Chapter 1

Introduction and Principal Findings

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INTRODUCTION

Congress must soon make critical decisions about the future of U.S. space transportation. Although these decisions will have a profound effect on the Nation's ability to meet long-term space program goals, they must be made in a highly uncertain environment. A decision to deploy SDI, or to send humans to Mars, would call for space transportation systems of greatly increased capability, and configurations quite different from today's fleet. Alternatively, a decision to maintain the current level of space program activity might be accomplished with existing space transportation systems.

As a result of this uncertainty, projections of future yearly demand normalized to low-Earth orbit (LEO) range from 600,000 pounds to more than 4 million pounds.[1] Such uncertainty makes rational choice among alternative paths extremely difficult. Nevertheless, failing to choose now may leave the 'United States incapable of meeting future needs.

This special report examines both economic and noneconomic criteria for evaluating these launch systems and presents a "Buyer's Guide" to help the reader choose the launch systems most consistent with his or her own view of the future of the U.S. space program.

In this special report, OTA has analyzed three different mission models (levels of demand) and three different space transportation investment strategies for meeting each level of demand. The mission models describe a range of possible demand levels from 1989 to 2010 (see table 1-1 and figures 1-1 and 1-2).[2] Each model assumes that the United States will maintain a mix of piloted, and medium- and heavy-lift expendable vehicles:

- Low Growth — 3 percent average annual growth in launch rate (41 launches per year by 2010).
- Growth –5 percent average annual growth in launch rate (55 launches per year by 2010).
- Expanded –7 percent average annual growth in launch rate (91 launches per year by 2010).

In order to find the most cost-effective way of meeting the lift requirements of each mission model, this special report examines three space transportation investment strategies:

- improving existing launch systems in a series of evolutionary steps;

1 Not all payloads have LEO as their final destination. Payloads launched to high orbits require additional upper stages and fuel, OTA has added these upper stages and fuel to the payload masses launched to LEO in order to arrive at a consistent estimate of the total mass launched to space.

2 OTA assumes that the continuing growth in governmental uses of space, plus the possibility of growth in the commercial uses of space, makes a "No Growth" scenario unlikely. However, chs. 2 and 3 explain that existing or slightly enhanced launch systems could support a limitcd or no-growth space program.

3 Although 91 launches per year may seem high relative to recent U.S. experience, it is important to note that in 1966 the United States did launch 73 vehicles. Also, the Sovict Union has averaged 94 launchcs per year since 1974,(TRW Space Log, TRW Space and Technology Group, Redondo Beach, CA, 1986).

- designing and developing new launch systems for the mid-90s, using existing technology; or
- investing in the development of new technologies for the next century's launch systems.

These strategies, when applied to the various mission models, suggest seven different combinations of launch systems (see box l-l). With this information in hand, the concerned congressional "buyer" should be able to match his or her space program goals with an appropriate mix of launch vehicles.

Although OTA believes that the cost estimating methodology used in this special report is representative of the state-of-the-art, current methods for estimating launch system costs are partially subjective and uncertain. Because of this uncertainty, small differences in the estimated costs of launch systems are probably not meaningful and should not be the sole basis for national decisions. In addition, cost estimates for future launch systems that would rely on unproven or undeveloped technologies should be regarded with greater skepticism than estimates for existing or modified launch systems.

Box 1-1. – Space Transportation Options Considered by OTA

OTA estimated the life-cycle costs, from 1989 to 2010, of seven different space transportation fleets. To obtain cost estimates, OTA assumed specific configurations for both existing and proposed launch systems. This list is not comprehensive; other system designs are possible.

Enhanced Baseline Option– features an improved Shuttle with Advanced Solid Rocket Motors (ASRMs), improved Titan IVS with new solid rocket motors and fault-tolerant avionics, medium launch vehicles (MLVs–either Deltas or Atlas-Centaurs), and one additional Titan IV pad. This option could not accommodate the flight rates of either Growth or Expanded models.

Interim Option with Titan IV– features the Titan IV and as many new Titan IV launch facilities as are necessary to accommodate the peak launch rate for each mission model. Also includes existing facilities and launch vehicles now operational or in production (the Shuttle and MLVs).

Interim Option with Titan V–features the Titan V. Also includes unimproved Shuttles, MLVs, unimproved Titan IVs, and additional launch facilities.

Interim Option with Shuttle-C –features NASA's proposed Shuttle-C cargo vehicle. Also includes unimproved Shuttles, MLVs, unimproved Titan IVs and additional launch facilities.

Interim Option with Transition Launch Vehicle–features Transition Launch Vehicle. Also includes unimproved Shuttles, MLVs, unimproved Titan IVs, and additional launch facilities.

Future Option with Advanced Launch System (ALS) –features an ALS. Also includes the Shuttle, MLVs, unimproved Titan IVs, and additional launch facilities.

Future Option with Shuttle II –features a Shuttle II. Also includes unimproved Titan IVs, MLVs, and additional launch facilities.

