch facilities for large ELVs operating near capacity, a stand down inevitably causes delays for upcoming launches. Such delays can cost launch companies millions of dollars. For example, Arianespace estimates that its recent one month stand down will cost the company between $35 and $53 million.[73] Delays from stand downs can also be extremely expensive for commercial satellite owners. A launch delay postpones the revenues that will be earned from sales of the satellites services, and a one month delay can reduce the value of that revenue stream by as much as $1 to $2 million.[74] In addition, if the communications satellite is already constructed it must be stored and maintained during the delay which can cost about $100,000 to $200,000 per month.[75]

Technology has an extremely limited ability to reduce down time after launch failures. Quite simply, standing down after a launch failure represents a policy choice. For example, while the U.S. government has chosen to implement stand downs, the Soviets generally continue with launches as scheduled after a failure occurs.[76] The decision to implement stand downs is based on the perceived value of reliability. Because the U.S. government periodically launches one of a kind and expensive payloads it places an extremely high value on reliability and requires stand downs to ensure higher reliability for future launches. Commercial launch companies attempting to compete in the market place will inevitably have a greater incentive to reduce stand down time than the government. Not only is the value of reliability lower for commercial payloads (see section 5.2), but the company must consider the impact delay costs will have on itself and customers.

The problem is that even with the creation of a commercial launch industry, launch companies will likely have little control over the decision to have a stand

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[72] "Space Launch Systems Resiliency", Bernstein, Aerospace Corporation, P. 8-10.

[73] "Ariane Accident Cause Found", *Space News*, 4/6/90, p. 44.

[74] *Scheduling Commercial Launch Operations at National Ranges*, Office of Commercial Space Transportation, 5/89, p. 15.

[75] Personal Communication, Bill Tosney, Aerospace Corporation, 1/30/90.

[76] *Launch Options for the Future*, OTA-ISC-383, 7/88, p. 23.

down, or government involvement in the ensuing investigation. For commercial launch failures which do not threaten the safety of third parties, no legal requirement exists for government involvement in an investigation, and even when statutes mandate a government investigation, no legal requirement exists for a stand down period.[77] However, since the government places such high value on reliability, it will continue to desire the resolution of any problem which causes a launch failure before proceeding with scheduled government launches of the same vehicle.[78] In addition, to ensure that the problem is properly taken care of, government will very likely continue to be involved in failure investigations. For example, after an accident with a crane that damaged an Indian satellite being prepared for a commercial Delta launch, an investigation was carried out by McDonnell Douglas, India, and the Air Force.[79] Government involvement in launch vehicle investigations will inevitably restrict the ability of the company to hasten investigations if for no other reason than more people and agencies will be involved. In addition, since both commercial and government launches use the same launch facilities, any postponement of government launches will inevitably cause delays for upcoming commercial launches. Therefore, even though a launch company may not wish to stand down after a launch failure, and even though they are not required by law to do so, it is reasonable to expect that the government will require, and be involved in, investigations of launch failures causing similar downtimes as experienced in the past.

Although improvements in technology can not significantly reduce the length of a stand down, the existence of stand downs has a direct impact on the need for improvements in launch facilities. A stand down creates a backlog of payloads awaiting launch. If no capability exists to launch at a higher rate (called a "surge rate") in order to clear this backlog, then every satellite awaiting launch will experience a delay equal to the stand down time. A surge after a stand down allows the backlog of payloads to be cleared so that satellites further back on the manifest will experience less delay, or no delay at all. For example, after its recent failure and one month stand down, Arianespace plans to increase its launch rate from nine

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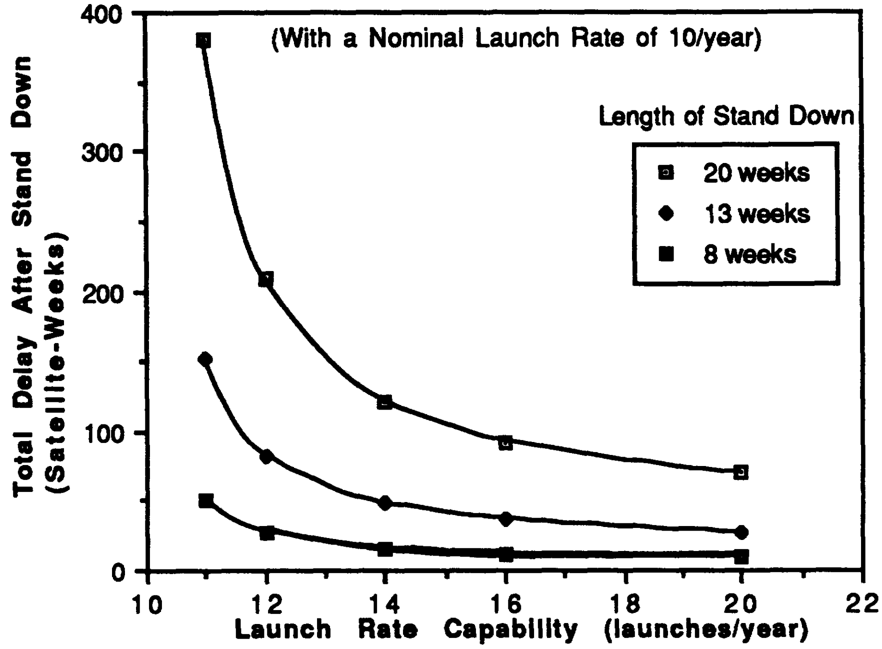
[77] Personal Communication, Eric Gabler, Office of Commercial Space Transportation, 1/23/90.

[78] Personal Communication, Mike Vanscoy, McDonnell Douglas, 1/30/90.

[79] "U.S. Reenters Commercial Launch Arena With Private Delta Mission", *AW&ST*, 9/4/89, p. 25.



Estimated Effect of Surge Capability and Down Time on Launch Delays

SOURCE: See Appendix B

FIGURE 5-7

to twelve per year (the maximum capability of its facilities). Arianespace estimates this will clear its backlog within 18 months.[80]

To get an idea of the sensitivity of launch delays after a launch failure to surge capability, a dynamic model was built simulating the flow of launches, creation of a backlog after a failure, and the clearing of this backlog with a surge rate (see Appendix B). It should be stressed that this type of model differs significantly from the cost models which have proven to be so inaccurate. This model does not require the establishment of cost trends which may be incorrect, or educated guesses about unknown factors. The model simply simulates the flow of launches and tallies the time each payload will be delayed after a failure. In addition, the objective of this model is not to explicitly quantify the value of improved surge capability because even if the value of improvements could be found accurately, it is not clear that the cost of such improvements could be accurately estimated. Rather, the objective is to demonstrate how the existence of stand downs after launch failures can drive the need for improved launch capability.

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[80] "Ariane Accident Cause Found", *Space News*, 4/6/90, p. 44.

Figure 5-7 shows how, in general, the total delay experienced will vary with different launch rate capabilities and down times at a launch rate of 10 per year (approximately that experienced by the Delta ELVs). The total delay is just the some of the delays experienced by each satellite awaiting launch. One might be hesitant to believe the graph at first because it appears that the total delay would proceed to infinity if no surge capability existed and obviously this would be unrealistic because it would mean that delays occurred even for payloads which are not yet planned. In actuality the total delay will reach a maximum value equal to the total delay experienced by all satellites currently awaiting launch. However, this maximum will be very high. For example, typical launch manifests cover the next 18 to 24 months. With stand downs of 13 weeks, a nominal launch rate of 10 per year, and no surge capability the total delay experienced by the next 18 months of the scheduled manifest would be 195 satellite-weeks (10 satellites per year X 1.5 years X 13 weeks delay for each satellite). This is higher than any data shown on the graph for 13 week stand downs.

Two important features are demonstrated by the graph. First, the impact of surge capability on delays depends highly on the downtime, and is limited by the length of stand downs in its ability to reduce delays. In other words, no matter how great the surge capability, a delay will be experienced by those spacecraft manifested to launch during the stand down. Second, if virtually no surge capability exists, initial increases will result in significant reductions in the total delay experienced by payloads awaiting launch. Thus, with ESMC operating near capacity even a small increase in launch capability could significantly reduce the delays that will be experienced by satellites awaiting launch assuming stand downs will continue to run about four to five months. Increased launch capability could be brought about by simple expansion of facilities, or by increasing operational efficiency (as discussed in the previous section) reducing the amount of time required for each launch. Significantly reducing or eliminating the stand down time would reduce or negate the need for increased launch capability.

Small ELVs

The small commercial ELVs are launched out of DOD facilities in New Mexico and California. Unlike ESMR these facilities are not overwhelmed with launches, and launches are sparsely scheduled. As a result, delays generally only effect the vehicle at hand. Pre-launch anomalies of the small ELVs currently being offered commercially predominantly arise from the fact that they are new devices.

Unfamiliarity with the vehicle, and design "bugs" cause pre-launch anomalies and payload integration complications. Such problems will remain common events until these vehicles become well-tested and proven. In the near term, reduction of launch delays for small ELVs will be obtained almost exclusively through further launches which increase knowledge of the vehicle.

Conclusions

The technologies for reducing launch delays fall in the same general category as those for reducing launch costs: simplified designs, information systems, and automation. Many of the technologies which have been explored for making improvements to launch facilities already exist. Because launch vehicles and their facilities are so integrated and interdependent, most improvements in operations will require changes in the vehicle as well as facilities. Selection of the technologies which might be most advantageous for improving launch operations will be strongly influenced by the value placed on reliability. Because the government places extremely high value on reliability, the technologies it would select may not be the most advantageous for increasing the competitiveness of the CLI.

The length of stand downs after launch failures can have a significant impact on the delay experienced by satellites awaiting launch. Continued government involvement in launch failure investigations, and postponement of government launches after such a failure, will cause lengthy delays from stand downs to continue for commercial launches. The need to increase the capacity of the ESMC launch facilities is directly linked to the length of stand downs. At present launch rates and stand down lengths of four to five months, even a small increase in launch rate capability could significantly reduce the delay experienced after a stand down by allowing for an increased rate of launch. In addition, if increased capacity included improvements to launch facilities common to all vehicles it could aide in the prevention of "one slip all slip" delays caused by pre-launch anomalies on other launch pads.

Finally, launch delays for small ELVs usually only effect the vehicle at hand since launches are sparsely scheduled, and the delays which do occur result primarily from inexperience with the vehicle.

5.4 SUMMARY

Reducing the specific launch cost of current ELVs will require efforts to reduce the labor intensiveness of manufacturing and launch operations. The key technologies for achieving this have application deeply rooted in the manufacturing and launch operations process. These technologies generally fall into the categories of improved information systems, automation, and simplified designs, and many of the technologies which have been explored for reducing labor costs do not require extensive R&D because they are already available or under development. Efforts to improve performance through advanced technologies such as, higher efficiency rocket engines, or advanced lightweight materials will need to be coupled with efforts to prevent the increase in labor cost which usually accompanies their use. Also, simply increasing payload capability may not lead to reductions in specific launch cost at current levels of demand, and even if it did, it may not increase the competitiveness of the launch industry if it requires commercial satellites to be launched together with other payloads.

Improvements in the reliability of the large ELVs could be achieved through greater quality control, tighter specifications, more effective testing, automation, and simpler designs. However, it is not clear that the added cost of efforts to improve reliability would be justified for commercial payloads. The large U.S. ELVs have demonstrated higher reliabilities than their foreign competitors, and for any improvement to have an impact on competitiveness it must be demonstrated to insurers and customers which can take a long time. In addition, even if improvements are made, they may have only a small impact on the insurance premiums paid by the company because premiums are controlled primarily by market forces.

Regardless of the level of reliability which might be considered optimum for commercial launches, a disparity exists between the extremely high reliabilities required for critical government payloads, and the reliabilities required for commercial launches. In order to achieve the highest possible reliability for critical payloads, the government requires stringent quality control and tight design specifications which affect the cost of all launch vehicles. In addition, the government oversight to ensure specifications are met limits the ability of launch companies to select the procedures or technologies which they believe would be most efficient and lead to the optimal reliability for commercial launches.

