Chapter 5

Future Solutions

CONTENTS

Page

Boxes

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The FUTURE SOLUTIONS option is the U.S. Government's "Best Buy" if... it wants to support a very aggressive space program that would not only develop specific launch systems but would also advance space technology. Launch systems based on emerging technologies could allow greatly reduced cost, increased performance, and operational flexibility but would entail high degrees of economic and technical risk. To obtain advanced technology launch systems by the the turn of the century, the United States must begin a sustained technology development program now.

This section examines three potential future launch systems: the Air Force's proposed unpiloted cargo vehicle, the Advanced Launch System (ALS); NASA's proposed piloted follow-on to the Space Shuttle, the Shuttle H; and the National Aerospace Plane (NASP), a piloted hypersonic vehicle that would be capable of taking off and landing like an airplane. These launch systems, particularly the Shuttle II and NASP, require more dramatic technology advances than the systems described in previous chapters. All three of these launch systems envision applying advanced technologies to vehicle design and fabrication; launch processing, integration, and check-out; mission planning and control; and if appropriate, vehicle recovery and refurbishment.

As an unpiloted cargo vehicle, the ALS would be less technically challenging than either the crew-rated Shuttle II or NASP. If aggressively funded now, ALS could be available around the end of this century. Because both Shuttle II and NASP would use highly advanced technology, and entail considerably more technical risk, they could not be operational before the early part of the next century.

These proposed vehicles would be pursued in *addition* to those vehicles already described in the Baseline or Enhanced Baseline. If the Administration and Congress decide to pursue a near-term deployment of SDI, or a piloted lunar or Mars mission, then the Nation might need the vehicles described in the Enhanced Baseline program (chapter 3) *plus* an Interim vehicle (chapter 4), plus one or more of the advanced vehicles described here.

Future space transportation systems will serve two broad mission categories: those requiring high mass payloads (propellants, consumables, large monolithic payloads) launched to orbit at a low cost per pound; and those using extremely high value payloads (humans or unique, expensive spacecraft), or servicing and repair, for which a low cost per flight but not necessarily low cost per pound would be desirable. An unpiloted cargo vehicle such as the ALS could probably serve the former role best. Design of the Shuttle-11 and the NASP are oriented toward the latter mission type.

ADVANCED LAUNCH SYSTEM (ALS)

In undertaking the ALS, the Air Force seeks to develop a reliable, heavy-lift launch vehicle able to achieve high launch rates at low cost. ALS managers are tasked to achieve a factor of ten reduction over current costs per pound of payload orbited. The design of the ALS is also supposed to allow growth to meet changing mission requirements.[1]

In July 1987, seven contractors were each awarded $5 million, l-year contracts by the Air Force to define conceptual designs. The Air Force asked them to include consideration of ground operations in the system designs and cost estimates and to prepare technology development plans and industrial preparedness plans. Although the details of the contractors' initial concepts are proprietary, they have considered both expendable and partially reusable vehicles (some with flyback boosters or recoverable propulsion/avionics modules), with capabilities varying from 100,000 to 200,000 pounds to LEO. Proposed engines include combinations of uprated existing engines, solid rockets, and a variety of new liquid engines.

The ALS is expected to capitalize on advanced materials and manufacturing and launch processing technologies to cut costs. For example, aluminum-lithium alloys could be used in tanks and other primary structures, which could result in 20 percent lower cost and a 10 percent increase in strength over common steel and aluminum alloys, once manufacturing and supply development is achieved. Filament-wound composite motor casings, shrouds and adapters likewise may offer cost advantages to the ALS by increasing strength and performance while reducing weight. Automation could cut the present high cost of fabricating composite structures, and robotics may be applied to plasma arc welding and other processes effectively, even in relatively low rate production. ALS managers are exploring a variety of launch operations concepts, including horizontal processing, new launch complexes and improved manufacturing, systems integration, and checkout procedures.[2]

The ALS could be a low cost per flight "space truck" capable of lifting 100,000 to 200,000 pounds to LEO, sending heavy satellites into orbit or delivering bulk supplies such as water, food, and fuel to a Space Station. The Air Force has stated that such a lift capability would primarily be required to launch elements of a ballistic missile defense system and to alleviate payload design weight constraints.[3] The Air Force estimates that the ALS could be capable of 20 to 30 flights per year after 1998.