PRINCIPAL FINDINGS

Finding 1: The United States possesses a capable fleet of launch vehicles and the facilities necessary to meet current launch demands and provide for limited near-term growth.

The existing U.S. space transportation fleet consists of the Space Shuttle, a variety of Titan, Delta, and Atlas launch vehicles, and the manufacturing and launch facilities necessary to build and launch these vehicles. Providing that failures are infrequent, these vehicles and facilities are capable of meeting U.S. space transportation requirements at recent historical (1984-85) or even slightly increased levels. The capacity of each system is limited by the rate at which the vehicles can be produced at the factory and flown from the launch pads. With existing vehicles, launch pads, and manufacturing facilities, the United States could launch a maximum of 860,000 pounds per year to low-Earth orbit (LEO).[4] To put such performance in perspective, consider that the United States launched about 600,000 pounds to LEO in 1984 and 1985, while the average for the period 1980-85 was about 400,000 pounds to low-Earth orbit per year. Until the Challenger disaster and the succession of expendable launch vehicle (ELV) failures in 1985 and 1986, the U.S. launch vehicle fleet was meeting military and civil demand reasonably on schedule.

Should the United States choose to use its existing space transportation assets more aggressively, these assets would support limited program growth once the current backlog of payloads is flown off. Current launch systems should be sufficient to support the continuation of existing programs and the increase in launch demand required by the Space Station. However, they could not provide enough lift capacity or the low launch costs sought for SDI deployment, although they could support some SDI experiments.

This is, however, a best-case scenario. Considerable uncertainty exists concerning the Shuttle's lift capabilities and achievable flight rate. In addition, recent Shuttle and ELV failures have shown that existing launch systems lack "resilience," that is, they do not recover rapidly from failure. To increase the resilience of its launcher fleet, the United States may wish to invest in new launch vehicles that it believes can be made more reliable. Resiliency could also be achieved by improving the reliability of existing launch vehicles or reducing the periods of inactivity ("downtime") following launch failures[5] or building backup launch vehicles and pads, as well as payloads.

Finding 2: The incremental improvement of current vehicles and facilities could provide a low-cost means to enhance U.S. launch capabilities.

The United States possesses the technology to improve the capabilities of existing launch vehicles and facilities through evolutionary modifications. For example, incremental improvements to current systems could reduce their operations cost and increase their lift capacity. If improvements in vehicle reliability can be achieved, then current vehicles could be used with greater con-

4 This number signifies the estimated upper bound of the system's capacity, not the historical launch capacity. To reach 860,000 pounds per year the United States would have to launch 9 Space Shuttle flights, 6 Titan IVs, 4 Titan IIIs, 5 Titan IIs, 4 Atlas-Centaurs, 12 Delta IIs, and 12 Scouts.

5 The United States could increase resiliency by adopting a policy of launching immediately after a failure. However, the existence of one-of-a-kind payloads and the high-profile nature of piloted spaceflights make such a change in policy inappropriate.

Table 1-1. – Mission Model Activities

NASA missions	Low Growth	Growth	Expanded
Spacelab	X	X	X
Space Station deployment and operation	X	X	X
Orbital Observatories	X	X	X
Unpiloted lunar and planetary	X	X	X
High-altitude servicing		X	
Station capability growth		X	
Piloted lunar or planetary			X*
DoD missions			
Meteorological	X	X	X
Communications	X	X	X
Defense Support Program	X	X	X
Navigation	X	X	X
Support Missions	X	X	X
Space Test Program	X	X	X
Improved Surveillance		X	
Demonstrations		X	
Advanced Capabilities		X	
SDI System Deployment			X*

* OTA's Expanded mission model could support either deployment of a Phase 1 Strategic Defense System or a major NASA piloted lunar or planetary mission, but not both.

Box 1-2. –Effect of Heavy-Lift Launch Vehicles on Mission Models

Introducing new heavy-lift launch vehicle would have a profound effect on the demand for other vehicles in the U.S. launch fleet. In its attempt to account for this influence, OTA has made the following assumptions:

- A new heavy-lift vehicle will be able to carry all the large cargo in the mission models with 20 percent fewer flights; that is, two of five payloads could piggy-back on one heavy cargo vehicle;
- 20 percent of Shuttle or Shuttle 11 payloads could fly on the heavy-lift launch vehicle on a one-for-one basis; that is, 20 percent fewer Shuttle or Shuttle 11 and 20 percent more heavy-lift vehicle launches would be required;
- Because they could fly on a space-available basis, 30 percent of MLV-class payloads could piggyback on heavy-lift vehicles without increasing the number of heavy-lift vehicle launches required.

Figure 1-1 shows the launch rates of the three mission models for options without heavy-lift vehicles, and Figure 1-2 shows the lower launch rates for options with a heavy-lift vehicle that would begin operations in 1995. Comparing these two sets of launch rates indicates that the addition of a heavy-lift vehicle reduces the number of flights required for all mission models.