The technologies for reducing launch delays fall in the same general category as those for reducing launch costs, and many of the technologies which have been explored for making improvements to launch facilities already exist. Because launch vehicles and their facilities are so integrated and interdependent, most improvements in operations will require changes in the vehicle as well as facilities. However, the selection of technologies most advantageous for improving launch operations will be strongly influenced by the value placed on reliability. Because the government places extremely high value on reliability, the technologies it would select may not be the most advantageous for increasing the competitiveness of the CLI. The extremely high value placed on reliability by the government will also lead to the continuation of stand downs after launch failures, and government involvement in the ensuing investigation. This will inhibit the ability of companies to shorten or eliminate stand downs which lead to costly launch delays. The need to increase the capacity of the ESMC launch facilities is directly linked to the length of stand downs. At present launch rates and stand down lengths of four to five months, even a small increase in launch rate capability could significantly reduce the delay experienced after a stand down by allowing for an increased rate of launch. In addition, if increased capacity included improvements to launch facilities common to all vehicles it could aide in the prevention of "one slip all slip" delays caused by pre-launch anomalies on other launch pads.

Thus, for the large launch vehicles enhancing competitiveness through technological development does not, in general, require extremely advanced or leading edge technologies. Rather, it requires technologies which can improve the efficiency and quality of manufacturing and launch operations. Also, important disparities exist between government and commercial needs from large launch vehicles centering around the extremely high value placed on reliability by the government to ensure successful launch of critical payloads. These disparities lead to government procedures which inhibit the selection of technologies and procedures which would lead to the most efficient and competitive commercial launch vehicles.

For the small launch vehicles being offered commercially to the government, such a disparity does not exist because government represents the only customer. These companies are competing among one another for small government and government financed payloads which are generally inexpensive and often experimental. For these vehicles, increased competitiveness is almost synonymous with increased successful launch attempts. These vehicles need launches to demonstrate reliability, improve efficiency, and decrease costs through economies of scale.

6.0 ENHANCING COMPETITIVENESS WITH NEW LAUNCH VEHICLES

Being the most colorful type of technological development for the launch industry, proposals for entirely new launch vehicles generally receive much public attention. Many different designs have been proposed and touted as the best launch vehicles for the future. The two vehicles which have been talked about most often are the National Aerospace Plane (NASP) and the Advanced Launch System (ALS). Even within these two programs a plethora of designs have been proposed, often with engineers arguing about the most effective way to reduce costs. Estimates of the development costs for these launch systems vary enormously. For example, R&D cost estimates for NASP have ranged from $3 billion to over $17 billion with operations cost estimates ranging from a tenth to a hundredth of present ELV launch costs.[1] Development cost estimates for ALS have ranged from $3 billion to $10 billion.

It would be foolish to believe that in the space of one chapter the innumerable arguments about the best design for, and ability of, new launch vehicles to reduce launch costs could be resolved. Rather than attempting to do so, this chapter addresses two questions which are very important for developing a government policy to enhance the competitiveness of the CLI. First, could private companies economically develop a new large launch vehicle on their own which would be more cost-effective than todays large launch vehicles? Second, what are the main factors which drive the most economical design of any new launch vehicle?

6.1 THE ECONOMICS OF LAUNCH DEMAND

If the cost of R&D were ignored then it seems likely that a properly designed new launch system of some kind could reduce launch costs. After all, the three large ELVs used in the U.S. today were originally designed as missiles, and thus were not optimized as launch vehicles. When claims are made about the potential of a new launch system to reduce launch cost they usually refer only to the reduction in incremental cost (i.e., the cost of a launch or flight) and ignore sunk R&D and overhead costs. But incremental costs are only a portion of the picture.

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[1] "The Aerospace Plane: Technological Feasibility and Policy Implications", Korthals-Altes, MIT-PSTIS, report #15, 7/86.

Whether government or industry invests in a new launch vehicle, the sunk cost of R&D and overhead must be amortized over ensuing launches to determine the vehicle's economic viability.

When industry invests in any project it expects to obtain a return on its investment. The rate of return required to make a project feasible varies from company to company, however the return rate is almost never below the cost of capital, and in general the higher the perceived risk of the project the higher the rate of return required.[2] With the present cost of capital hovering around 10% it seems reasonable that a company investing in a new launch system would expect to get at least 15%, and in fact due to the risk involved they would probably require more. Investment in a new launch vehicle would be recovered by the launch company as an annuity in the form of profit on each launch of the vehicle during the year. The charge per kilogram of payload required to obtain a 15% return on the investment will therefore be highly dependent on the the amount of payload launched into orbit by the new vehicle each year. The greater the amount placed into orbit annually, the lower the profit required on each kilogram of payload to obtain the return on investment.

Figure 6-1 shows the profit per kilogram necessary to recover various levels of investment at a 15% rate of return for different annual launch rates as a fraction of the presently available Titan III specific launch cost. The figure assumes that the lifetime of the new launch vehicle will be 20 years, and that no further investments will be necessary. Presently the large U.S. launch companies each place the equivalent of 20,000 to 40,000 kg into LEO annually.[3] For a $3 billion investment (the lowest predictions for NASP and ALS) and 40,000 kg per year, the company would need to make a profit on each kilogram greater than the price available today! To make that profit the company would also have to charge for the incremental cost of the launch including the cost of operations and in the case of an expendable, the cost of producing the vehicle itself. Clearly even if a new launch vehicle cost only $3 billion to develop, at present launch rates it would not be economical for a company to individually invest in one.

Some argue that reduced incremental costs would allow a company to charge less in expectation of vastly increased launch demand. If a company reduced its launch price significantly, it makes sense that launch demand for the company

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[2] *Essentials of Engineering Economics*, Riggs & West, McGrawHill, 1986, p.126.

[3] Compiled from company manifests.

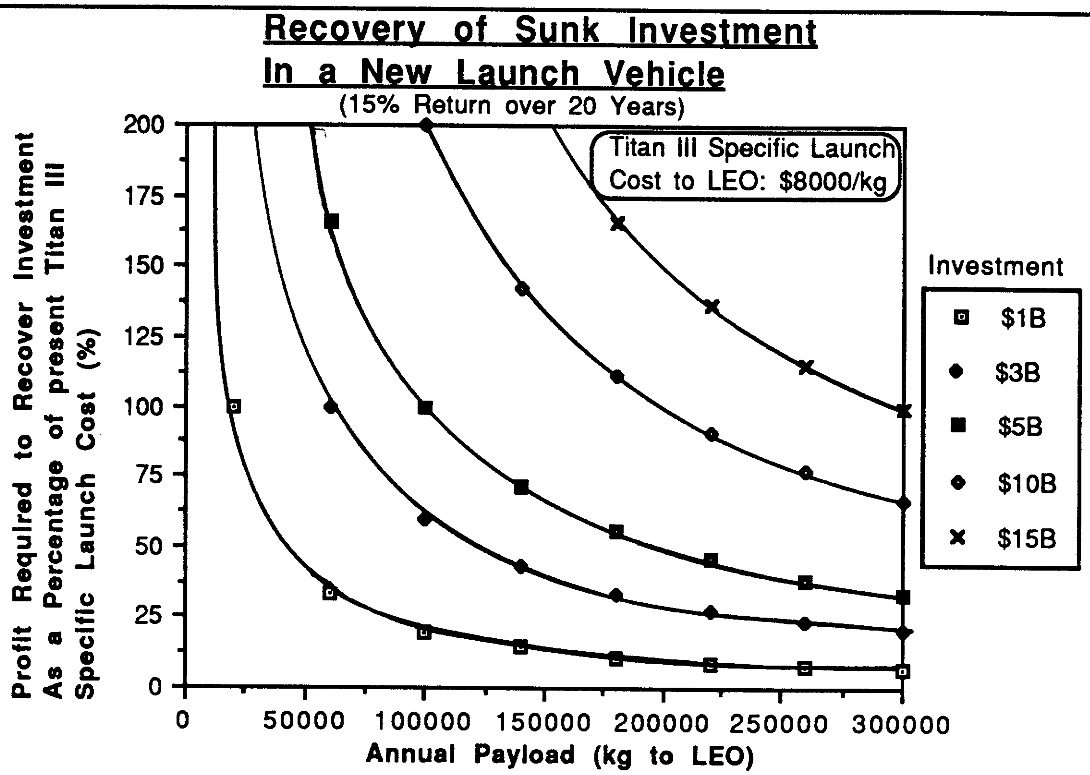

FIGURE 6-1

would increase as some commercial projects became economically viable and as the company obtained a greater market share. However, it must be remembered that presently well over 60% of launch demand comes from the government. While government demand for launches might increase very slightly with reduced cost, increases in government space programs are driven primarily by politics and policy, not economics. Thus, even if present commercial demand were to double, total demand would only increase by 40%. Even if an individual company expects to double its total launch rate in the future to 80,000 kg to LEO annually, on a $3 billion investment it would have to make a <u>profit</u> on each kilogram launched equal to 75% of current launch costs. If a company could captured all present launch demand (120,000 kg per year to LEO), a $3 billion investment would require a <u>profit</u> on each kilogram launched equivalent to about 50% of presently available launch prices. This means that even if the new launch vehicle could reduce incremental costs by 50%, the company would have to charge prices comparable to today's to make a modest 15% return on investment. With higher (and thus more realistic) return rates and sunk costs a new launch vehicle becomes even more uneconomical for an individual company.

What if government covers R&D expenses? It would seem then that the company would only have to incur the incremental costs associated with the vehicle. However, many of the launch vehicles being explored today would be partially or fully reusable. Depending on the arrangements made by the government these vehicles may require the company to purchase the reusable parts and amortize their cost over ensuing launches. The cost of these parts could be enormous. OTA estimates that the reusable portions of ALS might cost $1.7 billion. This large sunk cost would lead to significant increases in the projected launch costs, which only include incremental costs. At present launch rates even a $1 billion dollar investment in reusable parts (or in development of a new vehicle for that matter) would result in an amortization cost approaching present specific costs. Even at double present launch rates, the profit required on each kilogram of payload for a $1 billion investment would be over 25% of present launch cost. That profit alone would be three times the projected incremental cost of ALS. Thus, even if government pays the R&D cost of a new launch system, if the new vehicle requires large investment in reusable parts by the private company incremental launch costs may not be reduced significantly.

Confidence in Reliability After A Series of Successful Launches

SOURCE: See Appendix A

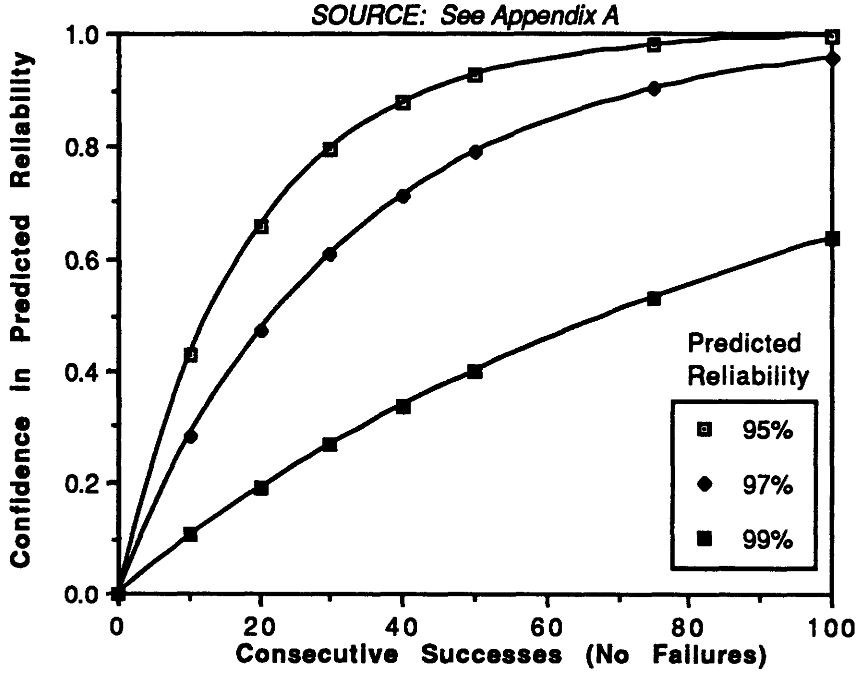

FIGURE 6-2

In addition to the initial costs of R&D and reusable parts, there would inevitably be expenditures required to correct problems which develop in early launches. For that matter, any new vehicle will require numerous test launches adding more cost, and making them more uneconomical for private development. For a commercial launch vehicle, reliability would have to be demonstrated to customers and insurers (see section 5.2). This would take many successful launches especially if extremely high reliabilities are being strived for. Figure 6-2 shows the confidence that a launch vehicle's reliability is at least the predicted reliability after a string of successful launches (see Appendix A for derivation). Demonstrating a 95% reliability to 90% confidence would take a over 40 consecutive successful launches. To obtain just a 50% confidence in a 99% reliability would take over 65 consecutive successes. One failure and the confidence in the predicted reliability would decrease significantly.

