Chapter 6

Reducing Space System Costs

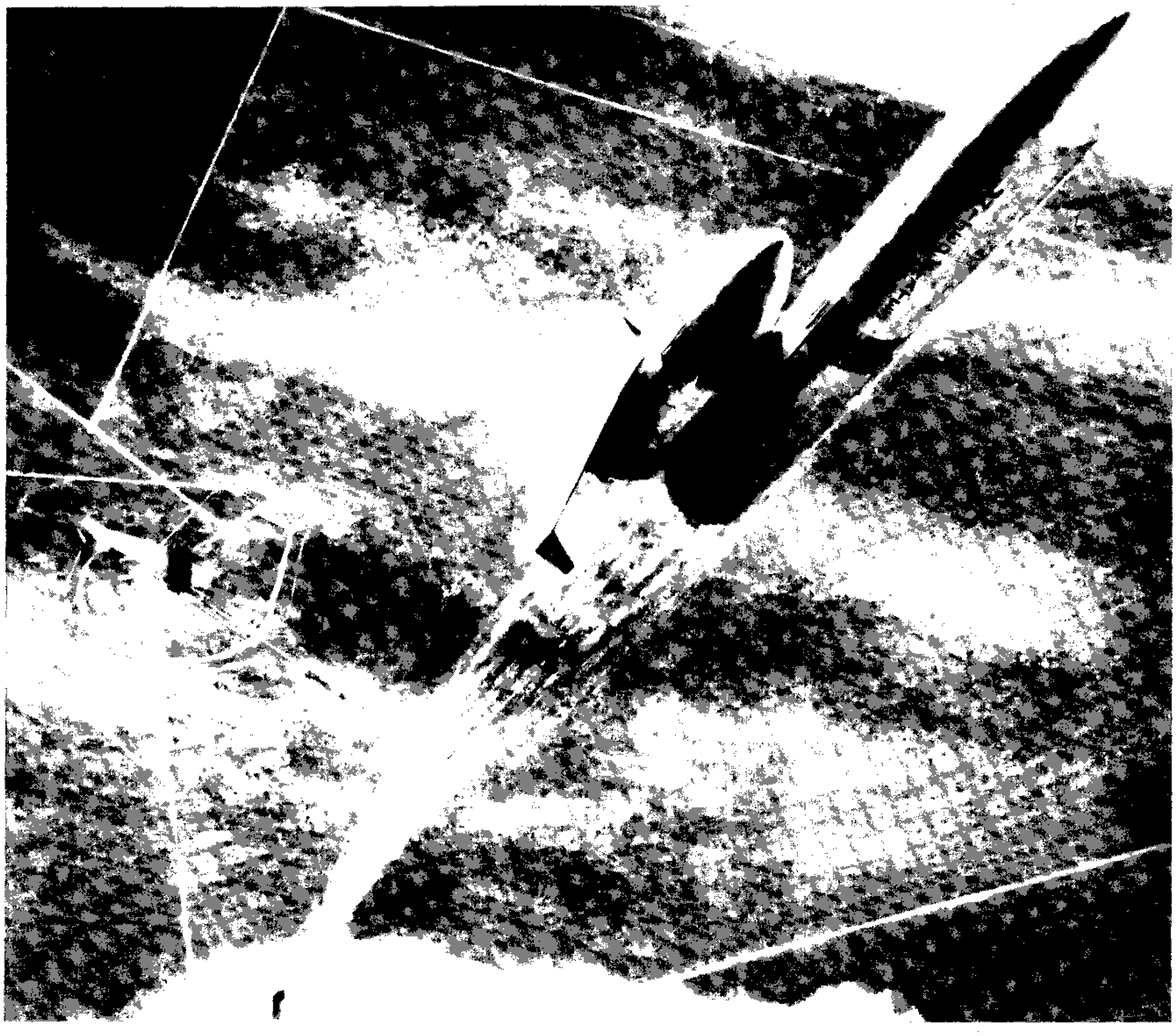

Photo credit: *General Dynamics Corp.*

Artist's conception of an Advanced Launch System launch vehicle

Reducing Space System Costs

Reducing the cost of exploring and using the space environment is crucial to the continued development and exploitation of outer space. America's wish list for projects in outer space far exceeds its ability to pay, given the many pressures on the Federal budget. Launch costs currently range from $3,000 to $12,000 per pound to reach low Earth orbit (LEO), depending on payload weight and the launch system employed. Launching communications satellites into geosynchronous transfer orbit costs between $11,000 and $20,000 per pound. If these costs could be reduced significantly, outer space would be more attractive to potential users, both within Government and in the private sector. However, for many spacecraft, space transportation costs are relatively small compared to the costs of designing and building the spacecraft. Hence, reducing spacecraft costs plays an essential part in bringing down overall space program costs.

SPACE TRANSPORTATION

New technologies promise to make the process of manufacture, assembly, and processing of launch vehicles less expensive (table 6-l). The Advanced Launch System (ALS) program, for example, is exploring a wide variety of technologies that could be employed to reduce space transportation costs.[1] However, **for these technologies to be effective, new management practices must be introduced (table 6-2). Launch operations, for example, tend to be highly labor-intensive, and comprise a significant percentage of the cost of a launch.** As the example of the Delta 180 experiment for the Strategic Defense Initiative Office demonstrated, sharply reducing the burden of oversight and review in a project, and delegating authority to those closest to the technical problems, can result in meeting a tight launch schedule and reducing overall costs.[2] In addition, launch system designs that reduce the number and complexity of tasks requiring human involvement would also contribute to reducing costs (table 6-3). The ALS program is also assessing various management and organizational techniques that would speed launch processing and reduce its complexity. It has incorporated some of the features of the so-called Big Dumb Booster concept (box 6-A) in its planning, viz., the concept of designing a launch system to achieve minimum cost, rather than maximum performance.