With or without a heavy-lift launch vehicle, this report assumes that the number of piloted and light cargo vehicle flights required for the Growth arid Expanded mission models will be no greater than that required for the Low Growth mission model. Holding the number of piloted and light cargo flights constant assumes that ambitious piloted (e.g., mission to Mars or the Moon) or military missions (e.g., SDI deployment) will increase demand for large cargo transport much faster than the demand for human or small cargo transportation. Furthermore, it assumes that a large cargo vehicle can carry some payloads that would have otherwise been launched on either small or piloted vehicles. These assumptions notwithstanding, the more vigorously the United States pursues programs involving humans in space, the sooner it will have to replace or augment the existing Space Shuttle,

Figure 1-1. – Launch Rates Without a Heavy-Lift Launch Vehicle

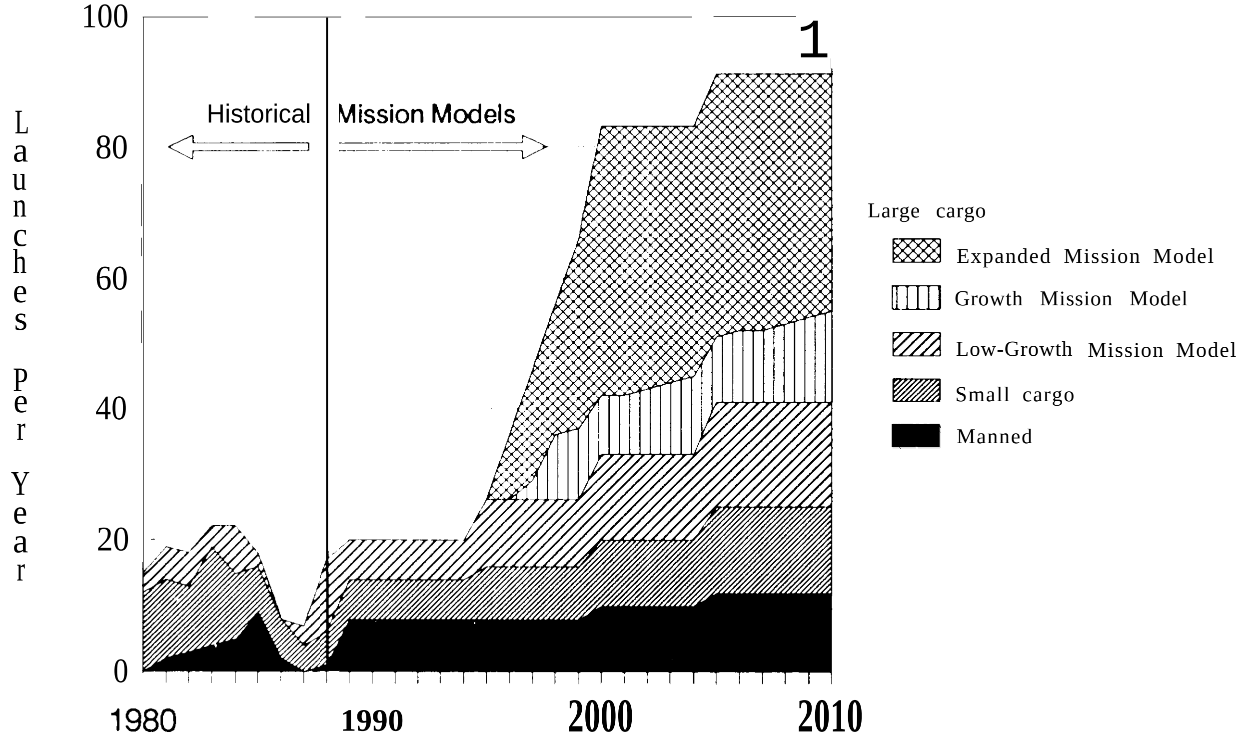


Figure 1-2. – Launch Rates With a Heavy-Lift Launch Vehicle

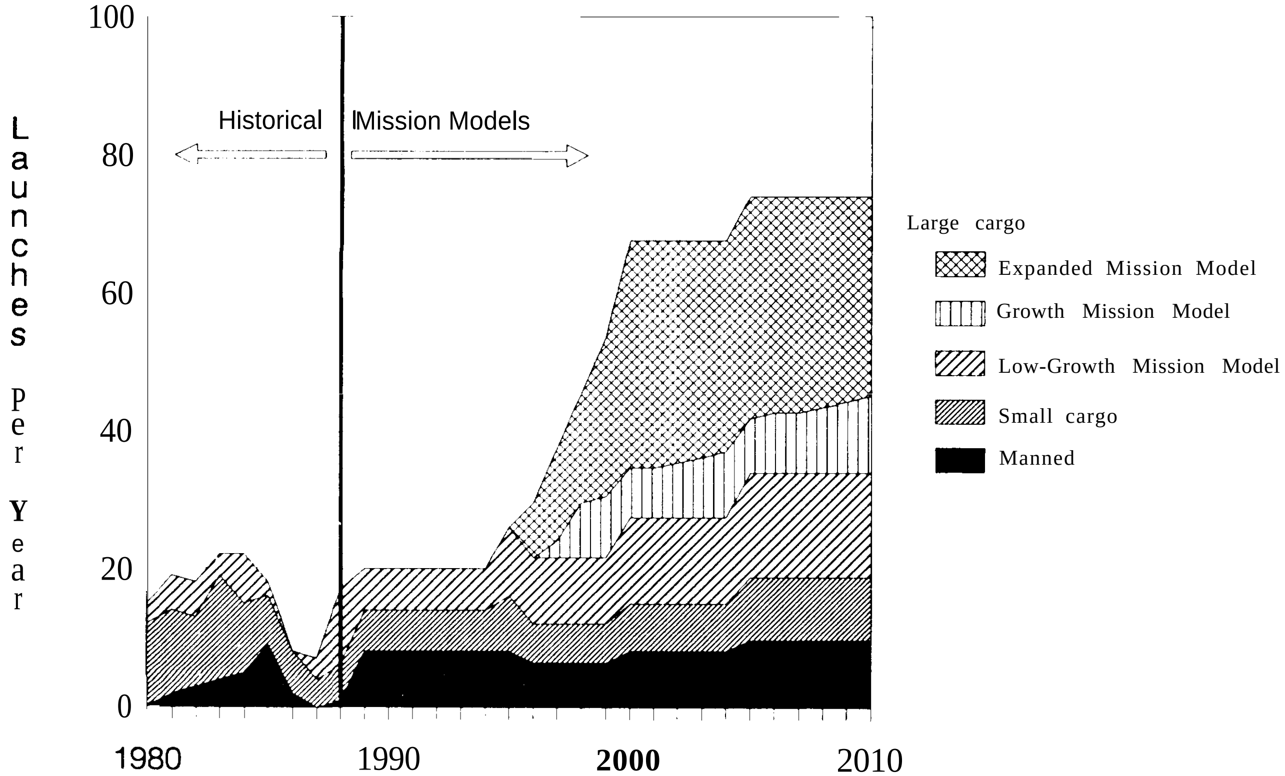
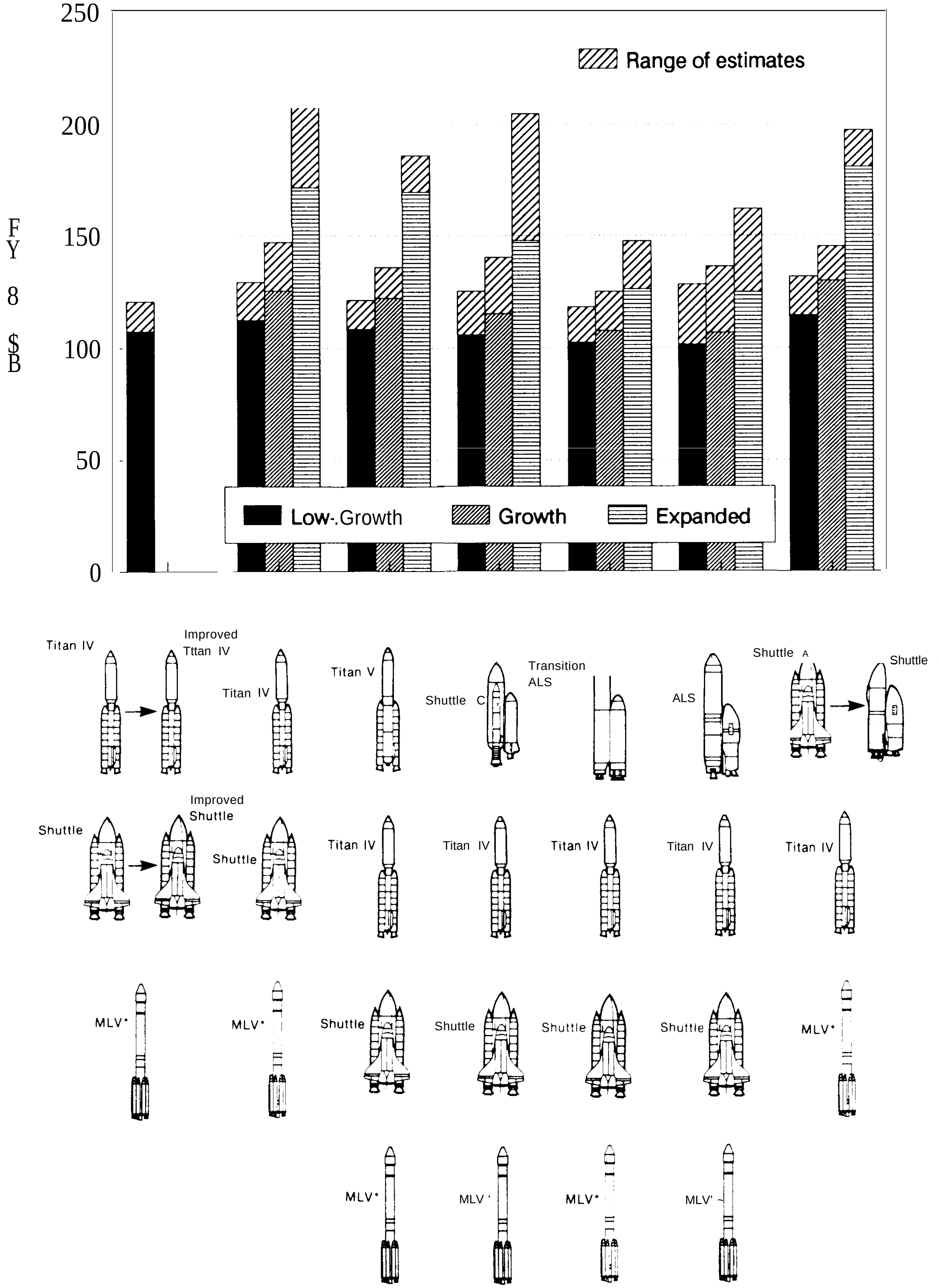