Between the cost of development, the cost of any reusable parts, the cost of launches for testing the vehicle, and the need to demonstrate reliability to customers and insurers, a new launch vehicle would not be economical for private companies to develop at present or even significantly increased launch rates without considerable government funding.

6.2 DESIGNING TO SUIT DEMAND

It may seem almost trivial to say that the most economical design of any new launch vehicle will be driven by the number and type of payloads to be launched on it each year. But this is a very important point which is sometimes overlooked in formulating policies about future launch vehicles. Since government will represent the vast majority of launch demand for the foreseeable future (see section 2.5), government's planned use of a vehicle will drive the design. If a new expendable launch vehicle were to be built then certainly many of the lessons from the previous chapter, such as simple designs to reduce labor costs, could be applied to its design. However, the most economical selection of the major design choices such as degree of reusability, payload capability, and reliability, will depend on the expected use of the vehicle.

Degree of Reusability

The previous section demonstrated very clearly that higher launch rates are required to make larger up front costs economical. This also holds true for government investments although they are usually evaluated at much lower discount rates. In general, the greater the reusability of any new launch vehicle the higher the R&D costs will be. In addition, reusable vehicles will require large initial investments in reusable parts. Ideally, a reusable vehicle will have lower incremental costs than an expendable. Thus, depending on the expected launch rate, there will be a trade-off between vehicles with high sunk R&D and capital costs, but low increment costs, and those with lower sunk cost but higher incremental cost. Selection of the most economical vehicle will depend highly on the future launch rates expected for the vehicle as shown graphically in Figure 6-3. At lower launch rates it would be more economical to select a vehicle with lower up front costs (i.e., more expendability), while at higher launch rates vehicles with lower incremental cost (i.e., more reusability) would be more cost-effective.

Trade-Off In Future Launch Vehicle Selection

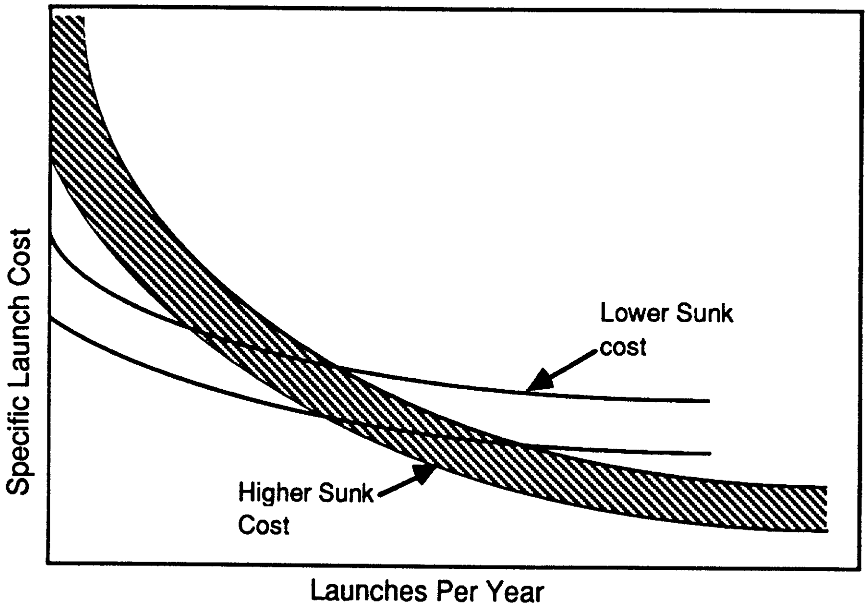

FIGURE 6-3

Another important factor which would influence the degree of reusability desired would be the need to return payloads to Earth. If humans are to be launched on the new vehicle then some portion of it must come safely back to earth. This part does not have to be reusable per se (take Apollo for example), but the need to have a returnable portion of the vehicle will influence the economy of having some reusability.

Payload Capability

The expected demand for any new launch vehicle will also effect the desired payload capability. In section 5.1 it was noted that at current launch rates and commercial payload sizes, a vehicle significantly larger than todays largest ELVs would probably not be cost-effective for commercial use. However, if launch demand were expected to increase significantly (for example as a result of SDI deployment) then larger launch vehicles would become more cost-effective in terms of dollars per kilogram to orbit. Also, the type of payloads to be launched, and the destination must be considered. If a new vehicle was going to be used to launch larger payloads, or send them further (for example to Mars), then greater payload capabilities would be required.

Reliability

Attempting to achieve higher reliabilities will inevitably incur added costs as redundant systems, tighter design specifications, and greater quality control are required (see section 5.2). The level of reliability desired from any new vehicle will be driven by the value of payloads to be launched, and the value of the vehicle itself if it is reusable. For example, a vehicle with reusable parts costing billions of dollars which will be used to launch astronauts would justify greater development and incremental expenditures to achieve high reliability than an expendable launching inexpensive payloads.

6.3 SUMMARY

Development of a new large launch vehicle will likely require a significant investment on the order of billions of dollars. At present or even significantly increased launch rates, billion dollar investments by private launch companies in development, or purchase of billion dollar reusable portions of a new launch vehicle would not be economical. Thus, the ability of future launch vehicles to enhance industry competitiveness will depend directly on government funding of such vehicles.

The selection of the most cost-effective design for a new launch vehicle will depend highly on the type and number of payloads to be launched on it. Since the government will account for the vast majority of launch demand for some time to come (see section 2.5), expected government use of any new vehicle will be the driving factor in the most cost-effective design for future launch systems.

7.0 GOVERNMENT ROLES IN TECHNOLOGICAL DEVELOPMENT

The government can play many different roles in the development of technology. Efforts to improve technology can be very direct such as through funding of a specific R&D project, or indirect such as by providing incentives for private innovation. For the launch industry, government can influence the development of technology in four broad ways: as developer of technology, as a customer for launch vehicles, as a catalyst to private innovation, and by providing infrastructure. Coupling the lessons of the previous chapters with the realities of government operation these roles are evaluated to formulate appropriate and feasible government actions for developing, or influencing the development, of technology to enhance the competitiveness of the CLI.

7.1 GOVERNMENT AS DEVELOPER

The government plays the role of developer when it selects specific technologies for development, manages the necessary R&D, and funds the project. When developing technologies sometimes the government will perform the R&D itself, but often it contracts the work out to a private company. Throughout the years leading up to the creation of the CLI, the government acted as developer of all launch vehicle technology. When the government needed a bigger or better launch vehicle it set the requirements, managed, and funded the project. The launch vehicles being used today by the large commercial launch companies are the direct result of those improvements.

In general, the government has been very effective at developing technologies for its own use. But government needs are fulfilled primarily through technical success rather than cost-effectiveness or commercial viability. For example, the Apollo program achieved success by placing a man on the moon, and defense projects are successful if the equipment operates to specification. On occasion the technologies developed for government use have resulted in technologies useful to the private sector. For example, the early computer, jet engine, and launch vehicles all resulted from government programs with technical goals aimed at fulfilling national security needs. However, while government was instrumental in the development of these technologies, the commercial applications were unexpected side benefits ("spinoffs") and not the impetus for the programs which created them. The concept of a commercial launch industry did not even reach the political agenda until twenty-five years after the development of launch vehicle technology. The question of this thesis is whether the government should develop technologies specifically for enhancing the competitiveness of the CLI. So, it must be asked how effective government has been in directed development of technologies for commercial use.

Historically the government has been extremely poor at selecting and developing commercially viable or cost-effective technologies. For example, in the 1960's the federal government funded a program to develop a strictly commercial supersonic aircraft in order to maintain U.S. dominance of the world aircraft market. Yet, American aircraft manufacturers were dubious about the commercial viability of such a vehicle and translated this into an unwillingness to share in the costs of the program. This, coupled with rapidly increasing cost estimates, led to the cancellation of the project after the government sunk $700 million into it.[1] The British and French governments then proceeded to develop a supersonic aircraft (the Concorde) which has proven to be a commercial failure. A more recent example of government's inability to target and develop commercially viable technologies is the Advanced Communications Technology Satellite (ACTS) program.[2] This satellite has been touted as essential for keeping American preeminence in the communications satellite industry. Yet, now that it is approaching completion, the government can't find any commercial companies interested in performing experiments using its capabilities.[3] The Space Shuttle, although not intended for commercial operation, stands as an excellent example of the government's ineffectiveness at developing cost-effective technologies since the Shuttle has never come close to meeting its targeted launch cost goals. These examples are far from unique, and studies which have explored government support of R&D have consistently found government poor at selecting and then developing commercially viable or cost-effective technologies.[4]

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[1] "The Government's Role in the Commercialization of New Technologies: Lessons for Space Policy", Rose, Economics and Technology in U.S. Space Policy Symposium, 6/86, p. 106.

[2] For an in depth discussion of the ACTs program see "Misreading History: Governments Intervention in the Development of Commercial Communications Satellites", Cunniffe, MIT Thesis, 6/90.

[3] "NASA Having Trouble Finding Users for ACTS", *Space News*, 3/12/90, p. 7.

[4] See "Industrial Innovation Policy: Lessons from American History", Nelson and Langlois, *Science*, Vol. 219, pp. 814-818. and "The Government's Role in the Commercialization of New Technologies: Lessons for Space Policy", Rose, Economics and Technology in U.S. Space Policy Symposium, 6/86, pp. 97-126.

Why is the government so poor at developing commercial technologies? In part because government does not inherently possess knowledge of the needs that commercial customers and suppliers have. Unlike procurement related technology development where the government knows its needs, for commercially viable technologies the government must evaluate the needs of customers and suppliers. While the government scientists and engineers who manage or carry out the projects are good at identifying what may be technically feasible, they often lack the expertise to evaluate the cost-effectiveness or market potential of technologies for commercial use.[5] As a result they tend to focus on what is technically possible, rather than what is profitable, forgetting that one does not necessarily guarantee the other. Meanwhile, Members of Congress and heads of government agencies react more to political than market forces. As a result they are attracted to technical achievements where success is relatively easy to gauge and very visible to the public. The visibility of technical successes can in turn generate more attention and needed political support. The need for political support can also lead a program to take on a broader role than strictly enhancing competitiveness in order to bring in a greater constituency. These additional goals create additional technical requirements which can interfere with the commercial viability of the technology.[6]

In retrospect then it should not be surprising that the Civilian Space Technology Initiative (CSTI) and the proposed Advanced Launch Technology Program (ALTP) focus on leading edge technology demonstrations, nor that these programs have objectives broader than maintaining the competitiveness of the CLI (i.e., developing systems for manned missions to Mars, or SDI). Both programs focus on developing large high performance engines which may not be the most cost-effective for the CLI (see section 5.1). Likewise, NASP has national security and national prestige goals which will inevitably conflict with its putative role as a commercial launch vehicle. For example, present designs call for NASP to be manned. This will require additional systems that are unnecessary for placing payloads into orbit which will add weight and cost to the vehicle. All of these efforts merely follow in the footsteps of previous government technology development programs by striving for leading edge technology and assuming

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[5] *Using Federal R&D To Promote Commercial Innovation*, Congressional Budget Office, 4/88, p. 40.

[6] High Technology Policies: A Five Nation Comparison, Nelson, American Enterprise Institute, 1984, p. 72.

multiple roles to build constituencies. Unfortunately this approach rarely leads to development of the technologies most needed for enhancing industry competitiveness.

Often the impetus for government technology development programs, especially those which are space related, comes from the threat of a foreign country developing the technology first and the fear that this will place the U.S. at a competitive disadvantage in the future. National technology development programs aimed at improving competitiveness seem to proceed from an implicit assumption that leading the world in advanced technology at the R&D stage guarantees operational and commercial success.[7] Not only does such an assumption further focus the objective of any government program on technical rather than commercial success, but it has usually proven to be incorrect.

