Chapter 1

Executive Summary

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INTRODUCTION

Achieving low-cost, reliable space transportation is one of the most important space policy challenges facing the United States today. The Nation's ability to assure timely access to space, to guarantee the general welfare of U.S. civilian space activities, and to compete effectively with other countries depends on meeting this challenge squarely and thoughtfully.

Ground and mission operations processes are highly complex and involve a wide variety of technologies. As support functions, they only become obvious to the public and to Congress when they fail to work properly. Because they constitute a significant percentage of launch costs, reducing the costs of these operations is crucial to lowering the overall costs of space transportation. Improed operations technology and management could also lead to greater flexibility and responsiveness to changing conditions in space activities. Yet these relatively mundane processes and procedures seldom receive close scrutiny from the Congress, or attention from the policy community.

This technical memorandum is intended to help Congress understand the launch process and how the use of advanced technologies and management techniques could reduce the costs of launching payloads. It does not discuss the management of payloads or crews for passenger-carrying vehicles.

The memorandum is part of an assessment of advanced launch technologies, which was requested by the House Committee on Science, Space, and Technology, and the Senate Committee on Commerce, Science, and Transportation. It derives in part from a workshop held at OTA on September 10, *1987*, which met to discuss issues of launch operations technology and man-

Box l-A.—Launch Operations Processes

Launch operations includes the procedures necessary for launching payloads to orbit. It does not include the management of payload or crew (for piloted vehicles) on orbit, which are generally considered mission operations. Launch operations can be divided into the following overlapping steps:

- *Processing and integration of vehicle:* includes the assembly and testing of the launch vehicle, as well as the integration of electrical, mechanical, and fluid systems. For reusable, or partially reusable vehicles, this step also includes testing of refurbished components to assure that their characteristics remain within design specifications.
- *Processing and integration of payloads:* comprises the assembly, testing, and mechanical and electrical integration of payloads with the launch vehicle. Payloads must also be tested with the vehicle's mechanical and electrical systems to assure they will not interfere with proper operation of the launch vehicle.
- *Launch management and control:* includes the preparation and testing of the launch pad, the control center, and all of the other facilities critical for launch, as well as the actual launch countdown. During countdown, each critical subsystem must be continually monitored.
- *Post launch responsibilities:* includes the retrieval, return, and refurbishment of all reusable vehicle components, and the cleanup and post-launch refurbishment of the launch pad. The launch of reusable, or partially reusable, vehicles introduces an extra layer of complexity to the launch process and involves additional facilities and personnel.
- Logistics: encompasses the provision of spares, and replacement parts, as well as the scheduling of tasks, personnel, and equipment, which must be coordinated across the entire launch process.

agement, and from OTA staff research. OTA staff visited Air Force and National Aeronautics and Space Administration (NASA) facilities[1] and gathered additional information from a literature review and personal interviews with individuals from the major aerospace firms.

[1]OTA site visits included: Air Force Space Division, Los Angeles; Cape Canaveral Air Force Station; Edwards Air Force Base; Johnson Space Center; Kennedy Space Center; Langley Research Center; Marshall Space Flight Center; Vandenberg Air Force Base.

PRINCIPAL FINDINGS

Finding 1: Because launch and mission operations constitute a sizable fraction of the cost of launching payloads to orbit, developing new launch vehicles will not, in itself, result in significant reductions of launch costs. If the United States wishes to reduce launch costs, system designers and policymakers must give greater attention to operations.

Because launch and mission operations are responsible for up to 45 percent of the cost of each launch, lowering these costs is crucial to reducing the overall cost of space missions. Prompted by the needs of the spacecraft community, launch system designers have traditionally focused greater attention on achieving high performance than on operational simplicity or low cost. Recently, plans for a permanently inhabited space station, more extensive Department of Defense (DoD) space activities, and problems with existing U.S. launch systems have suggested the desirability of attaining routine, low-cost launch operations. NASA and DoD have funded several studies aimed at identifying technologies and management practices capable of reducing the costs of launch services.[2] The results show that a variety of technologies, either new or in use in other industries, could help to reduce operations costs. They also indicate that important reductions of launch costs are unlikely unless launch operations engineers and facilities managers have a greater role in the design of future launch systems. The development process should encourage a thorough and frequent interchange of information and ideas among representatives from operations, logistics, design, and manufacturing. It should also contain sufficient incentives for reducing costs.