Figure 1-3. –Ranges of Estimates of Life-Cycle Costs (1988 dollars, discounted at 5 percent)



"Medium Launch Vehicle

SOURCE Office of Technology Assessment, 1988 fidence at higher flight rates. By improving existing vehicles and ground facilities and buying more launch vehicles, the United States could easily increase its launch capabilities to 1.4 million pounds to LEO per year.[6] Such a launch capability would support a space program with slow growth for many years.

One proposed Shuttle improvement under study is the development of Advanced Solid Rocket Motors (ASRMs). ASRMs are projected to increase the Shuttle's lift capacity by 12,000 pounds, improve Shuttle reliability, and allow the Space Station to be deployed in fewer flights and with less assembly in space. Planned improvements to the Titan IV solid rocket motors would increase the Titan IV's payload capability to LEO from 40,000 to 48,000 pounds.

Other possible enhancements for both the Shuttle and ELV launch systems include:

- improved liquid rocket engine components;
- new ground processing technologies;
- advanced avionics and flight software;
- new high-strength, light-weight materials; and
- new launch pads and flight control facilities.

Although the cost of development and the technical risks of such evolutionary improvements would be low compared to developing new vehicles, only small operating cost reductions could be expected.[7] Because the cost of launch failures is so high, improving the reliability of current vehicles would also be a desirable goal and would result in cost savings. Failing to increase the reliability of current vehicles would make it difficult to fly them at higher rates, since at higher rates failures would be more frequent. Unless other measures were taken, more frequent failures would reduce the periods of activity between "downtimes" and could result in substantial flight backlogs.[8]

The improved versions of existing vehicles contained in OTA's Enhanced Baseline could be used to launch the payloads in the Low-Growth mission model, but could not launch the payloads in either of the more aggressive mission models. Figure 1-3 indicates that the cost of using the Enhanced Baseline to meet the Low-Growth mission model might be between $110 billion and $1X) billion.[9] This would be comparable to accomplishing the same task with a fleet of vehicles that included the Transition launch vehicle ($100 billion to $120 billion). Given the uncertainties in cost estimation, the life-cycle costs of these two fleets of launch vehicles are practically indistinguishable at the Low-Growth mission model.

6 To reach 1.4 million pounds, the United States would have to make 13 Space Shuttle flights with Advanced Solid Rocket Motors, and launch 10 Titan IVs with new solid rocket motors, 4 Titan IIIs, 5 Titan IIs, 4 Atlas-Centaurs, 12 Delta IIs, and 12 Scouts.

7 U.S. Congress, Office of Technology Assessment, *Reducing Launch Operations Costs: New Technologies and Practices*, OTA-TM-ISC-28 (Washington, DC: U.S. Government Printing Office, in press).

8 The resiliency problem can be addressed in other ways. See discussion above.

9 Unless otherwise specified, life-cycle costs are given in 1988 dollars, discounted at 5 percent.

Finding 3: By the mid-1990s, the United States could build a variety of new, more capable launch vehicles, or greatly enhance its ability to launch current vehicles by expanding existing manufacturing and launch facilities.

The United States could develop at least four different types of interim launchs stems to add to its current fleet of vehicles:[10]

- NASA has suggested that the Nation develop an unpiloted version of the Space Shuttle, "Shuttle-C," for hauling cargo;
- The Air Force proposed in 1987 to develop a state-of-the-art "Transition" launch vehicle from existing technology that would allow routine operations.[11]
- Some aerospace companies have suggested that growth versions of current launch systems could accomplish the tasks that NASA and the Air Force seek to address with their new launch systems.[12]
- The United States could attempt to improve the reliabilities of current vehicles and greatly increase the number of launch pads and production facilities so that existing launch vehicles could be flown at substantially higher launch rates.