Being first to demonstrate a technology, even when commercially viable, does not guarantee commercial success.[8] Integrated circuits, VCRs, and televisions are just a few examples of products developed in the U.S. and now manufactured almost exclusively by foreign companies. The companies which dominate these markets have done so primarily through incremental improvements in quality and price. The same is true in the launch industry where the company which dominates the commercial launch market, Arianespace, is the newest to the launch scene. Yet, the Ariane launch vehicles do not have extraordinarily efficient engines, extremely light weight materials, or any other break away technology. Rather, Ariane was designed using the base of technology created in the 1960s by the U.S. government and Arianespace has focused its attention on reducing the cost of constructing and launching Ariane.[9] While revolutionary development may instigate a new product, continued commercial success requires being at the forefront of evolutionary improvements in quality and price.[10]

The detailed evaluation of Chapter 5.0 demonstrated that the key technologies for improving the competitiveness of existing launch systems are not the extremely large high performance engines of ALTP, nor the esoteric technologies being explored in CSTI for NASA's manned missions (see section 2.6). Rather, the

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[7] "Government Policy: Technology Demonstration or Service Delivery?", Brooks, *Technology in Society*, vol. 11, 1989, p. 49.

[8] See "Government Policy: Technology Demonstration or Service Delivery?", Brooks, *Technology in Society*, Vol 11, 1989.

[9] *Reducing Launch Operations Costs*, OTA-TM-ISC-28, 9/88, p. 85.

[10] See "The Technological Factor in U.S. Competitiveness", Brooks, JFK School of Government, Science, Technology, and Public Policy Program, Discussion Paper 89-03.

key technologies are those which increase the quality and efficiency of manufacturing and launch operations -- such as improved automation, information systems, and simplified designs. Some of the technologies in these areas which might be most beneficial to the CLI already exist in other industries and do not require significant technical breakthroughs (see section 5.1). Thus, if the government wishes to develop technologies which would be most beneficial to improving the competitiveness of current launch systems it will have to focus on cost-effective technologies deeply rooted in the commercial process of manufacturing and operating launch vehicles rather than leading edge technologies -- something government has been poor at doing in the past.

Similarly, one must be skeptical about the ability of government to develop a completely new cost-effective launch vehicle specifically aimed at enhancing the competitiveness of the CLI. Such a launch vehicle will inevitably require attention to manufacturing and operational efficiency if it is to be cost-effective. But even aside from this, the primary driver of the economic viability of any new launch system will be the type and number of payloads to be launched each year (see section 6.2). Any new government developed vehicle will inevitably be designed to fulfill government needs. To the extent that government needs match commercial needs, a new government developed launch vehicle might aide the competitiveness of the CLI. But as has been shown, government requirements often differ significantly from commercial needs especially in terms of payload capability and reliability. In addition, any government program to develop a new launch vehicle will be expensive requiring it to take on multiple roles to build a constituency. Many of these roles, such as manned capability, or a vehicle for a voyage to Mars, will inevitably be disparate from commercial needs. As a result, even if the government could successfully develop a cost-effective launch vehicle for government payloads, it probably would not be of a design which is optimum for commercial use.

Finally, the most reasonable economic rational for direct government support of technological development to enhance the competitiveness of the CLI are the expenditures foreign governments are making on launch vehicle technology, and even this justification is debatable (see section 4.3). As previously discussed in Chapter 4.0, even if one accepts this rationale at some point the economic benefit from increased domestic launch contracts would be outweighed by the cost of technology development regardless of the level of expenditures by other nations on launch vehicle technology. If national security or national prestige were reasonable justifications for government expenditures to increase the competitiveness of the CLI, then expenditures beyond the economic benefit might be justified. But the only reasonable motivations identified in Chapter 3.0 for taking steps to enhance the competitiveness of the CLI are economic. Because government technology development programs tend to take on multiple roles, and to focus on leading edge technologies and technical success, they are prone to be very costly and to experience cost overruns. Therefore, a government development program would be apt to call for spending that may be beyond the value any technology produced will render to the economy in increased launch contracts. In addition, government technology development programs were identified as a key barrier to private development of launch vehicle technologies. The more the government invests in launch vehicle technology development, the less private industry will invest. This detracts from cost savings the government might obtain from private expenditures on innovation in the CLI (see section 3.3). Thus, a government technology development program specifically aimed at enhancing the competitiveness of the CLI would likely reduce or eliminate the economic benefit to the national economy and to the government from a competitive CLI.

7.2 GOVERNMENT AS CUSTOMER

Government is not your normal customer, especially in the launch industry. The government has and will continue to represent the majority of the demand for the launch industry (see section 2.5). Without this demand, launch companies would be hard pressed to continue commercial service. Since the role of government as customer differs for small and large ELVs, each will be discussed separately below.

Large ELVs

The substantial government demand for Large ELVs is not all a bed of roses. Government needs often differ considerably from commercial customers. The procedures used by government to meet these needs can interfere with the ability of, and incentive for, launch companies to develop and implement new technologies (see section 4.1). This drives the technology of launch vehicles away from what might be commercially optimal and increases cost. Certainly government should attempt to mitigate the negative impact it has on the launch industry as a customer, but at the same time, as the primary user of launch vehicles, the government must ensure that its needs are met.

Government places an extremely high value on reliability to ensure successful launches for critical government payloads (high cost or one of a kind and essential to the public welfare). This quest for extremely high reliabilities causes the government (primarily the Air Force and NASA) to require very tight design specifications and quality control for large ELVs which add to the production and operations cost of the launch vehicle. Because all launch vehicles are built on the same assembly lines using interchangeable parts, all vehicles, including those used for commercial launches, must meet the strict government requirements. Yet, the added costs may not always justify the potential improvements in reliability for commercial payloads (see section 5.2). And in any event, companies are restricted in their ability to select the most cost-effective technologies and procedures to obtain reliable vehicles.

Government's desire for high reliabilities also leads to government investigations of launch failures which require resolution of the problem before continuation of launches. Such stand downs cause lengthy launch delays costing the launch companies and their customers millions of dollars in expenses and lost revenues (see section 5.3). Government involvement in such investigations inevitably adds inefficiencies that increases their length. In addition, companies do not have the freedom to make the decision about whether a stand down is necessary after a launch failure.

The restrictions and added costs imposed by government procurement of launch vehicles, coupled with the low incentive launch companies often have to reduce costs on government procured vehicles (see section 4.1) have led many to call for government purchase of commercial launch services without production oversight, and with limited oversight of operations. But such a move is fraught with problems. The logic generally presented argues that commercial purchases would remove the barriers of oversight and provide economic incentive for companies to reduce cost. While this is true, the argument fails to remember that one of the primary reasons for such an action should be to increase industry competitiveness <u>not</u> to pad the pockets of launch companies. Imagine a launch company faced with this purchasing situation. If the company develops a technology which reduces cost, the only incentive to translate the savings into reduced price comes from the potential for increased customers. The problem lies in the inelasticity of government demand. In other words a change in price will result in little increase in government demand. Ideally the company would like to charge a lower price to commercial customers to obtain more sales while maintaining a high price to government. Would the government accept such a differential price? Certainly not. The government would demand fair prices and would establish its definition of fair by examining the prices paid by the few commercial customers. This means that any effort to increase sales to commercial customers would result in significant reductions in profit on government contracts which represent the majority of the company's demand. As a result the company would maintain higher prices inhibiting its competitiveness.

In addition to the problem of providing incentive for launch companies to reduce price, launching critical government payloads commercially makes no more sense than launching commercial payloads on vehicles required to strive for extremely high reliabilities. The government must ensure that launch vehicles used for critical payloads achieve the highest reliability possible. Thus, while procurement of commercial launch services by the government would increase the incentive for private industry to invest in technology development, any cost reductions would result primarily in increased profits for launch companies rather than increased competitiveness, and would result in the launches of critical government payloads without oversight needed to ensure high reliability.

Is there a way out of this quagmire? There are several actions which could help alleviate the problem. First, the government could launch all critical payloads on NASA's Space Shuttle or the Air Force's Titan IV (which is not being sold commercially). While non-critical government payloads could be launched on the ELVs which are being offered commercially. Explicitly defining a "critical" payload would be a somewhat tricky matter. Congress could mandate a payload cost above which any payload would be launched on Shuttle or Titan IV. A reasonable value might be any payload valued above $200 or $300 million, but such a move would not be flawless. Some payloads have importance to the nation beyond their explicit cost, and gauging this value would not be easy. So it might make sense to designate an official to make such a determination, or who can overrule the established regulations in exceptional cases. The exact method would require careful study and would inevitably be subject to political compromises, but regardless of the exact method such a system is certainly feasible. In addition, it would probably be easier to achieve than strictly commercial purchases because the Air Force would retain its coveted role as launch provider (see section 3.3) with Titan IV. Since most critical payloads are already being launched on Shuttle or

Titan IV, such a move would only effect a few payloads each year leaving the bulk of government demand for the commercial launch companies. For example, in 1989 two to three payloads launched on commercially available vehicles might have been classified as critical.[11]

Non-critical government payloads would not require extremely high reliabilities, so the government could reasonably reduce or even eliminate its stringent oversight of specifications and quality control. This would allow companies to select procedures and technologies that are more in line with the needs of commercial customers. In addition, the government could allow companies to individually manage and carry out reviews of any launch failures which did not endanger public safety, thereby giving them the freedom to determine whether such an investigation is even warranted, and removing the inefficiencies incurred by government involvement.

However, one of the reasons government carries out oversight of launch vehicles is because launch companies have little incentive to ensure successful launches of government payloads. For commercial payloads the launch company's incentive to have a successful launch lies in the potential for future commercial launch contracts. However, it would be unlikely that the government would turn to foreign launch providers to obtain launches for its non-critical government payloads. Thus, to provide sufficient incentive for the companies to ensure successful launches of government payloads, bonuses could be awarded to launch companies for each successful launch. Such a measure is not unprecedented in government contracting arrangements and has even been used by the Air Force in its recent Medium Launch Vehicle (Delta II) contract.

Using Titan IV for critical government payloads is not a perfect solution because the commercial Titan III's are built on the same assembly lines and use many of the same launch facilities. As a result the Titan III's would be subjected to much of the oversight required for the Titan IV's to ensure high reliability for critical government payloads. Ideally all critical government payloads would be flown on the Shuttle because, as a manned vehicle, it will likely be the most reliable launch vehicle available. However, the Shuttle is unlikely to be able to launch all critical government payloads, especially if the Space Station is built. Also, the *Challenger* accident taught an important lesson about placing all faith in a single launch system. A complimentary heavy lift launch vehicle such as Titan IV is

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[11] *Space Log*, TRW, 1989.

essential for assuring access to space for critical government payloads. Thus, the Titan IV would also be needed to meet government launch demand for critical payloads. While this is not a perfect solution, the Titan III has the lowest commercial launch demand of the three big U.S. companies, and there is some indication that Martin Marietta may in fact decide to withdraw from the commercial market.[12] Thus, the government could eliminate much of the negative impact it has as a customer on the commercial launch industry, and ensure the highest reliabilities for critical government payloads by launching critical payloads exclusively on the Shuttle and Titan IV, coupled with significantly reduced production and operations oversight of other ELVs.

What remains is the complex problem of providing incentives for launch companies to not only reduce cost, but also to translate this into reduced price. As previously mentioned, this cannot be achieved simply by government purchases of commercial launch services. Somehow the government must provide incentives for the company to reduce prices to commercial customers. One simplistic solution would be to allow the launch companies to charge a greater price to government users, effectively freeing them to compete for commercial payloads at lower prices. While this might make rational sense it is in essence an indirect subsidy of launch prices, and as such would raise an uproar from Arianespace, which combined with Congress' general distaste for outright subsidies, makes it an improbable solution. In reality, solving the dilemma of providing incentive for the CLI to reduce both cost and price will require very innovative purchasing arrangements. With the labyrinthine complexities of government procurement practices any solution will require detailed study. Suggesting specific action here is beyond the scope of this thesis.

Small ELVs

For the new launch companies offering small launch vehicles the government represents the only real customer, without whom the companies would cease to exist (the few other entities which have contracted for these vehicles all receive government support for their projects, see section 2.5). Thus, at present there is no "competitiveness" to be effected by government purchases because no truly commercial customers exist. But as the sole user, the method by which

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[12] "Energizing the Space Launch Industry", Berkowitz, *Issues in Science and Technology*, Winter 1989-90, p. 78. and *Space News*, "Future Clouded for Commercial Titan", 3/26/90, p. 4.

government purchases these launch vehicles can create an environment which promotes innovation. Not only could this save the government money, but on the off chance that commercial customers do surface the industry will be better prepared to serve them. Creating such an environment represents much less of a dilemma than with large launch vehicles for two simple reasons. First, the government presently uses these launch vehicles for inexpensive experimental payloads which are by no means critical. Second, several launch companies currently offer launch services with very similar capabilities. Thus, the government can competitively procure small launch vehicles on the basis of price and quality without extensive oversight allowing the competition for government contracts to drive improvements in technology which increase quality and decrease cost. In fact, this is exactly what the government is presently doing.[13]

7.3 GOVERNMENT AS CATALYST

One of the more traditional roles for government in technological development has been to create an environment which promotes private innovation. This has been done through patents, tax laws, regulations, and more recently joint ventures. There are innumerable actions which the government might take to spawn greater private innovation in all industries, such as tax reform or actions to lower the cost of capital. But the germane question here is whether the government should take action specifically to increase private innovation in the CLI.