Table 6-1--Cost-Saving Technologies for Launch Systems

- Automated manufacturing processes
- Advanced, lightweight materials
- Automated data management system
- Automated test and inspection
- Automated launch vehicle and payload handling
- Modular subsystems
- Database management systems
- Computer-aided software development
- Expert systems

SOURCE: Office of Technology Assessment, 1990.

Table 6-2-Cost-Reducing Strategies

- Reduce documentation and oversight
- Create better incentives for lowering costs
- Provide adequate spares to reduce cannibalization of parts
- Develop and use computerized management information systems
- Use an improved integrate/transfer/launch philosophv[a]

[a]The integrate/transfer/launch (ITL) **philosophy refers to the practice Of separating categories** of launch operations procedures to make each more efficient.

SOURCE: Office of Technology Assessment, 1990.

Table 6-3-Launch System Design Strategies

- Engage all major segments of launch team in launch system design process
- Design for simplicity of operation as well as performance
- Design for accessibility and modularity

SOURCE: Office of Technology Assessment, 1990.

Purchasing launch services competitively from private firms, rather than managing launches from within NASA or the armed services might well save money. The intent of purchasing launch services is to remove the Government as much as possible from setting detailed engineering specifications for the launch system and to reduce the burden of excessive oversight by Government managers. Several entrepreneurial launch vehicle firms are developing new launch systems for small or medium-size payloads (see *Small Launch Systems* in ch. 4). These projects present opportunities to incorporate low-

[1]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, September 1988) for a detailed discussion of these points.

[2]Department of Defense Strategic Defense Initiative Office/Kinetic Energy Office> "Delta 180 Final Report," vol. 5, March 1987.

Box 6-A--*The Big Dumb Booster Concept*[1]

Some launch system analysts believe that a "Big Dumb Booster"[2] using modern technology could markedly reduce space transportation costs. Other analysts disagree. Current U.S. expendable launch vehicles (ELVs) are derived from 1960s intercontinental ballistic missile designs that used high-performance engines and lightweight structures in order to minimize launch vehicle weight and maximize payload and range. Launch system designers gave relatively little priority to reducing launch costs.