Which, if any, of these Interim Options should be chosen depends in large measure on the tasks they would be asked to accomplish. To some extent, these launch systems compete among themselves because all would be asked to function as the primary cargo vehicle in the U.S. launch vehicle fleet. Unlike some of the very advanced vehicle concepts discussed in the next section, the Interim Options do not involve such novel technology that their development programs can be regarded as ends in themselves.

Current programs and projected funding levels do not "require" an interim launch vehicle or greatly expanded launch facilities; desires for increased resiliency could be satisfied in other ways. Should the United States define programs that greatly increase the demand for space transportation, the specific nature of that demand should determine the nature and timing of any interim vehicle development.

NASA and Air Force estimates indicate that NASA's proposed Shuttle-C could provide the Nation with a heavy-lift launch vehicle in a shorter development time (4 years) and at a lower development cost (about $1 billion) than the Air Force Transition vehicle (about $5 billion over 7 years). However, a derivative of an existing ELV might be developed in a still shorter time and at a lower cost than either the NASA or the Air Force systems.

Examining the life-cycle costs of these vehicles could reverse their attractiveness. Shuttle-C and the ELV derivative would be relatively expensive vehicles to operate at high launch rates. For example, figure 1-3 suggests that to fly the Expanded mission model could cost between $150 billion and $200 billion, using a launch fleet that relied on the Shuttle-C as its heavy cargo vehicle, and between $170 billion and $185 billion,

10 One idea not discussed here is the so-called "Big Dumb Booster," a concept that originated in the 1960s. The concept suggests that a combination of simple technologies, such as pressure-fed engines and welded steel tanks, could substantially reduce launch costs. No thorough analysis has yet been carried out on the life-cycle costs of using such a booster. OTA will publish a background paper on this subject in the Fall of 1988.

11 In 1987, Congress specifically prohibited the Air Force from pursuing this concept, directing instead that the Air Force only investigate concepts that could offer a tenfold reduction in operating costs.

12 Martln Marietta, for example, has studied the growth potential of the Titan IV and concluded that by increasing the core diameter and adding additional liquid rocket engines and solid rocket motors, Titans could be produced with lift capacities ranging from 60,000 to 150,000 pounds to 1.130, Because the Titan is the largest U.S. expendable launch vehicle, it is used in this special report as one example of how current vehicles could be grown into heavy-lift cargo vehicles. Other existing vehicles may also have this potential.

using a fleet that relied on a Titan V. Figure 1-3 suggests that the same mission model might be flown for between $125 billion and $150 billion with a fleet that relied on a new Transition launch vehicle.

Shuttle-C and the ELV derivatives would primarily use current flight hardware, so the development risk would be lower than for a new vehicle. This technological commonality is advantageous because the new vehicles might share the demonstrated reliability of the existing flight hardware. On the other hand, failures of current vehicles, when they did occur, could cause derivative vehicles to be grounded if components they have in common caused the problem.

Shuttle-C appears most attractive for NASA-unique (i. e., Space Station or planetary) missions requiring infrequent heavy-lift capabilities.[13] The Transition launch vehicle appears most attractive for routine operations at increased demand levels, such as the Air Force will probably engage in over the next decade. ELV derivatives look most attractive for infrequent demand for launching heavy payloads and might serve both Air Force and NASA needs.

The final Interim Option (Titan IV Option) assumes that the United States would continue to use existing launch vehicles, but would add as many new Titan IV launch and manufacturing facilities as are needed to handle the peak launch rate for each of the mission models. Greatly expanding launch and manufacturing facilities, like the other three Interim Options, would require years to accomplish and investments of billions of dollars. This option might not be viable unless vehicles were made more reliable or the downtime between failures were reduced.

Constructing additional launch facilities would provide insurance against launch vehicle failures that damage or destroy launch pads, like the April 1986 Titan explosion that damaged Vandenberg Space Launch Complex 4. On the other hard, suitable sites in the continental United States for processing and launching large space vehicles are very scarce; a total of only four or five sites remain at Cape Canaveral and Vandenberg Air Force Base. Most of the existing launch pads were originally built in the 1950s and 1960s when environmental restrictions were much less severe. Satisfying the current restrictions on new construction in these environmentally sensitive areas would be a complex, expensive, and time-consuming task.

OTA calculations indicate that for the Low-Growth mission model, the Titan IV Option is reasonably competitive with all other launch vehicle options. This option is much less attractive for the Growth or the Expanded mission models (see figure 1-3).

Finding 4: Emerging technologies offer **the promise of new launch systems that could reduce cost while increasing performance and reliability. Such systems would entail high economic and technological risk and would require a sustained technology development program.**

13 For example. Shuttle-C could reduce from 19 to 12 the number of flights needed to launch the Space Station. reduce the asscmbly time from three years to 19 months, and reduce (he amount of risky on-orbit outfitting of laboratory and habitation modules. In addition, at low flight rates, Shut tie-C might provide a cost-effective alternative for near-term launch capability.