Since government is such a poor developer of the technologies which would be most beneficial to the CLI, private innovation will be very important for enhancing the competitiveness of the industry. To increase private innovation in the CLI, government efforts should focus on removing the barriers to private development which are unique to the industry. Recalling the conclusions of Chapter 4.0, two primary barriers were identified to private development of technology in the launch industry. The first was government itself through its role as developer and customer which have been previously discussed. In a nut shell, to reduce the barrier government presents to private development of launch vehicle technology, it must refrain from funding technologies which industry might develop alone, and must purchase launch vehicles in such a way as to provide incentive for companies to reduce costs. The other barrier identified was

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[13] See "U.S. Government Ready to Place Orders for Small Launchers", *Space News*, 3/12/90,p. 8.

the segmentation of the large U.S. ELV industry which divides relatively low launch demand among several companies and prevents significant competition among these companies which might drive innovation. It should be stressed that this barrier is unique to the large ELV industry, and that the small ELVs being offered privately compete for government contracts which appears to be driving private innovation. The division of launch demand among the large ELV providers reduces the benefit an individual company might receive from an innovation, deterring private investment. Without increasing launch demand the only way to reduce this barrier is by lowering the cost to individual companies of developing technologies.

One way in which government might take action specific to the launch industry to reduce the effect of industry segmentation, would be to encourage the formation of a consortium among launch companies. This would allow the companies to share in the cost of technology development generic to all launch vehicles. If government desired to reduce the cost of R&D to these companies even more then it could jointly fund the consortium. The development of launch vehicle technologies by a jointly funded consortium rather than directly through a government development program has several advantageous. First, since the companies would have a financial stake in such a consortium, they will have strong interest in ensuring that the technologies developed are commercially viable. Second, development of technologies by a consortium will ensure that the R&D program is not forced to take on roles which conflict with developing commercially viable technologies. Third, a consortium could increase private contributions to technology development by making research expenditures viable which would not be on an individual basis for the companies. The technologies developed from these additional private expenditures could yield cost reductions for the government.

Unfortunately, many of the technologies identified in Chapter 5.0 for improving the competitiveness of existing launch systems do not require extensive R&D and would be unique for each launch system. As a result they would be of little interest to a consortium of all launch companies. However, the analysis of Chapter 5.0 focused on broad groups of technologies and did not exhaustively explore the R&D needed for specific individual technologies (to do so would take a lengthy study of its own). It may be that there are enough common technology interests which require some R&D to merit formation of a consortium. The only way to determine with certainty if enough common technological interests exist among launch companies to merit formation of a consortium would be to discuss the possibility with those companies. If enough interest exists, such a consortium could be very beneficial to the launch industry and possibly even to the government.

Any effort to form such a consortium would only be effective if government, as their primary customer, takes steps to purchase its launch vehicles in such a way that provides incentive for the companies to reduce cost. Without such steps the companies would be uninterested in investing significantly in any new technologies. Also, simultaneous government development of technologies specifically aimed at enhancing the competitiveness of the CLI would eliminate the incentive for companies to be involved in any consortium. Thus, for any consortium to be successful, the government must refrain from developing similar technologies on its own, and must purchase launch vehicles in such a way that provides incentives for the launch companies to reduce cost.

One way to eliminate the problem presented by having several unique launch vehicles with unique technology needs would be to develop a single new commercial launch vehicle. If developed through a consortium of launch companies, most of the problems associated with direct government development could be mitigated. However, as discussed in Chapter 6.0, a new launch vehicle will likely require such large investments that at current or launch rates even a consortia of all U.S. launch companies probably would not find it economical to invest in one. As a result, government would almost certainly have to jointly fund the consortium to make development of a new launch vehicle viable. An enormous amount of uncertainty exists about the economic costs and benefits of government expenditures on a new commercial launch vehicle. The willingness of launch companies to contribute to such a project would be a good measure of the need for a new commercial ELV. Creation of a single launch consortium would, however, eliminate even the small amount of competition which presently exists between the large U.S. launch companies. Yet, such a consortium would not be monopolistic because it would face extensive foreign competition. Thus, development of a new launch vehicle through a jointly funded consortium would prevent many of the pitfalls experienced in government development of commercial technologies, and industry's willingness to fund such a project could offer a means to gauge the need for such a vehicle.

As was discussed in section 6.2, the level and type of demand drives the design of any new launch vehicle, and since government will continue to represent the majority of demand, the design of any new vehicle will be driven by government use. If government developed a new launch vehicle on its own, the vehicle would inevitably be required to take on roles requiring a design disparate from what would be commercially optimal (see section 7.1). For the development of a new launch vehicle through a consortium to result in the most commercially competitive design, the government could not plan to use it to fulfill roles which are government unique and would require special design measures to accommodate, such as manned missions or launches of critical payloads.

7.4 GOVERNMENT AS INFRASTRUCTURE

From roads, to airports, to launch facilities, the government has historically provided essential infrastructure for transportation industries. But the current situation with launch facilities differs significantly from those of roads or airports. The primary users of airports and roads are the private sector, and the public. The primary user of launch facilities is government itself. As a result, the upkeep of, and improvements to, launch facilities are driven primarily by government, not commercial needs.[14] For small ELVs where launches are relatively sparse and government represents the only customer, this does not present a significant problem. But the situation for large ELVs being launched commercially out of the Eastern Space and Missile Center is very different.

The launch delays caused by inefficient government owned launch facilities cost large commercial launch companies and their customers millions of dollars, directly effecting the industry's competitiveness (see section 5.3). As a result, commercial launch companies have considerable incentive to improve the efficiency and capabilities of launch facilities. If government took steps to purchase its vehicles in a manner which provided incentives for launch companies to reduce costs, then the impetus for private improvements would be even greater. Unfortunately, the necessity to keep in line with established procedures and facilities used for launching government payloads constrains the ability of companies to institute new technologies and practices.[15] This does not mean that the rules and regulations which have been established are incorrect per se. Rather, government and commercial needs are often not one in the same with the government emphasizing extremely high reliability at the cost of operational efficiency (see section 5.3). While some government launch operations procedures

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[14] *Reducing Launch Operations Costs*, OTA-TM-ISC-28, 9/88, p. 8.

[15] *Reducing Launch Operations Costs*, OTA-TM-ISC-28, 9/88, p. 80.

and facilities may be superfluous, many are in place to ensure the extremely high reliability required for critical government payloads.

But even in those places where improvements in efficiency could be made without sacrificing necessary reliability in the eyes of government, the ability of government to manage and implement those changes is doubtful. Most of the technologies needed to make such improvements already exist or are under development. In addition, many improvements in launch operations will require coordinated improvements to both facilities and launch vehicles because of the highly interdependent nature of launch operations. For the most part, improvements in efficiency will be brought about by cost-effective implementation of existing technology. After the discussion of section 7.1., one must be skeptical about the ability of government to effectively carry out such improvements. Thus, unless the government changes the way in which it manages the Eastern Space and Missile Center launch facilities used by commercial companies, significant improvements in efficiency will be unlikely.

Certainly the government should attempt to mitigate the negative impact it has on the CLI, but as the primary customer for launch vehicles it must also ensure that its needs are met. Several alternative management structures have been suggested for these launch facilities including turning management over to the private sector and establishing a government launch operations division with sole responsibility over the facilities.[16] But as long as the commercially available launch vehicles are used to launch critical government payloads which require extremely high reliability, government and commercial needs will be at odds making it difficult to reasonably implement changes in the management structure that might lead to improved efficiency. If the government were to take the steps discussed in section 7.2, and launch critical payloads only on the Shuttle and Titan IV, it would resolve this conflict for the Atlas and Delta ELVs. (Commercial Titan III uses the same launch facilities as Titan IV). For those launch vehicles this would open the door for reasonable consideration of the sweeping management changes which have been suggested. However, after 30 years of managing the ESMC launch facilities, the Air Force will not be quick to relinquish its role. Any drastic changes will likely require an Executive Order or an act of Congress.

Changes in the management structure of the ESMC launch facilities which allow launch companies greater freedom in selecting and implementing

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[16] See Reducing *Launch Operations Costs*, OTA-TM-ISC-28, 9/88, p. 7.

technologies and procedures would lead to improved competitiveness of the CLI. Making the necessary changes, and at the same time ensuring that government needs are met, will not be a simple matter, especially if the commercially available ELVs continue to launch critical government payloads. Any specific recommendation for changing the management structure will require detailed study and is beyond the scope of this thesis. However, inaction would certainly have a deleterious effect on the competitiveness of the CLI.

8.0 CONCLUSIONS & RECOMMENDATIONS

Presently for the small launch vehicles being offered by several new entrepreneurial companies, there is no "competitiveness" which might be improved because government represents the only true customer. For these launch vehicles improvements will come primarily through the learning obtained from additional launches. Thus, the greatest way government can improve these vehicles is simply by being a customer for them. As the sole purchaser of these privately offered launch vehicles, government can create an environment which promotes innovation. Not only could this save the government money, but on the off chance that commercial customers do surface, the industry will be better prepared to serve them.

For large launch vehicles the interdependence between launch companies and national defense and space programs often clouds discussions about the need to enhance the competitiveness of the Commercial Launch Industry. A vigorous Commercial Launch Industry is neither needed, nor is it necessarily the best means, for ensuring national security or promoting national prestige. In fact, the technical and procedural needs of the Commercial Launch Industry are often at odds with those of government programs. Even if launch companies ceased to offer commercial launch services, the government could continue to procure launch vehicles as needed just as has been done in the past. The only reasonable motivations for government action to enhance the competitiveness of the Commercial Launch Industry are economic -- the potential for increased domestic launches, and the possibility of cost savings for the government.

Under most circumstances a commercial industry would be left to operate without directed government intervention to enhance its competitiveness, allowing the free market to drive innovation and improvements. But the launch industry is quasi-commercial at best, and market flaws exist which prevent efficient allocation of resources by the private sector. However, the primary flaws do not lie in financial market failure, or appropriability of the results of R&D. The Commercial Launch Industry experiences no more of a barrier to private development in those areas than other industries. Rather, for large ELVs, government itself represents a primary inhibitor of private development through the methods it uses to purchase launch vehicles and the oversight it carries out of their production. In addition, government funding of launch vehicle R&D deters investment by providing a low risk alternative to private development. Another barrier to private development lies in the segmentation of the large launch vehicle industry which divides already low demand among three companies. This reduces the economic viability of private investment, but yields little of the increased incentive for investment which would normally come from increased competition because the large launch companies do not compete extensively with one another.

Sometimes it is argued that the Commercial Launch Industry represents a "strategic" industry important for the future economic well-being of the nation. Even if one accepts the controversial notion of a strategic industry, the Commercial Launch Industry is an unlikely candidate having spawned very few other commercial industries or innovations. The government support received by the industry's foreign competition may represent a reasonable economic rationale for government support although economists debate this reasoning. However, even if one accepts foreign government support as a rationale for domestic government spending, a limit to expenditures exists beyond which the net economic benefit to society from increased domestic launches would be eliminated.

Improving the competitiveness of existing large launch vehicles will require the cost-effective application of technologies deeply rooted in the process of manufacturing and launch operations which reduce labor intensiveness, many of which do not require extensive R&D. While government has been generally good at developing leading edge technologies, it has proven notoriously poor at developing commercially viable or cost-effective technologies. This results primarily because government lacks the knowledge of customers' and suppliers' needs, and reacts more to politics than profit. This inevitably leads to programs which focus on leading edge technologies, and take on roles broader than just enhancing competitiveness. This would be especially true of an expensive program to develop a completely new launch vehicle. These additional roles, and the focus on leading edge technology, make government programs prone to being costly and to experience cost overruns. The high costs in turn make government development programs apt to exceed the amount which might be reasonably spent to ensure a greater number of domestic launch contracts.