The genesis of the Big Dumb Booster debate derives from analysis done in the 1960s that indicated that launch vehicles could be designed to minimize manufacturing and operational costs by making them larger or heavier. Launch vehicles designed to achieve sharply reduced costs would be very different from today's launch vehicles. For example, according to this concept, the first stages of a rocket should be relatively unsophisticated, and heavier hardware produced at lower unit costs by relaxing manufacturing tolerances should replace expensive, state-of-the-art, lightweight hardware.

Although in the late 1960s several aerospace companies performed systems studies on minimum-cost launch vehicles, and the Government tested some demonstration pressure-fed engines, no systematic, thorough analysis of the overall life-cycle costs[3] of such a booster has been done. The Big Dumb Booster concept remains controversial. Supporters of the concept argue that it still has considerable merit and that it is not too late for the United States to adopt this rocket design philosophy. Opponents maintain that time and improved technology have passed it by.

Specific **designs that might have been the minimum-cost solution two decades ago are certainly not today% minimum-coat design. Technology has advanced since the early Big Dumb Booster studies, significantly altering potential trade-offs among cost performance, and weight.** Objective evaluation of the Big Dumb Booster concept would require systematic analysis, with attention to engineering details and costs. It would also involve some hardware development and testing. If a Big Dumb Booster study is done, it should be carried out as a systems study that integrates specific hardware choices with the entire system, including the launch facilities, logistics, launch and support. It should also include estimates of the demand expected for such a booster, as future demand would have a marked effect on program life-cycle costs. Such a study might also include consideration of recovery and reuse.[4] A Big Dumb Booster concept study might cost between $5 million and $10 million, depending on its scope. If Congress decides that the Big Dumb Booster requires more focused evaluation, it could task NASA or the Air Force to carry out such studies.

1U.S. Congress, Office of Technology Assessment, *Big Dumb Boosters: A Low-Cost Space Transportation Option? Background Paper* (Washington, DC: International Security and Commerce Program, 1989).

2The term Big Dumb Booster has been applied to a wide variety of concepts for low-cost launch vehicles, especially those that would use "low technology" approaches to engines and propellant tanks in the booster stage. As used in this report, it refers to launch systems designed for minimum cost by using simplified subsystems where appropriate.

3Life-cycle costs include not only the costs of manufacturing the launch vehicle, but also the costs of ground operations and launch facilities, developing and testing. It also includes the discounting of all these costs to reflect opportunity costs and inflation.

4For example, the Naval Research Laboratory is now exploring a reusable sea-launched booster that would use a pressurized liquid propellant,

SOURCE: Office of Technology Assessment, 1990.

cost approaches at little direct[3] cost to the Government. 'However, launch firms complain that the cost of continued excessive government oversight and complicated procurement regulations unnecessarily raises the costs of launch services. They argue that the cost of government oversight far exceeds the actual cost risk of a failed mission. Launch firms suggest that the government role, which may be vital during the development and demonstration phases of a new, complicated technology, becomes counterproductive when the basic technology has been successfully acquired and is needed for ongoing operations. Then, matters of cost and reliability become paramount. However, Government users

3Private development will result in some indirect costs to the Government. However, if these firms are operating within a competitive market, the eventual cost to the Government should be lower than if the Government paid for the improvements directly.

4For a detailed discussion of the DoD acquisition system, especially rules and oversight, see U.S. Congress, Office of Technology Assessment, *Holding the Edge: Maintaining the Defense Technology Base,* OTA-ISC-420 (Washington, DC: U.S. Government Printing Office, April 1989), especially ch. 8.

may fear that boosters not built to government specifications might be too unreliable, especially for one-of-a-kind spacecraft.