The United States is currently examining three advanced space transportation options. Two of these options – Shuttle II, a follow-on to the Shuttle, and the National Aerospace Plane (NASP),[14] a hypersonic spaceplane – would be piloted. The third concept, the Advanced Launch System (ALS), would be an unpiloted heavy-lift cargo vehicle. All of these pro rams would use new operational concepts,[15] advanced materials, and advanced manufacturing technologies to increase capability and reduce costs.

The Air Force envisions the ALS as a reliable, heavy-lift launch vehicle able to achieve high launch rates. The ALS is conceptually more mature and technically less challenging than either Shuttle II or NASP and is the focus of a joint NASA/Air Force technology development program. In defining the ALS program, the Air Force asked contractors to start with a "clean sheet of paper" and to emphasize cost efficiency rather than performance as the primary goal. If the ALS program were successful in significantly decreasing the costs of launching payloads, then, as shown in figure 1-3, it might cost between $125 billion and $160 billion to launch the Expanded mission model. OTA's calculations suggest that the Transition launch vehicle would have a comparable ($125 billion to $145 billion), or perhaps lower, life-cycle cost.[17]

The other Future Options, the Shuttle II and the National Aerospace Plane (NASP), may achieve a low cost per flight but not necessarily a low cost per pound to orbit. These two piloted vehicles would appear to have overlapping missions, including personnel transport, servicing and repair trips, and transport of high-value commercial products. One or both of these vehicles may eventually be needed as a replacement for the Space Shuttle; however, in the time period considered by this report, neither appears appropriate as the principal U.S. cargo vehicle.[18]

Of the two, NASP requires greater advances in technology and thus is more risky, but could also have a larger payoff. The high degree of technical and cost uncertainty associated with NASP make it impossible to provide useful cost estimates for its development and use.

In addition to these highly visible programs, several unconventional launch technologies such as laser propulsion, ram cannons, coil guns, and anti-matter rockets are in various stages of study. Because some of these concepts would subject payloads to extremely high accelerations, they could be used only for transporting certain types of cargo. These concepts push launch costs to the minimum but may have high development costs. Still, with continued research one of them may someday provide an inexpensive means for transporting supplies to space.

Meeting the space transportation needs of future programs is only part of the rationale for supporting advanced launch technology development. Other reasons include expanding the U.S. technology base and

14 NASP is a research program designed to explore the technical feasibility of hypersonic flight. The specific applications of NASP technology have yet to be determined.

15 For a detailed discussion of new operational concepts, see: U.S. Congress, Office of Technology Assessment, Reducing Launch Operations Costs: New Technologies and Practices, OTA-TM-ISC-28 (Washington DC: U.S. Government Printing Office, m press).

16 The ALS Phase I conceptual development activities are to conclude in August 1988. Through these studies NASA and the Air Force seek to document the major design trade-offs and to refine ALS cost, performance, and reliability models. Phase 11 (design/demonstration) is scheduled to begin in August 1988.

17 This is the result, in part, of the fact that certain versions of ALS are not assumed to become operational until the year 2000, so their greater development costs cannot be recovered by savings in operations costs before 2010, the last year of the OTA mission model.

18 Sometime in the 2000s, the current Space Shuttle will begin to exceed its useful lifetime or will become obsolete. At this point, if the United States wishes to continue its human presence in space, a replacement for the current Shuttle will be necessary whether or not it is competitive at launching cargo with then existing or planned cargo vehicles.

promoting space leadership and industrial competitiveness.

Finding 5: An aggressive technology development program could allow the United States to remain preeminent in selected space technology areas. Such a program must balance technology efforts focused on specific launch systems with basic research and technology development.

A variety of experts have expressed concern over the poor state of U.S. space technology development, especially in light of foreign activities, which have increased dramatically over the last decade. Research on basic technologies for launch systems has been particularly neglected. For example, the United States has not developed a new rocket engine in over 15 years and the space program has followed rather than led other industrial sectors in the development and use of new light-weight, high-strength materials and automation and robotics.

An aggressive technology development program would be beneficial to any of the options discussed in this special report. Even if Congress decides to defer development of a new launch system for a few years, investment now in new launch-related technologies would prepare the United States to proceed more quickly in the future. The Air Force and NASA budget submissions for fiscal year 1989 contain funds to begin such technology developments, but at a level of effort that appears low relative to that recommended by numerous recent studies.

Finding 6: The most appropriate economic measure of merit for comparing different launch system options is discounted life-cycle cost. Noneconomic criteria such as "space leadership" or international competitiveness must also be weighed in choosing among options.