[2]The results of these studies are summarized in the report of the Space Transportation Architecture Study: U.S. Government, ***National Space Transportation and Support Study 1995-2010, Summary*** Report of the Joint Steering Group, Department of Defense and National Aeronautics and Space Administration, May 1986.

Finding 2: Technologies capable of reducing the recurring costs of ground and mission operations exist today or are under development in a variety of fields.

These include technologies for:

- built-in test equipment;
- management information systems;
- automated test and inspection;
- advanced thermal protection systems;
- fault-tolerant computers;
- adaptive guidance, navigation, and flight control;
- automated handling of launch vehicles and payloads;
- computer-aided software development; and
- expert computer systems.

Some of these technologies could be incorporated into the design of the launch vehicle. For example, built-in test equipment and software could be used to detect faults in vehicle subsystems, reducing ground operations labor and cost. Other technologies might find application in the launch and mission operations facilities. For example, management information systems could sharply reduce the amount of human effort in making, distributing, and handling paper schedules and information. Such systems could also reduce the number of errors experienced, and speed up sign-off procedures.

The amount of money such new technologies could save, either from building new launch systerns, or from enhancing existing systems, depends strongly on three factors: 1) the demand for launch services, 2) the non-recurring costs of technology development and facilities, and 3) savings achieved in operations. Unless launch demand for the late 1990s increases sharply over current estimates, adopting new technologies could actually increase the total (life-cycle) cost of space transportation.

Finding 3: Dramatic reductions in the costs of launch operations (factors of 5 to 10) could be achieved only under highly limited conditions.

Most experts OTA consulted thought that reductions in operations costs by five- or ten-fold, as suggested by the Space Transportation Architecture Study and the Advanced Launch System (ALS) program,[3] were unobtainable in practice even with proposed new technology and new facilities. They pointed out that although the large capacity vehicles contemplated for an ALS might save costs by carrying more weight, they would not be efficient for smaller payloads. In addition, new ground facilities (e.g., launch complexes, fabrication and assembly buildings) typically require investments of several hundred million or even billions of dollars. Such investments seldom look attractive in the short run—the most relevant time period in a stringent budget environment—and are therefore seldom adequately funded. Finally, dramatic reductions in cost would require significant changes in the institutional mechanisms of launch operations, which would be very difficult to achieve without considerable institutional upheaval.

Such reductions would require high launch demand, a new generation of launch vehicles and ground facilities designed to accommodate rapid turn around, and payloads of uniform design and orbital characteristics. In theory, it would be possible to create new advanced-technology launch systems, such as those proposed for the ALS program. These launch systems would be most beneficial for launching many payloads with similar technical and orbital characteristics, such as components of a space-based missile defense system, or perhaps fuel to send humans to and from Mars. Absent a decision to deploy SDI, or to increase sharply spending on civilian payloads, the number and diversity of payloads NASA and DoD now plan to launch through the late 1990s do not meet the conditions necessary for dramatic cost reductions.

Thus, under these conditions, the discounted *life-cycle* cost—the total of recurring and non-recurring costs, appropriately discounted—of launching known or currently projected payloads probably can be reduced only marginally by developing completely new launch systems. In addition, because a revolutionary launch design such as envisioned for ALS would involve new design approaches and some new technologies,[4] the technological and economic risks would be higher than for an evolutionary approach.

Finding 4: If the Federal Government wishes to invest in new operations technologies, it should have clear long-term goals and a well-defined plan for developing and incorporating new technologies in space transportation operations. Such a plan must be buttressed by data from new and more reliable cost models.