Current space policy provides for the civilian agencies to "encourage, to the maximum extent feasible, a domestic commercial launch industry by contracting for necessary ELV launch services directly from the private sector or with DoD."[5] Extending this policy to all Government launches, both civilian and military, except those on the Space Shuttle, could also save the Government money, but only if Government oversight and paperwork were reduced.

The Federal Government might encourage the private sector launch industry by issuing space transportation vouchers to space scientists whose experiments are being supported by the government.[6] These vouchers could be redeemed for transportation on any appropriate U.S. launch vehicle, and would free scientists to choose the vehicle they thought most suitable to the needs of the spacecraft. This policy would free space scientists from dependence on the Shuttle and its schedule. It might also increase opportunities for researchers to reach space. By reducing scientist's dependence on the Shuttle, such a policy should help in raising the demand for ELVs and in bringing down the cost of space transportation.

PAYLOADS

Dramatic reductions in launch costs will not, by themselves, lower spacecraft program costs substantially, because it may cost from $40,000 to $650,000 per pound to design and build many payloads,[7] while it costs only about $3,000 **per pound to launch one to LEO.** Reducing launch costs to $300 per pound, a goal of the ALS program,[8] may reduce the total cost of procuring and launching an expensive spacecraft by less than 2 percent. Commercial communications satellites, however, often cost on the order of $10,000 per pound. Because they need to be placed in geosynchronous orbit, which is more expensive to achieve than LEO, the cost of a launch is comparable to the cost of the payload. Therefore, commercial operators are extremely interested in cost reductions in both areas.

To reduce payload costs, and for other reasons, novel approaches to payload design and fabrication have been proposed:

- *Provide for Weight Margin:* Designing payloads to fit launch vehicles while reserving ample size and weight margins can reduce the risk of incurring delay and expense after assembly has begun.

  Satellites often grow substantially heavier than expected as they proceed from design to construction. If a payload grows so heavy that its weight equals or exceeds the maximum allowable gross lift-off weight, the payload must be redesigned, which causes delay and increases cost. To reduce the risk of exceeding vehicle payload capacity, program managers could require designers to allow extra weight margin for such contingencies. However, this design philosophy would lead to more stringent size and weight constraints than would otherwise be imposed. In many cases, sufficient margin could be provided by clever design, e.g., by designing several smaller single-mission payloads, to be launched separately, instead of a single multimission payload.[9]
- *Fatsats:* If payloads were allowed to be heavier for the same capability, some could cost substantially less. For example, OTA estimates that Titan-class payloads that cost several hundred million dollars might cost about $130 million less if allowed to be five times as heavy. If payloads were allowed to be much heavier, a manufacturer could forego expensive processes for removing inessential structural material, as well as expensive analyses and tests. Standardized subsystems, which could be produced economically in quantity, could be used instead of customized subsystems. Designers could also add redundant subsystems to increase

[5] White House, Office of the press Secretary, "National Space Policy," Nov. 2, 1989, p. 11.

[6] Molly Macauley, "Launch Vouchers for Space Science Research," *Space Policy*, vol. 5, No. 4, pp. 311-320.

[7] The low end of this range is for payloads consisting mostly of fuel; the high end would be for some satellites carrying little or no fuel. U.S. Congress, Office of Technology Assessment, *Affordable Spacecraft: Design and Launch Alternatives—Background Paper*, OTA-BP-ISC-60 (Washington, DC: U.S. Government Printing Office, January 1990).

[8] 101 stat. 1067.

[9] The number of new program starts allowed in a year tends to force program managers to add additional capabilities to the spacecraft. In addition, in some cases, a larger spacecraft bus can accommodate more functions at a reduced cost per function compared to multiple smaller buses.

reliability. An accurate estimate of potential savings requires a detailed trade-off analysis for each payload. Achieving these savings will probably require giving spacecraft program managers, and those who establish mission and spacecraft requirements, incentives crafted specifically for the purpose, and may require developing new launch vehicles.