In addition, the needs of government payloads are often different from those of the Commercial Launch Industry. These disparate needs lead government to select different technologies and procedures than might be optimal for commercial launches. For example, a new government developed launch vehicle would inevitably take on many non-commercial roles (such as providing transportation to Mars, launching SDI, or high speed intercontinental transportation) which would lead to a launch vehicle which was not commercially optimum and may not be commercial viable. For existing launch vehicles, government places an extremely high value on reliability, often without regard for manufacturing or operational efficiency, because some of the payloads it launches are extremely costly, one of a kind, or essential to national security. Government's drive for the highest possible reliabilities leads to implementation of new technologies and procedures, the delays and added costs of which, may not be optimal for commercial launches. Because government is the primary customer for large ELVs, and carries out extensive oversight of them, its drive for the highest reliabilities restricts the ability of launch companies to select the technologies and procedures which would be the most efficient for commercial launches. This is particularly true at the launch facilities which are government owned and managed.

Thus, a government technology development program would be unlikely to be successful in introducing the technologies most needed to improve current launch systems or in building a commercially viable and cost-effective new launch vehicle. In addition, a government led effort would be apt to exceed the value any technology produced would yield through additional domestic launch contracts. And finally, a government development program would tend to discourage private investment in launch vehicle technologies. Meanwhile, although government demand is essential to the existence of the Commercial Launch Industry, the methods used by government to meet its launch requirements directly effects the competitiveness and the opportunity for innovation in the Commercial Launch Industry.

Therefore, the greatest opportunities, and most appropriate actions, for government to enhance the competitiveness of the Commercial Launch Industry with improved technology lie, NOT in government development of technology, but in government's role as customer for launch vehicles, catalyst of private innovation, and provider of infrastructure.

RECOMMENDATIONS

The government should NOT initiate a technology development program specifically to enhance the competitiveness of the Commercial Launch Industry. Manufacturing and launching current ELVs is an extremely labor intensive process. The key to improving the competitiveness of existing large launch systems lies in cost-effective application of technologies which reduce labor costs. Any effort to improve the competitiveness of existing launch systems through advanced in materials,or rocket engines, will require close attention to manufacturing and launch operations efficiency. In addition, many of the technologies which might be most beneficial for reducing labor costs already exist or do not require extensive R&D. Because government represents such a poor developer of cost-effective or commercially viable technologies, and tends to focus on leading edge technologies, a government development program would be unlikely to develop the technologies most needed for enhancing competitiveness.

Any new commercial launch vehicle will also require attention to efficiency in manufacturing and launch operations. In addition, any new government developed launch vehicle will inevitably be designed to fulfill government needs and will be required to take on multiple roles to build the necessary constituency for political support. Government needs, and the additional roles beyond a commercially viable launch vehicle, are often disparate with commercial needs especially in terms of payload capability, reliability, and the need for manned spaceflight. Thus, any new government developed launch vehicle would be unlikely to be optimal for commercial use, and it may even be uneconomical as with the Space Shuttle.

Finally, the only possible economic rationale for government expenditures is the threat of foreign government support, and even this rationale is questionable. Even accepting this rationale, it must be remembered that at some point the cost of a technology development program would outweigh the economic benefits from increased domestic launches. Because government development programs tend to take on multiple roles and focus on leading edge technologies they are prone to be costly and to cost overruns. Therefore, a government development program would be apt to call for spending which may be beyond the value of domestic launches to the nation.

A procedure for identifying "critical" government payloads which will only be launched on Titan IV or the Space Shuttle should be established. This should then be coupled with significantly reduced oversight of the large ELVs being offered commercially.

Many of the barriers that government presents to private development of launch system technologies center around government's push for the highest attainable reliability. Striving for such reliabilities makes sense with critical government payloads which are extremely high cost, one of a kind, or essential to the public welfare. But for those non-critical government payloads which are less expensive or part of a constellation, striving for such reliabilities may not be worth the cost. Commercial launch companies must balance the drive for manufacturing and operational efficiency with the drive for high reliability. By removing critical government payloads from the commercially available launch vehicles the government could reasonably make significant reductions in the oversight of launch vehicle manufacture and operations without sacrificing the reliability needed of critical payloads. In addition, the government could allow commercial launch companies to fully and independently manage launch vehicle failure reviews except when the failure endangered public safety. This would enable launch companies to implement the most efficient and effective technologies and procedures for commercial payloads. Since most critical government payloads already are launched on Titan IV or the Shuttle this would only effect a few payloads each year leaving most government demand for the commercially available launch vehicles. The exact method used to to designate critical payloads will not be a simple matter and will inevitably require careful study. But such a system could eliminate many of the conflicts of interest between the government and commercial launch companies.

Innovative purchasing arrangements for the commercially available large ELVs should be established by the government which provide incentive for the companies to reduce both cost and price.

If the government launches critical payloads only on Titan IV and the Space Shuttle then it would be reasonable to purchase all commercially available large launch vehicles with significantly reduced oversight. However, moving to completely commercial purchases of launch services for government payloads would not be the most effective in promoting competitiveness of government cost reductions. Because government demand is very inelastic and represents the majority of launch vehicle demand, commercial launch companies will be inclined to maintain high prices. Reducing prices to win more commercial contracts would lead to lost profits on government payloads without a significant, if any, increase in government demand. Thus, while procurement of commercial launch services by the government would increase the incentive for private industry to invest in technology development, any cost savings would result primarily in increased profits for launch companies rather than increased competitiveness. Solving the dilemma of providing incentive for commercial launch companies to reduce both cost and price will require very innovative purchasing arrangements. Simply moving to commercial purchases of launch services would not be adequate.

The government should purchase small ELVs competitively as needed to fulfill government needs.

Government presently represents the only real customer for small ELVs, and thus there is no "competitiveness" to be effected by government purchases. But as the sole user government has the opportunity to create an environment which promotes private innovation. This could lead to government cost savings, and on the off chance that commercial customers do surface, the industry will be better prepared to serve them. Several launch companies exist which offer small ELVs with similar payload capabilities allowing government to competitively procure these launch vehicles. This competition should continue to drive innovation, and ensure that companies strive for successful launches of government payloads. Since the payloads being launched on these vehicles are almost exclusively inexpensive experiments, there should be no need for extensive government oversight. The government has already begun to procure small ELVs competitively, and should move to exclusive purchase of commercial launch services once all previously procured small ELVs have been used.

The government should explore and expedite changes in the management of the Eastern Space and Missile Center launch facilities which would provide greater incentive and opportunity for commercial launch companies to implement new technologies and practices, while ensuring that government needs are met.

Inefficient launch operations cost commercial launch companies millions of dollars in additional costs and delays. In addition to being antiquated, current launch facilities and procedures are geared towards ensuring successful launches of critical government payloads, emphasizing extremely high reliability at the cost of operational efficiency. The necessity of launch companies to stay within established procedures and facilities used for launching government payloads constrains their ability to institute new technologies and practices. Significant improvements in efficiency are unlikely to be made by government because they will come primarily from cost-effective implementation of technologies which do not require extensive R&D. However, changes should not be made which jeopardize the highest reliabilities possible for critical government payloads. If steps are taken to launch critical payloads only on the Space Shuttle and Titan IV, then this conflict of interest would be resolved for Atlas and Delta which are the primary large commercial ELVs. This would make it possible to more easily implement innovative management of the launch facilities for these vehicles while meeting government needs. However, for Titan III (which uses the same launch facilities as Titan IV), or if critical payloads continue to be launched on Atlas and Delta, making management changes and ensuring that government needs are met will be complex. Careful study will be required to determine appropriate and feasible actions. But unless the government changes the way in which it manages the Eastern Space and Missile Center launch facilities used by commercial companies, significant improvements in efficiency will be unlikely.

The government should explore the interest of launch companies in forming a consortium to research and develop new launch technologies.

The segmentation of launch capabilities in the large ELV industry divides relatively low launch demand among several companies and prevents significant competition among these companies which might drive innovation. A consortium would allow these companies to share in the cost of R&D generic to all launch vehicles allowing the companies to develop technologies which might otherwise be uneconomical. Because many of the technologies needed for improving current launch systems do not require extensive R&D or are unique to each launch system there may not be enough interest in formation of a consortium. However, if enough interest exists, a consortium could be very beneficial to the launch industry. Because the companies would have a financial stake in any consortium, the technologies developed would be more likely to be commercially viable than those developed by government. In addition, the government could directly benefit from the increased private expenditure which may yield cost reductions. But for any consortium to be successful, the government must refrain from developing similar technologies on its own, and must purchase launch vehicles in such a way that provides incentives for launch companies to reduce cost.

If the government desired to develop a completely new commercial launch vehicle, a consortium could provide an avenue for avoiding many of the pitfalls presented by direct government development of commercial technologies. However, for the development of a new launch vehicle through a consortium to result in the most commercial competitive design, the government could not plan to use it to fulfill roles which are government unique and would require special design measures to accommodate such as manned missions or launches of critical payloads. The government would almost certainly have to jointly fund such an effort to make it economically viable for a consortium, but the willingness of companies to contribute to the effort would be a good measure of the need for a new commercial launch vehicle.

APPENDIX A
RELIABILITY ANALYSIS

Based on historical data, the reliability of a launch vehicle can not be specified with certainty. However, given a set number of launches and failures it is possible to determine the probability that a launch vehicle's reliability lies within a certain range. This is referred to as a confidence interval. To calculate the confidence intervals for launch vehicles from historical data a Bayesian approach was used. The Bayes method formally combines the uncertainty associated with the estimation of reliability with the inherent variability of when launch failures will occur. With this approach the statistical information obtained from prior launch history is incorporated systematically with new observations of launches.

Given any prior probability distribution $f'(\beta)$ where β is the reliability, and a set of observed launches, the new probability distribution can be found from[1]:

$$f''(\beta)=kL(\beta)f'(\beta)$$

Where $L(\beta)$ is the likelihood of observing the given combination of failures and successes assuming that the reliability of the launch vehicle is β. For a binomial series of successes and failures the likelihood of observing any specific number of failures given a number of launches and an assumed reliability can be found by:

$$L(\beta)=\binom{n}{x}(1-\beta)^{x}\beta^{(n-x)}$$

where:
n=number of launches
x=number of failures
and,

$$\binom{n}{x}=\frac{n!}{x!(n-x)!}$$

---

[1] Probability Concepts in Engineering Planning and Design, Ang and Tang, John Wiley & Sons, 1975, p. 337.

The variable k is a normalizing constant given by:

$$k=\left[\int_{-\infty}^{\infty} L(\beta)f'(\beta)d\beta\right]^{-1}$$

which ensures that the area under the probability distribution integrates to one.

Thus, given a prior probability distribution and a set of observed launches, $L(\beta)$ and k can now be calculated followed by the new probability distribution $f''(\beta)$. Once the new probability distribution is found the confidence in any reliability interval is just the area under the probability distribution between the boundaries of the interval. Since we are interested only in lower bounds of the reliability, the interval can be taken from a selected reliability to a perfect reliability of one. Thus, the confidence that the reliability lies above some value, say r, would be given by:

$$\text{Confidence in Minimum Reliability of } r = \int_{r}^{1} f''(\beta)d\beta$$

Since the reliability is to be estimated strictly from historical data, before the first launch the reliability is completely unknown. Thus, there is equal probability that the launch vehicle's reliability is any value. The probability density distribution prior to any launches will therefore be flat between a reliability of zero and one, and zero everywhere else (Figure A-1). The area under the curve must be one so the prior probability density is constant at a value of one.

To carry out the confidence interval analysis for the various launch histories a spread sheet was created which numerically integrated the normalizing constant and the area under the probability density curve. An example of the output from this spread sheet for the case of the Atlas launch history with 32 successful launches and 2 failures is contained on the following pages. Also, figure A-2 shows a plot of the probability distribution generated from the data.