NASA and the Air Force are funding research on new technologies for launch systems. NASA's Civil Space Technology Initiative (CSTI) is pursuing research on a number of technologies, including autonomous systems and robotics, that could improve some launch procedures and might even lead to cost savings. NASA and the Air Force are collaborating on research in the Advanced Launch System's Focused Technology Program, which may contribute to reducing the costs of launch and mission operations. Yet these research programs devote only a small percentage of their budget to space transportation operations. In addition, 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.

[3] See especially U.S. Congress, Office of Technology Assessment, ***Launch Options for the Future: A Buyer's Guide,*** OTA-ISC-383 (Washington, DC: U.S. Government Printing Office, July 1988), for an extensive discussion of launch system costs and capabilities.

[4] U. S. Government, ***National Space Transportation and Support Study 1995-2010,*** Summary Report of the Joint Steering Group, Department of Defense and National Aeronautics and Space Administration, May 1986.

In fiscal year 1989, NASA plans to start an Advanced Operations Effectiveness Initiative, which would develop and carry out a plan for inserting the results of technology R&D into launch and mission operations. However, NASA is allocating only $5 million to this initiative in the 1989 budget, an amount that will have a very small effect on reducing launch and mission operations costs.

To complicate matters, the current restrictive budgetary environment makes it difficult to spend money now on research and facilities that *might* save money later. To respond to this suite of technical, institutional, and budgetary challenges, the United States needs a coherent long-term plan for developing and incorporating new operations technologies into existing and future launch systems. A technology development plan should include work in all development phases:

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

Such a plan should be part of a more comprehensive National Strategic Launch Technology Plan that would develop and insert new technologies into U.S. launch systems.

Instituting a long-term research, development, and technology application plan will be extremely difficult for three reasons. First, policymakers in Congress and the Administration have been unable to agree on overall long-term goals for the publicly funded U.S. space program. Operations procedures optimized for our current level of space activities would differ substantially from those designed to deploy space-based defenses or mount a mission carrying humans to Mars.

Second, current ground and mission operations are partially controlled or influenced by the technologies and management requirements from a dozen or so different research centers, hundreds of technical projects, and thousands of individuals in NASA, DoD, and the aerospace industry. The Administration’s latest space policy statement directs NASA and DoD to cooperate in pursuing “new launch and launch support concepts aimed at improving cost-effectiveness, responsiveness, capability, reliability, availability, maintainability, and flexibility.”[5] This directive could provide the impulse for developing a national research and development plan. However, the institutional structure and will to focus the efforts of these interested parties on the common purpose of reducing operations costs does not presently exist. Until Congress and the Administration reach agreement on specific national space policy goals, developing an effective, detailed, multi-year plan for developing and incorporating new technologies into space transportation operations will be extremely difficult. Encouraging NASA and DoD to reduce operations costs substantially may require making major institutional changes to these agencies, or developing a new agency for operations.

Finally, the lack of objective, verifiable cost estimation models makes it difficult to determine which technologies are worth pursuing or which should be discarded. Credible, objective operations cost methods—similar to those of the airline and other commercial industries—should be developed, which would allow the Government to estimate the total cost of incorporating a new technology or management practice and the savings it could generate. Current models have proven inadequate, in part because data on previous launch operations experience have neither been collected in an organized way nor properly maintained. Without adequate historical data to use as a benchmark, cost estimation involves too much guesswork. Congress may wish to direct NASA and DoD, or some independent agency, to collect the necessary historical data and to develop better cost estimating methods for space transportation systems.

Finding 5: Although making evolutionary improvements to exizting launch systems may prove difficult and expensive, such improvements could reduce the cost of existing launch and mission operations.

Because launch vehicles and their ground support facilities are highly integrated and interdependent, it is difficult and expensive to incorporate

[5]“Presidential Directive on National Space Policy,” White House Office of the Press Secretary, Fact Sheet, Feb. 11, 1988.

new cost or time saving technologies. Nevertheless, experts consulted by OTA agreed that it would be possible to reduce operations costs by improving vehicle subsystems such as onboard avionics, and many ground-based support activities such as payload handling and fuel loading, through redesign, automation, and standardization. Technologies pursued for new launch systems may have application to existing systems and vice-versa.