- *Lightsats:* If allowed to be less capable, reliable, or long-lived, payloads could be both lighter and less expensive. Useful functions such as communications and weather surveillance could be performed by payloads small enough to be launched on small rockets from airborne or mobile launchers.

  Small, simple, and relatively inexpensive civil and military satellites have been, and still are, launched at relatively low cost on small launch vehicles or at even lower cost, sometimes for free, as "piggyback" payloads on larger launch vehicles. DoD is considering whether the increased survivability and responsiveness such spacecraft could provide would compensate for possible decreased capability. A swarm of several small satellites might accomplish a given mission as well as a single large one, and, in many cases, would also be cheaper because smaller satellites typically cost much less per pound than do large ones. Even if the satellites are launched individually, which would increase total launch cost, overall mission cost could be lower.

- *Microspacecraft:* Spacecraft weighing only a few pounds could perform useful space science missions and might be uniquely economical for experiments requiring simultaneous measurements (e.g., of solar wind) at many widely separated points about the Earth, another planet, or the Sun.

Each type of spacecraft-fatsat, lightsat, or microspacecraft--would impose unique launch demands. New, large, heavy-lift launch vehicles would be needed to launch the heaviest satellites. Lightsats could be launched on existing launch vehicles, but new, smaller launch vehicles might launch them more economically. In wartime, small launch vehicles could be transported or launched by trucks or aircraft to provide a survivable means of space launch. Microspacecraft could be launched on existing launch vehicles, but they might eventually be launched by more exotic means such as a ram accelerator, railgun, coilgun, or laser-powered rocket (see ch. 7). Within the next decade, experiments now being planned may establish the feasibility of some of these launch systems. Their costs cannot be estimated confidently until feasibility is proven. However, they may prove more economical than conventional rockets for launching microspacecraft at high rates.

If Congress wishes to promote spacecraft cost reduction and, thereby, reduce the cost of space programs:

1. Congress could order a comprehensive study of how much the Nation could save on space programs by:

- designing payloads to reserve more weight and volume margin on a launch vehicle;
- allowing payloads to be heavier, less capable, shorter-lived, or less reliable;
- designing standard subsystems and buses for use in a variety of spacecraft;
- designing spacecraft to perform single rather than multiple missions; and
- using several inexpensive satellites instead of a single expensive one.

Lockheed completed such a study in 1972;[10] a new one should consider current mission needs and technology. It would complement the Space Transportation Architecture Study (STAS) and more recent and ongoing studies[11] that compare space transportation options but not payload design options.

As noted above, to estimate potential savings accurately, a detailed trade-off analysis must be done for each payload, or more generally, for each mission. So, for greater credibility,

2. Congress could require selected spacecraft programs-for example, those that might require a new launch vehicle to be developed-to award two design contracts, one to a contractor who would

[10] Lockheed Missiles & Space co., *Impact of Low Cost Refurbishable and Standard Spacecraft Upon Future NASA Space programs,* N72-27913 (Springfield, VA: National Technical Information Service, Apr. 30, 1972).

[11] E.g., the Air Force's Air Force-Focused STAS, NASA's Next Manned Space Transportation System study, the Defense Science Board's National Space Launch Strategy study, and the Space Transportation Comparison study for the National Aero-Space Plane Program.

consider the unconventional approaches mentioned above.

3. Congress could require both the Department of Defense and NASA to refrain from developing a spacecraft if the expected weight or size of the spacecraft, together with its propellants, upper stage, and support equipment, would exceed some fraction of the maximum weight or size that its intended launch vehicle can accommodate. Public Law 100-456 requires the Department of Defense to require at least 15 percent weight margin in fiscal year 1989.[12] New legislation could extend this restriction to NASA and could require size margins in future years.

In addition, Congress could promote the development of launch systems capable of launching small, inexpensive spacecraft at low cost or heavy spacecraft with generous weight margins.