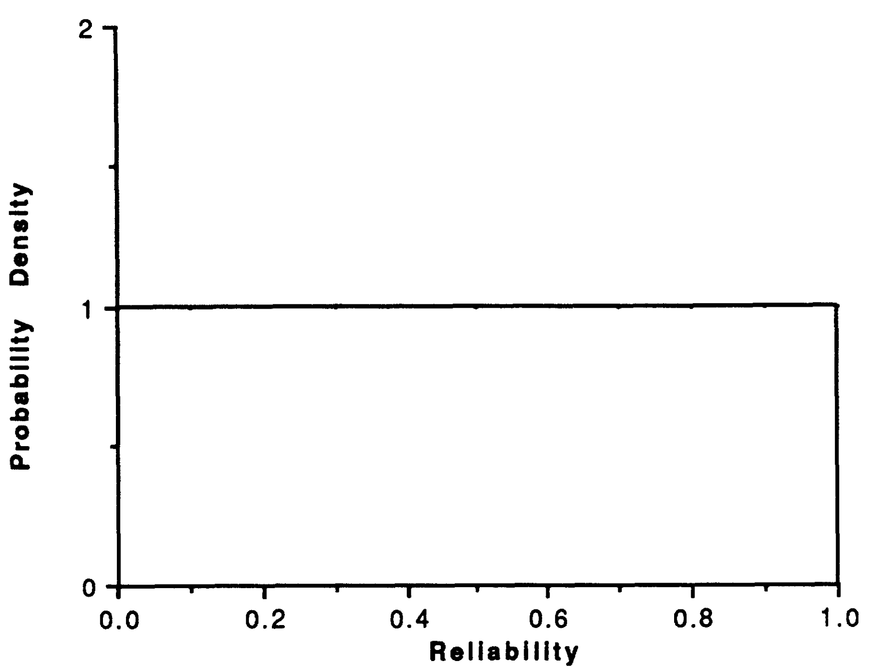

FIGURE A-1

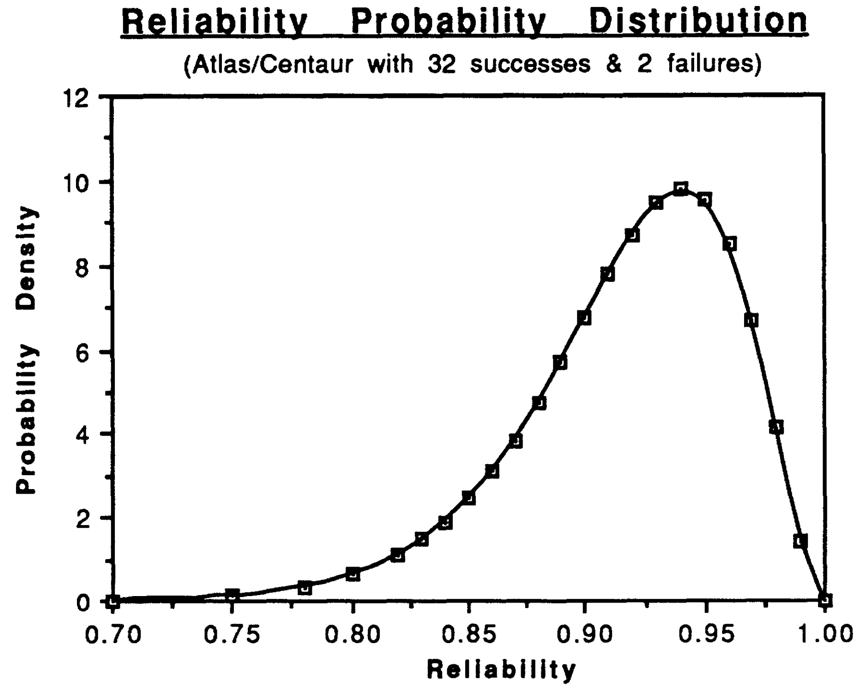

FIGURE A-2

	A	B	C	D	E	F	G	H	I	J
1	**Altas/Centaur Reliability Calculation From Break Point**									
2	**Posterior Probability Density/No prior knowledge**									
3										
4	Launches:	34								
5	Successes	32								
6			Normalizing		Normalized	Confidence	Check		Minimum	
7	Probability	Density	Integration	K	Density	Integration	Should =1		Reliability	Confidence
8	0.7	9.9398E-07	2.0685E-09	5.0905E-05	0.01952617	4.0635E-05	1		0.701	0.99995937
9	0.702	1.0745E-06	2.2357E-09		0.0211085	4.392E-05			0.703	0.99991545
10	0.704	1.1612E-06	2.4156E-09		0.02281107	4.7453E-05			0.705	0.99986799
11	0.706	1.2544E-06	2.6091E-09		0.02464236	5.1254E-05			0.707	0.99981674
12	0.708	1.3547E-06	2.817E-09		0.02661137	5.5339E-05			0.709	0.9997614
13	0.71	1.4624E-06	3.0405E-09		0.02872767	5.9729E-05			0.711	0.99970167
14	0.712	1.5781E-06	3.2806E-09		0.03100145	6.4445E-05			0.713	0.99963723
15	0.714	1.7025E-06	3.5384E-09		0.03344353	6.9509E-05			0.715	0.99956772
16	0.716	1.8359E-06	3.8151E-09		0.03606539	7.4945E-05			0.717	0.99949277
17	0.718	1.9792E-06	4.112E-09		0.03887923	8.0777E-05			0.719	0.99941199
18	0.72	2.1328E-06	4.4305E-09		0.04189799	8.7033E-05			0.721	0.99932496
19	0.722	2.2976E-06	4.7719E-09		0.04513538	9.3741E-05			0.723	0.99923122
20	0.724	2.4743E-06	5.1379E-09		0.04860596	0.00010093			0.725	0.99913029
21	0.726	2.6636E-06	5.5301E-09		0.05232512	0.00010863			0.727	0.99902165
22	0.728	2.8664E-06	5.95E-09		0.05630918	0.00011688			0.729	0.99890477
23	0.73	3.0836E-06	6.3997E-09		0.0605754	0.00012572			0.731	0.99877905
24	0.732	3.3161E-06	6.8809E-09		0.06514205	0.00013517			0.733	0.99864388
25	0.734	3.5648E-06	7.3957E-09		0.07002843	0.00014528			0.735	0.9984986
26	0.736	3.8309E-06	7.9462E-09		0.07525496	0.0001561			0.737	0.9983425
27	0.738	4.1153E-06	8.5347E-09		0.08084318	0.00016766			0.739	0.99817484
28	0.74	4.4194E-06	9.1636E-09		0.08681584	0.00018001			0.741	0.99799483
29	0.742	4.7442E-06	9.8353E-09		0.09319693	0.00019321			0.743	0.99780162
30	0.744	5.0911E-06	1.0553E-08		0.10001176	0.0002073			0.745	0.99759432
31	0.746	5.4615E-06	1.1318E-08		0.10728701	0.00022234			0.747	0.99737198
32	0.748	5.8567E-06	1.2135E-08		0.11505074	0.00023838			0.749	0.9971336
33	0.75	6.2783E-06	1.3006E-08		0.12333254	0.0002555			0.751	0.9968781
34	0.752	6.7278E-06	1.3935E-08		0.13216348	0.00027374			0.753	0.99660436
35	0.754	7.207E-06	1.4924E-08		0.14157628	0.00029318			0.755	0.99631118
36	0.756	7.7175E-06	1.5979E-08		0.15160528	0.00031389			0.757	0.99599729
37	0.758	8.2612E-06	1.7101E-08		0.16228655	0.00033594			0.759	0.99566135
38	0.76	8.8401E-06	1.8296E-08		0.17365794	0.00035942			0.761	0.99530193
39	0.762	9.4561E-06	1.9568E-08		0.18575915	0.00038439			0.763	0.99491754
40	0.764	1.0111E-05	2.092E-08		0.19863176	0.00041095			0.765	0.99450659

	A	B	C	D	E	F	G	H	I	J
41	0.766	1.0808E-05	2.2357E-08		0.21231934	0.00043919			0.767	0.9940674
42	0.768	1.1549E-05	2.3884E-08		0.22686747	0.00046919			0.769	0.99359821
43	0.77	1.2336E-05	2.5507E-08		0.24232381	0.00050106			0.771	0.99309715
44	0.772	1.3171E-05	2.7229E-08		0.25873818	0.0005349			0.773	0.99256225
45	0.774	1.4058E-05	2.9057E-08		0.27616259	0.00057081			0.775	0.99199143
46	0.776	1.4999E-05	3.0997E-08		0.29465128	0.00060891			0.777	0.99138252
47	0.778	1.5998E-05	3.3053E-08		0.31426084	0.00064931			0.779	0.99073321
48	0.78	1.7056E-05	3.5233E-08		0.33505019	0.00069213			0.781	0.99004108
49	0.782	1.8177E-05	3.7542E-08		0.35708064	0.0007375			0.783	0.98930358
50	0.784	1.9365E-05	3.9988E-08		0.38041596	0.00078554			0.785	0.98851804
51	0.786	2.0623E-05	4.2577E-08		0.40512238	0.00083639			0.787	0.98768165
52	0.788	2.1954E-05	4.5316E-08		0.43126866	0.00089019			0.789	0.98679146
53	0.79	2.3362E-05	4.8212E-08		0.45892607	0.00094709			0.791	0.98584436
54	0.792	2.485E-05	5.1274E-08		0.48816844	0.00100724			0.793	0.98483712
55	0.794	2.6424E-05	5.4509E-08		0.51907216	0.00107079			0.795	0.98376633
56	0.796	2.8085E-05	5.7925E-08		0.55171618	0.0011379			0.797	0.98262844
57	0.798	2.984E-05	6.1531E-08		0.586182	0.00120874			0.799	0.9814197
58	0.8	3.1691E-05	6.5335E-08		0.62255367	0.00128347			0.801	0.98013623
59	0.802	3.3644E-05	6.9347E-08		0.6609177	0.00136228			0.803	0.97877395
60	0.804	3.5703E-05	7.3576E-08		0.70136312	0.00144534			0.805	0.9773286
61	0.806	3.7873E-05	7.803E-08		0.7439813	0.00153285			0.807	0.97579576
62	0.808	4.0157E-05	8.272E-08		0.78886597	0.00162498			0.809	0.97417078
63	0.81	4.2563E-05	8.7656E-08		0.8361131	0.00172193			0.811	0.97244884
64	0.812	4.5093E-05	9.2847E-08		0.88582076	0.00182391			0.813	0.97062493
65	0.814	4.7754E-05	9.8304E-08		0.93808905	0.00193111			0.815	0.96869383
66	0.816	5.055E-05	1.0404E-07		0.99301989	0.00204374			0.817	0.96665009
67	0.818	5.3487E-05	1.1006E-07		1.05071689	0.002162			0.819	0.96448809
68	0.82	5.657E-05	1.1638E-07		1.11128514	0.00228612			0.821	0.96220197
69	0.822	5.9805E-05	1.23E-07		1.17483097	0.00241629			0.823	0.95978568
70	0.824	6.3197E-05	1.2995E-07		1.24146171	0.00255275			0.825	0.95723293
71	0.826	6.6751E-05	1.3723E-07		1.31128542	0.0026957			0.827	0.95453723
72	0.828	7.0474E-05	1.4484E-07		1.38441052	0.00284536			0.829	0.95169188
73	0.83	7.437E-05	1.5281E-07		1.46094551	0.00300194			0.831	0.94868993
74	0.832	7.8445E-05	1.6115E-07		1.54099853	0.00316568			0.833	0.94552426
75	0.834	8.2705E-05	1.6986E-07		1.62467694	0.00333676			0.835	0.9421875
76	0.836	8.7154E-05	1.7895E-07		1.71208686	0.00351542			0.837	0.93867208
77	0.838	9.1799E-05	1.8844E-07		1.80333265	0.00370185			0.839	0.93497023
78	0.84	9.6644E-05	1.9834E-07		1.89851634	0.00389625			0.841	0.93107397
79	0.842	0.0001017	2.0865E-07		1.99773704	0.00409883			0.843	0.92697515
80	0.844	0.00010696	2.1939E-07		2.10109026	0.00430976			0.845	0.92266539