Finding 6: It will be difficult to improve the way the United States manages its launch operations without making significant changes to the institutions currently responsible for those operations.

Current U.S. space management practices result from a launch operations philosophy that emphasizes long-lived, expensive payloads, high-performance launchers, very high reliability, and low launch rates. The Soviet Union, on the other hand–both by choice and as a result of its limited technology base—has in the past relied on relatively inexpensive short-lived satellites, reasonably reliable vehicles, and very high launch rates. As a result, the Soviet launch infrastructure is more "resilient" than its U.S. counterpart, although not necessarily more effective at accomplishing national goals.

The United States is now in the difficult position of attempting to retain its high-technology, high-performance approach to payloads and vehicles while attaining Soviet-style routine, lower cost access to space. This goal is probably unattainable unless the U.S. Government substantially alters the way it conducts space transportation operations. Such an alteration would require significant changes to the institutional structure and culture of NASA and DoD.

Congress could direct the Air Force and NASA to:

- turn launch operations for all new launch systems over to the private sector;
- establish operations divisions fully independent of launcher development, including development of a Shuttle or an ALS; or
- purchase launch services, rather than vehicles, from the private sector for existing ELV launch systems.

One way to manage the institutional challenge is to maintain separate institutions for launch vehicle development and operations by turning over operation of new launch systems to the private sector. Under such an arrangement, the launch company would assume control of launch operations after the systems were developed and would provide launch *services* to the Government on a contractual basis. In order to further reductions of cost, the company would also be encouraged to market its services to other payload customers, either from the United States or abroad. The European Space Agency (ESA) and Arianespace have demonstrated that such an arrangement can be highly effective. ESA funded development of the Ariane launch system under the management of the French space agency, CNES. Arianespace, S. A., a French corporation, which manages the Ariane operation and markets the Ariane launcher worldwide, set requirements for a successful commercial venture.

Although the European model may not be fully applicable to U.S. conditions, Congress must find ways to give space transportation operations extra visibility and "clout" so they will not be considered a costly afterthought. Congress could direct NASA and the Air Force to establish operations divisions fully independent of each agency's launch development organization, with the charge of operating launchers on the basis of increased efficiency and reduced costs. This would require considerable congressional oversight to assure that the agencies carried out the will of Congress.

NASA and DoD could also reduce operations costs by purchasing all expendable launch services, rather than launch vehicles, from the private sector for existing systems. Recent Administration policy directs the civilian agencies, including NASA, to purchase expendable launch services from private companies. However, the policy allows considerable latitude for DoD to continue its current practice of involving Air Force personnel deeply in the launch process.

Finding 7: In addition to new technologies, adopting new management practices and design philosophies could increase the efficiency and reduce the cost of ground operations.

Management strategy may often be more important than new technology for achieving low cost launches. Cost-reducing strategies include:

- 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, and
- use an improved integrate/transfer/launch philosophy.

Some management strategies could be enhanced through the appropriate use of technology. For example, OTA workshop participants pointed out that operations costs will never fall significantly unless ways are found to reduce the time consumed by human documentation and oversight. In many cases, automated procedures would reduce the need for certain documentation, and certainly shrink the necessary manpower to maintain it. However, reducing the amount of oversight significantly will be much more difficult. Since the Titan and Shuttle losses of *1985* and 1986, the number of Government personnel responsible for contractor oversight has increased.

Also needed are incentives to encourage lower operations costs. The current institutional management structure tends to penalize launch failure, but is poorly structured to reward the lowering of launch costs or increases in launch rate. However, the Strategic Defense Initiative Organization found in a recent project[6] that it was able to cut overall project costs in half by incorporating simple, common-sense management techniques such as reducing Government oversight, delegating authority to those closest to the technical problem, maintaining short schedules, and paying employees bonuses for meeting deadlines. Although the team was able to achieve some of its operations cost savings as a result of a concentrated, narrow effort that would be difficult to maintain for routine launches, the project nevertheless demonstrated that a management philosophy that includes incentives for launch managers and technicians can play a significant role in reducing the cost of launch operations.