INNOVATION AND THE U.S. TECHNOLOGY BASE

Building a new system, or even making substantial modifications to existing launchers, requires a vigorous private sector, well-supported research programs, a cadre of well-trained engineers, and an institutional structure capable of putting a vast variety of technologies to use in innovative ways. According to several recent reports, our existing space technology base has become inadequate in recent years.[13] Yet a strong technology base is an investment in the future; it provides insurance that the United States will be able to meet future technological challenges.

Government Programs

Several studies have recommended greater attention to improving the Nation's technology base for space transportation.[14] Though specific proposals differ in detail, these studies have cited propulsion, space power, materials, structures, and information systems as areas in need of special attention.

In response to these and other expressed concerns, NASA and the Air Force have initiated four programs to improve the Nation's launch system technology base (box 6-B). As currently organized, these programs are directed primarily toward developing new, advanced capabilities. **In the existing budgetary climate, it may be more realistic to redirect funding toward technologies that could be used to improve existing launch systems and make them more cost-effective to operate.** Each of the three ALS prime contractors are exploring ways to insert technology conceived in the ALS program into existing launch systems.

Although launch operations and logistics are labor-intensive and therefore expensive compared to manufacturing or materials, launch system designers have focused little attention on technologies that would reduce these costs. NASA's technology programs are addressing issues in automation and robotics, technology areas that could significantly reduce launch operations costs. However, to date NASA has spent relatively little on applying these technologies more effectively to Shuttle launch operations. In the yearly budget process, when budgets are cut, technology programs tend to be cut more sharply than operational programs because they focus on future efforts, rather than near-term results. Launch operations is the direct focus of about 30 percent of the ALS program. Outside of this effort, however, no well-organized or well-funded plan exists to *apply the* technologies developed in these programs to launch operations procedures, or to coordinate research being carried out through the existing technology R&D programs.

It may be appropriate to institute a long-term National Strategic Launch Technology Plan that would set the agenda for developing and incorporating new technologies into existing and future launch systems. It should include work in all development phases:

- broad technology exploration (basic research);
- focused research leading to a demonstration; and
- implementation to support specific applications.

Even if specific applications have not been identified, the United States needs to fund basic and

[12] See S. Rept. 100-326, p. 36, and H. Rept. 100-989, p. 282.

[13] National Research Council, Aeronautics and Space Engineering Board, *Space Technology to Meet Future Needs* (Washington, DC: National Academy Press, December 1987); Joint DoD/NASA Steering Group, National Space *Transportation and Support Study*, Summary Report, May 14, 1986,

[14] Ibid.

Box 6-B--Technology Development Programs

- *Advanced Launch System* (ALS) *Focused Technology Program*—A joint program between NASA and the Air Force, carried out as an integral part of the ALS Demonstration/Validation Program. Its aim is to pursue research on specific technologies of interest to the development of an ALS. The program's contribution to crew-carrying capabilities will be limited, but important. As much as possible, ALS program managers have deliberately targeted their research at generic space transportation issues, in order to develop a broad technology base for designing an ALS. The ALS program plans to spend most of its fiscal year 1991 budget of $125.3 million on focused technology development.
- *Civil Space Technology Initiative*—A NASA program designed to revitalize "the Nation's civil space technology capabilities and enable more efficient, reliable, and less costly space transportation and Earth orbit operations. Funding for fiscal year 1990 is $123.8 million (1991 request-$ 171.0 million).
- *National Aero-Space Plane*—A DoD/NASA program to develop an aerospace plane capable of reaching orbit with a single propulsion stage. Although this program does not have the specific focus of improving the Nation's technology base, some of the technology under development necessary for building the NASP, particularly new materials and structures, new propulsion techniques, new computational techniques, and methods of handling liquid and slush hydrogen, will find application elsewhere. The NASP Joint Program Office is spending $150 million over a 30-month period on materials development alone.
- *Pathfinder-A* NASA program especially directed at technologies for future human space exploration. Very few of this program's technologies will be usdful for Earth-to-orbit transportation, as it is directed primarily toward cm-mbit and interplanetary transportation and life-support issues. Congress appropriated $26.9 million for Pathfinder in fiscal year 1990. The Administration has requested $179.4 million-a 567 percent incease--in fiscal year 1991 to prepare for lunar and Martian exploration.