Minimizing a launch system's upfront costs (technology development, vehicle design, and facilities) is often done at the expense of driving up its recurring costs (fuel, expendable components, personnel). The least cost to the taxpayers is incurred by minimizing total life-cycle costs –the sum of all upfront and recurring costs, including costs of failure –discounted to reflect the value of money over time. This special report assumes a 5 percent real discount rate, which is generally accepted for government investments. A higher discount rate would penalize options that require greater upfront investments.

Estimated life-cycle cost cannot be the sole criterion for decisions on launch system development. The United States may prefer to sacrifice some life-cycle economy for other benefits, such as near-term affordability or noneconomic benefits such as "leadership" or national security. Some advanced programs require large investments and promise no immediate pay-back but would contribute to the status of the United States as a technology innovator. Other investments, although uneconomical, might be needed to counter the military activities of our adversaries.

Finding 7: Demand for launch services is the most important determinant of the value of investing in new launch systems.

If future missions are as infrequent and diverse as they have been in the 1980s, no option reviewed by OTA appears likely to reduce average launch costs significantly, although several could provide improved reliability, capability, and resiliency. However, if over the next 20 years demand for launch services continues to increase, it would become economical to develop and procure new launch vehicles that could be processed and launched efficiently at high launch rates. Small payloads that could be co-manifested with others would benefit even more from such new vehicles. However, until the country decides whether to deploy SDI, revisit the Moon, explore Mars, embark on some other major space project, or limit space activities to those requiring only modest budget increases, accurate projections cannot be made of either the number or type of space transportation vehicles and facilities that will be needed. Such projections are essential if new facilities or vehicles are to be designed for maximum economy.

Finding 8: At Low-Growth launch rates it is uncertain whether it is more desirable to invest in new vehicle technology or to expand production and launch facilities and incrementally improve current vehicles.

At the launch rates assumed in the Low Growth mission model, none of the options considered by OTA offers a discounted life-cycle cost that is substantially different than that of current vehicles. Because the differences in life-cycle cost are small, choices among the options must be based on other economic criteria, such as magnitude of near-term investment or peak annual funding, or on noneconomic criteria such as lift capability and reliability.

New launch vehicles could lift heavier payloads or improve reliability and resiliency, but would require more investment than current vehicles or improved versions of current vehicles. Upgrading existing vehicles would have low development costs but would save less on operations costs. In addition, launching current vehicles at high rates would require improvements in reliability, backup launch vehicles and facilities, or reductions in "downtime" following failures. If such changes could not be achieved economically with current vehicles, then the most advisable course would be to pursue a new cargo vehicle.

The inability of current vehicles to meet specific near-term needs would also provide a reason for developing new launch capabilities. For example, should the United States determine that it requires a Shuttle-C for Space Station or that it has a payload too large for the Titan IV, then a new vehicle might be appropriate. In such circumstances, the specific nature of the need should be allowed to dictate the nature of the new vehicle.

Finding 9: At Growth launch rates it appears that the development of a Transition launch vehicle might yield savings.

At Growth mission model levels, OTA estimates that the Transition launch vehicle would cost between $110 billion and $125 billion (see figure 1-3). Judged according to these cost estimates, the life-cycle cost of the Transition launch vehicle could be as much as 10 percent less costly than either the Titan V or the ALS. In addition, the Transition vehicle might have greater reliability, and less environmental impact at high launch rates than a Titan V and would entail less development cost than the ALS.

Finding 10: At Expanded launch rates the Transition launch vehicle or the Advanced Launch System should both yield savings.

If launch rates more than quadruple by 2005, with heavy cargo launch rates increasing more than tenfold, an Advanced Launch System or less advanced Transition launch vehicle should have lower life-cycle costs than the other options considered by OTA.

Finding 11: Current methods for estimating launch system costs are subjective and unreliable. Improving the science of cost estimation should be part of any launch vehicle or technology development program.

Even if future demand were known, estimated costs of launch systems would still be highly uncertain because the United States' space transportation operations experience is limited compared to the mature commercial aviation industry and a highly detailed database is unavailable. Although the Space Transportation Architecture Study[19] improved cost estimating models and these models continue to be improved in the NASA/Air Force ALS studies, much work is still needed to find and aggregate historical cost data, record and analyze more system details, make uncertainties more explicit, and develop the means to estimate the effects of new technologies on manufacturing costs and launch system operations. Congress may wish to direct the Air Force and NASA to increase their effort to develop new, more credible cost estimation models.

Finding 12: Large development projects for new space transportation systems are not likely to achieve their cost or technical objectives without continuity in commitment and funding.

The ultimate cost of any large system depends, in some degree, on how it was purchased. The nature of the annual budgeting and appropriations process often causes yearly fluctuations in the continuity of development funds, or delays in purchasing systems and facilities. These effects can produce significant increases in the cost of large systems. When examining the credibility of any launch system cost estimate, Congress must take into account the effect of its own actions on program costs.

19 U.S. Department of Defense and National Aeronautics and Space Administration, National Space Transportation and Support Study 1995-2010, Summary Report of the Joint Steering Group, May 1986, pp. 15-19.