	A	B	C	D	E	F	G	H	I	J
81	0.846	0.00011243	2.3056E-07		2.20866719	0.00452922			0.847	0.91813617
82	0.848	0.00011813	2.4218E-07		2.32055394	0.00475738			0.849	0.91337878
83	0.85	0.00012405	2.5424E-07		2.43683072	0.0049944			0.851	0.90838438
84	0.852	0.00013019	2.6676E-07		2.55757091	0.00524041			0.853	0.90314397
85	0.854	0.00013657	2.7975E-07		2.68284013	0.00549554			0.855	0.89764843
86	0.856	0.00014318	2.9321E-07		2.81269521	0.00575988			0.857	0.89188856
87	0.858	0.00015003	3.0714E-07		2.94718311	0.00603352			0.859	0.88585503
88	0.86	0.00015711	3.2154E-07		3.08633974	0.00631653			0.861	0.87953851
89	0.862	0.00016443	3.3643E-07		3.23018874	0.00660893			0.863	0.87292958
90	0.864	0.000172	3.5179E-07		3.37874018	0.00691073			0.865	0.86601885
91	0.866	0.0001798	3.6763E-07		3.53198915	0.0072219			0.867	0.85879694
92	0.868	0.00018784	3.8395E-07		3.68991437	0.00754239			0.869	0.85125455
93	0.87	0.00019611	4.0073E-07		3.85247659	0.00787209			0.871	0.84338246
94	0.872	0.00020462	4.1798E-07		4.01961703	0.00821087			0.873	0.83517159
95	0.874	0.00021336	4.3568E-07		4.19125567	0.00855855			0.875	0.82661304
96	0.876	0.00022232	4.5381E-07		4.36728956	0.00891488			0.877	0.81769816
97	0.878	0.0002315	4.7238E-07		4.54759092	0.0092796			0.879	0.80841856
98	0.88	0.00024088	4.9136E-07		4.73200528	0.00965235			0.881	0.79876621
99	0.882	0.00025047	5.1072E-07		4.92034957	0.01003276			0.883	0.78873345
100	0.884	0.00026025	5.3045E-07		5.11241004	0.01042035			0.885	0.7783131
101	0.886	0.0002702	5.5052E-07		5.30794022	0.0108146			0.887	0.7674985
102	0.888	0.00028032	5.709E-07		5.50665883	0.01121491			0.889	0.75628359
103	0.89	0.00029058	5.9155E-07		5.7082476	0.0116206			0.891	0.744663
104	0.892	0.00030097	6.1244E-07		5.91234912	0.01203091			0.893	0.73263208
105	0.894	0.00031147	6.3352E-07		6.11856463	0.01244502			0.895	0.72018707
106	0.896	0.00032205	6.5474E-07		6.32645186	0.01286197			0.897	0.70732509
107	0.898	0.00033269	6.7606E-07		6.53552284	0.01328076			0.899	0.69404433
108	0.9	0.00034337	6.9742E-07		6.74524179	0.01370026			0.901	0.68034406
109	0.902	0.00035405	7.1874E-07		6.95502303	0.01411925			0.903	0.66622481
110	0.904	0.0003647	7.3998E-07		7.16422903	0.0145364			0.905	0.65168841
111	0.906	0.00037528	7.6105E-07		7.3721685	0.01495026			0.907	0.63673815
112	0.908	0.00038576	7.8187E-07		7.57809469	0.0153593			0.909	0.62137885
113	0.91	0.0003961	8.0236E-07		7.78120385	0.01576184			0.911	0.60561701
114	0.912	0.00040626	8.2243E-07		7.98063394	0.0161561			0.913	0.58946092
115	0.914	0.00041617	8.4198E-07		8.17546354	0.01654017			0.915	0.57292074
116	0.916	0.00042581	8.6091E-07		8.36471117	0.01691205			0.917	0.5560087
117	0.918	0.0004351	8.7911E-07		8.54733495	0.01726957			0.919	0.53873913
118	0.92	0.00044401	8.9647E-07		8.7222327	0.01761048			0.921	0.52112865
119	0.922	0.00045246	9.1285E-07		8.88824258	0.01793239			0.923	0.50319627
120	0.924	0.00046039	9.2815E-07		9.04414431	0.01823281			0.925	0.48496346

	A	B	C	D	E	F	G	H	I	J
121	0.926	0.00046775	9.4221E-07		9.18866108	0.01850912			0.927	0.46645434
122	0.928	0.00047446	9.5491E-07		9.32046225	0.01875863			0.929	0.44769571
123	0.93	0.00048045	9.6611E-07		9.43816692	0.01897852			0.931	0.42871719
124	0.932	0.00048565	9.7564E-07		9.54034853	0.01916589			0.933	0.4095513
125	0.934	0.00048999	9.8338E-07		9.6255406	0.01931778			0.935	0.39023352
126	0.936	0.00049339	9.8915E-07		9.69224375	0.01943118			0.937	0.37080234
127	0.938	0.00049576	9.9281E-07		9.7389341	0.01950301			0.939	0.35129933
128	0.94	0.00049704	9.9419E-07		9.76407341	0.01953019			0.941	0.33176914
129	0.942	0.00049715	9.9314E-07		9.7661209	0.01950967			0.943	0.31225947
130	0.944	0.000496	9.8952E-07		9.74354716	0.0194384			0.945	0.29282107
131	0.946	0.00049352	9.8316E-07		9.69485023	0.01931342			0.947	0.27350765
132	0.948	0.00048964	9.7391E-07		9.61857425	0.01913191			0.949	0.25437574
133	0.95	0.00048428	9.6166E-07		9.51333079	0.01889115			0.951	0.23548459
134	0.952	0.00047738	9.4626E-07		9.37782325	0.0185887			0.953	0.21689589
135	0.954	0.00046888	9.2761E-07		9.21087469	0.01822233			0.955	0.19867356
136	0.956	0.00045873	9.0561E-07		9.0114593	0.0177902			0.957	0.18088336
137	0.958	0.00044688	8.8019E-07		8.77873807	0.01729084			0.959	0.16359252
138	0.96	0.00043331	8.513E-07		8.51209888	0.0167233			0.961	0.14686922
139	0.962	0.00041799	8.1892E-07		8.21120166	0.01608723			0.963	0.13078199
140	0.964	0.00040093	7.8307E-07		7.876029	0.01538297			0.965	0.11539902
141	0.966	0.00038214	7.4381E-07		7.50694267	0.01461169			0.967	0.10078733
142	0.968	0.00036167	7.0125E-07		7.10474689	0.01377551			0.969	0.08701183
143	0.97	0.00033958	6.5554E-07		6.67075862	0.01287764			0.971	0.07413418
144	0.972	0.00031596	6.0692E-07		6.20688588	0.0119226			0.973	0.06221158
145	0.974	0.00029096	5.557E-07		5.71571461	0.01091632			0.975	0.05129526
146	0.976	0.00026474	5.0225E-07		5.20060499	0.0098664			0.977	0.04142886
147	0.978	0.00023751	4.4707E-07		4.66579802	0.00878233			0.979	0.03264653
148	0.98	0.00020955	3.9073E-07		4.1165333	0.00767571			0.981	0.02497081
149	0.982	0.00018118	3.3397E-07		3.55917907	0.00656055			0.983	0.01841026
150	0.984	0.00015279	2.7762E-07		3.00137551	0.00545357			0.985	0.01295669
151	0.986	0.00012483	2.2268E-07		2.45219255	0.0043745			0.987	0.0085822
152	0.988	9.7855E-05	1.7035E-07		1.92230342	0.00334648			0.989	0.00523572
153	0.99	7.2498E-05	1.2199E-07		1.42417529	0.00239645			0.991	0.00283926
154	0.992	4.9494E-05	7.9188E-08		0.97227855	0.00155559			0.993	0.00128367
155	0.994	2.9694E-05	4.3768E-08		0.58331618	0.00085979			0.995	0.00042388
156	0.996	1.4074E-05	1.7826E-08		0.27647511	0.00035018			0.997	7.3701E-05
157	0.998	3.7518E-06	3.7518E-09		0.0737012	7.3701E-05			0.999	-2.22E-16
158	1									

APPENDIX B
LAUNCH DELAY MODEL

To simulate the backlog which is created after a stand down, and the clearing of that backlog with a surge launch rate, a dynamic model was built using STELLA software. STELLA allows the modeler to pictorially represent the time derivatives and integrals of a dynamic system as show in Figure B-1. In this figure the flows (which appear as valves) represent time derivatives, and the stocks (which appear as squares) the integral over those derivatives. Constants appear as circles in the diagram. In the following paragraphs, a qualitatively description of the model will be given followed by the system of equations it represents.

STELLA DYNAMIC LAUNCH DELAY MODEL

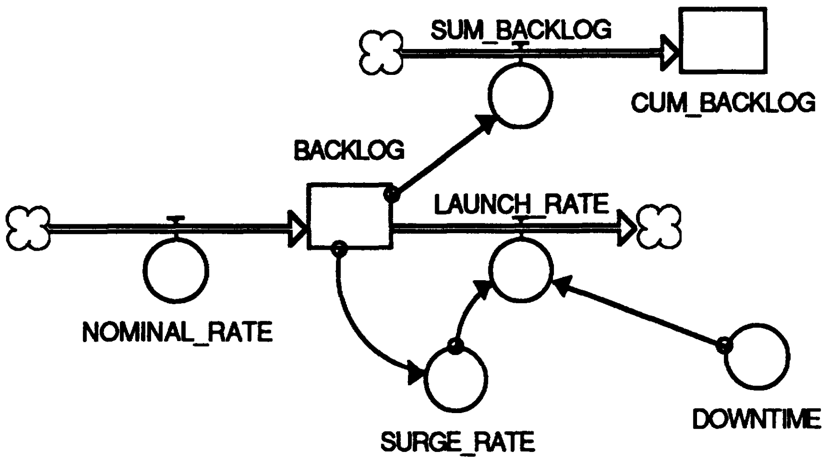

FIGURE B-1

The NOMINAL_RATE represents the rate at which satellite launches are ordered, and under nominal conditions would be equal to the launch rate. Similarly, the LAUNCH_RATE represents the rate at which satellites on the manifest are actually launched. A BACKLOG is created when the LAUNCH_RATE drops below the NOMINAL_RATE. One might be tempted to model the LAUNCH_RATE and NOMINAL_RATE as periodic pulses because an order or launch only occurs every few months, but a better model is obtained if these variables are modeled as smooth flows. The reason for this is quite simple. Think of the real situation with launches and payloads awaiting launches. If one launch experiences a short delay, say a week or two, it would inevitably cause delays for upcoming launches.

However, if LAUNCH_RATE and NOMINAL_RATE were modeled as pulses, a delay shorter than the period between pulses would not manifest itself in the model as creating a BACKLOG. Thus, these factors are modeled as a weekly flow rate of launches to give the model finer sensitivity to shorter delays.

When the model is run, initially the NOMINAL_RATE equals the LAUNCH_RATE and no BACKLOG exists. However, after a few weeks of simulated time, the DOWNTIME variable turns off the LAUNCH_RATE for a length of time equal to the stand down. This causes satellites from the NOMINAL_RATE to create a BACKLOG. Once the stand down is over, the DOWNTIME variable reengages the LAUNCH_RATE, and the SURGE_RATE variable increases the LAUNCH_RATE up to the surge capability. For example, if the surge capability is 12 launches per year and the nominal launch rate 10/year, then SURGE_RATE multiplies the LAUNCH_RATE by 1.2. Since the LAUNCH_RATE is now greater than the NOMINAL_RATE the backlog will be cleared over ensuing launches.

The BACKLOG represents the number of satellites which are experiencing a delay at any given time. For instance, two weeks into a stand down the BACKLOG will be greater than one week earlier. The item of interest is the total delay experienced by all satellites from a stand down, and not the number experiencing a delay at any given time. In other words, an integral is desired of the BACKLOG from before the stand down to after the BACKLOG is cleared. This is done in STELLA by summing the BACKLOG experienced at each calculation interval. The SUM_BACKLOG flow is equal to the BACKLOG at each calculation interval, and CUM_BACKLOG is just the summation of SUM_BACKLOG. Thus, CUM_BACKLOG represents the total delay experienced by all satellites.

The system of equations represented in this model are as follows:

```
BACKLOG=(NOMINAL_RATE-LAUNCH_RATE)*dt
CUM_BACKLOG=(SUM_BACKLOG)*dt
DOWNTIME=if(Time>t) and (Time<t') then 0 else 1
   where (t'-t)=length of stand down
LAUNCH_RATE=NOMINAL_RATE*SURGE_RATE*DOWNTIME
NOMINAL_RATE=constant
SUM_BACKLOG=BACKLOG
SURGE_RATE=if(BACKLOG>0) then Surge Capability else 1
```

STELLA numerically solves these equations with the output being a dynamic flow of the variables as they change during the simulation. The model was run with a

NOMINAL_RATE of .192 launches/week (10 launches/year), and with various stand down times and surge capabilities with the following output.

TOTAL LAUNCH DELAY EXPERIENCED AFTER A STAND DOWN
(Nominal Launch Rate of 10/year)
(Satellite-Weeks)

Stand Down (weeks)	Launch Rate Capability (Launches/year) 11	12	14	16	20
8	51.7	28.2	16.5	12.6	9.4
13	151.7	82.8	48.1	36.8	27.7
20	381.2	207.9	121.3	92.4	69.3

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