[1]National Aeronautics and Space Administration, Office of Aeronautics and Space Technology, "CSTI Overview," April 19$8.

SOURCE: Office of Technology Assessment, 1990.

focused research in order to build an adequate base for future applications.

The Private Sector's Role

In space transportation, the private sector now serves primarily as contractor for Government-defined needs. It is just beginning to act as a commercial service provider.[15] Two firms launched their first commercial payloads in 1989.[16]

Private firms are unlikely to develop major new launch systems until well into the next century unless Congress and the Administration set a high priority on involving them more directly in setting the terms of space transportation development.[17] The Government controls access to space[18] and most of the technology. It will continue to determine launch specifications and provide most of the funding. Government control of systems involving crews in space will continue, in large part because such systems are costly and represent a major national commitment.

Harnessing industry's innovative power in a more competitive environment could lead to reduced launch costs and more effective use of U.S. resources for outer space. By promoting private sector innovation toward improving the design, manufacture, and operations of launch sys-terns, the Government could reduce the cost of Government launches, yet relatively few incentives to involve private firms exist today. As a result, firms have spent little of their own money on R&D

[15]The Department of Transportation regulates the private launch industry.

[16]McDonnell Douglas (Delta) and Martin Marietta (Titan)

[17]The NASP program, for example, has sent a high priority on directly involving private firms and the universities in materials and other advanced research on the X-30.

[18]According to the 1967 *Treaty on Outer Space,* which the United States signed, and to which it adheres, "States parties to the Treaty shall bear international responsibility for national activities in outer space . . . whether such activities arc carried on by governmental agencies or by non-governmental entities. . ." The *Commercial Space Launch Act of 2984,* which sets out the basic provisions regulating the commercial launch industry, recognizes this responsibility by stating,". . . the United States should regulate such launches and services in order to ensure compliance with international obligations of the United States . . ."

to improve the capability of launch systems or reduce their costs.

If outer space becomes a more important arena for private investment, competitive pressures will provide the incentives for launch system innovation. For the near term, however, incentives must come from the Government because projected future demand for commercial launch services is extremely small compared to Government demand.[19]

Incentives could include:

- direct grants to develop new technology for launch systems specifically directed toward saving costs rather than increasing performance;
- cash incentives to firms for reducing the manufacturing costs of specific items procured by the Government;[20]
- encouragement of industrial teaming arrangements in focused technology areas such as the National Aerospace Plane Materials Consortium (see ch. 7).

In addition, the U.S. Government could stimulate the private sector's innovative creativity by issuing a request for proposal for launch systems or services similar to the Advanced Launch System, and have industry bid for them. Such an approach assumes minimum Government oversight over the design and manufacturing processes. It would also require the aerospace community to assume much greater financial risk than it has taken on in the past. In order to offset that risk, the Government might have to agree to a minimum purchase that would allow the companies involved to earn a profit on their investment

Finally, America's ability to foster the innovative process depends directly on having an adequate supply of scientists and engineers. In order to assure that the United States has sufficient trained personnel to contribute to the development of new launch systems and other space activities, the Government could strengthen its support for science, mathematics, and engineering education from grade school through graduate school.[21]

[19] Richard Brackeen, *Space Challenge '88: Fourth Annual Space Symposium Proceedings Report* (Colorado Springs, CO: U.S. Space Foundation 1988), pp. 76-79,

[20] For example, Rockwell International earns 20% of every dollar it saves NASA on building orbiter OV-105.

[21] U.S. Congress, Office of Technology Assessment, *Educating Scientists and Engineers Grade School to Graduate School, OTA-SET-377* (Washington, DC: U.S. Government Printing Office, June 1988).