[6] The Delta 180 experiment. See ch. 2, ***Issues,*** for a discussion.

Vehicle design can also play a crucial part in the ability to reduce launch and mission operations costs. The accessibility of critical parts, the weight and size of components, and the ability to change out modules quickly all affect the speed and effectiveness of operations. Several design principles are particularly important. One should:

- engage all major segments of launch team in launch system design process;
- design for simplicity of operation as well as performance; and
- design for accessibility, modularity, and simplicity of operation.

For example, considering all elements of the launch system, including the operations infrastructure and operations management, as a collection of highly interactive parts will allow system designers to anticipate potential operations and maintenance problems and provide for them before the system is built. As was discovered with the Space Shuttle main engines, certain subsystems may pose unexpected maintenance problems. All major subsystems should be designed to be readily accessible, and, as much as possible within weight and size constraints, should also be of modular design in order to reduce maintenance and integration costs.

Many concepts for improved launch operations tend to shift costs from operations to other stages in the launch services process, such as payload processing. For example, requiring payloads to provide their own internal power, rather than relying on a source in the launcher, may reduce ground operations costs, but could also increase the cost of preparing payloads. In altering the structure of space transportation operations, such changes in procedure or technology should not merely send problems elsewhere.

Finding 8: Unless the Government can stimulate the innovative capacity of the private sector, private sector contributions to reducing the costs of space transportation operations will continue to be quite limited.

Almost all of the recent effort in improving launch operations has been instigated by NASA and the Air Force in connection with the Space

Transportation Architecture and the Advanced Launch System studies.[8] Private sector initiatives, such as competitive bidding for components, and introducing some new technologies, show what can be done in a modest way to reduce costs. However, these efforts are still relatively limited and reflect the tenuous nature of the U.S. commercial launch industry.

The Government could use the talents of the private sector most effectively, and in the process encourage a more competitive industry, by purchasing the services of expendable launchers rather than vehicle systems, and by offering strong incentives for decreasing costs. Although it is theoretically possible for the Government to purchase services for piloted launchers, such as the Space Shuttle, private industry is unlikely to offer such services in the near future because the technologies of reusable vehicles are still immature and the costs of change are great.

Congress could also enhance the development of new operations technologies and assist private sector competitiveness by funding an "operations test center" composed of a mock launch pad and facilities. Such a center should be specifically designed to enable tests of new technologies for incorporation into existing and new launch systems. The ability to try out new operations technologies on a working launch pad is limited. A center would give the private sector the opportunity to try out new operations technologies free from the demands of routine operations. Such a center could be a government-owned, contractor-operated facility. Alternatively it could be partially funded by the private sector, and operated by a consortium of Government agencies, private sector companies, and universities.

Finding 9: For certain aspects of launch operations, the broad operational experience of the airlines and the methods they employ to maintain efficiency may provide a useful model for space operations.

Although airline operations face different technical and managerial constraints than space launch operations, certain airline methods used in logistics, maintenance, task scheduling, and other ground operations categories could make launch operations more efficient and cost-effective.

The following airline practices could be of particular interest for space transportation operations:

- involve operations personnel in design changes;
- develop detailed operations cost estimation models;
- stand down to trace and repair failures only when the evidence points to a generic failure of consequence;
- design for fault tolerance;
- design for maintainability;
- encourage competitive pricing;
- maintain strong training programs; and
- use automatic built-in checkout of subsystems between flights.

‘U.S. Government, ***National Space Transportation and Support Study*** 1995-2020, Summary Report of the Joint Steering Group, Department of Defense and National Aeronautics and Space Administration, May 1986.

[8]The results of seven contractor reports for phase I of these studies have not yet been released. ALS phase II studies are scheduled to begin in August 1988.