Reliability estimates for an ALS are difficult to specify at this early phase; however, the program stresses the achievement of significantly higher reliability than current vehicles. One concept ALS contractors are investigating would incorporate an "engine-out" capability, in which the loss of one rocket engine would not endanger completion of the mission. Commercial aircraft use a similar safety feature.

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1 As Air Force Secretary Aldridge testified before the Senate Committee on Armed Services Subcommittee on Strategic Forces and Nuclear Deterrence on March 2.5, 1988: "ALS will develop technologies, system design, and operational concepts for the next generation of responsive launch vehicles. These vehicles would provide the capability to meet requirements from the heaviest to the smallest payloads."

2 See U.S. Congress, Office of Technology Assessment, Reducing Launch Operations Costs: New Tchnologies and Practices, OTA-TM-ISC-28 (Washington, DC: U.S. Government Printing Office, August 1988), for a more comprehensive list of technologies and management strategies for launch systems.

3 see, for example, Star Wars at the Crossroads: The Strategic Defense Initiative After Five Years, Staff Report to Senators Bennett Johnston, Dale Bumpers, and William Proxmire, June 12, 1988.

Because development of the ALS would push the state-of-the-art in selected areas of technology, it would entail considerable cost and development risk, yet such risk would be lower than the risks involved in NASP or Shuttle II development. The aerospace field is rife with examples of technologies that took much longer to ‘develop and implement and cost much more than originally anticipated, such as structural composites or the Shuttle’s thermal protection system. Many of the goals for ALS are reminiscent of goals set in the early 1970s for the Space Shuttle regarding its lift capabilities, turnaround, and cost. The greatest impediment to the ALS program will be the high cost of developing the vehicle and building new facilities to manufacture and launch it. Historically, programs with high up-front costs and no quick return are difficult to sell. This sometimes leads to compromises in the system design that reduce the front-end costs, but also increase the operations cost. Many argue that this is what happened to the Shuttle and may be happening again to the Space Station.[4]

As mentioned in the previous chapter, another potential limitation of any heavy lifter is the difficulty of placing several different payloads, with different orbital destinations, on a single launch vehicle.[5] Maintaining a high launch rate for these vehicles may also require changing the way we presently prepare and handle payloads. For example, commonality of payload interfaces and on-pad auxiliary services may be required.

Box 5-1. – Cost Savings From New Technology

Many aerospace experts argue that significant cost savings could be achieved if time and money were spent on modernizing manufacturing facilities and on applying new technologies, some of which already exist in other industries. Yet, the application of these new technologies would increase the front-end cost, which would have to be recouped later in the program through reduced production and operations costs. ‘

One aerospace company has estimated that automation of certain tasks could provide a 30 percent to 50 percent savings over manual processes by reducing labor and hard tooling needs. For example, Variable Polarity Plasma Arc (VPPA) welding reportedly could yield up to 70 percent savings over conventional welding and possibly eliminate the need for x-ray inspection. Computer integrated manufacturing, paperless management, modern inventory control systems, expert systems for checkout and preparation, and co-locating manufacturing and launch facilities are all being investigated for their efficacy in reducing costs and improving efficiency.

The Space Transportation Architecture Study (STAS) gave other examples of significant savings that would derive from use of various technologies. High on the list of cost-saving technologies were built-in-testing, automated data management systems, and low cost aluminum-lithium expendable cryogenic tanks.[a] Other apparently cost-effective technologies would include improved expendable tanks and structures, automatic software generation, and improved flight-management systcms.[b]

[a] Boeing Aerospace Company, “Space Transportation Architecture Study,” Interim Progress Review No. 5, Apr. 7, 1987, p. 209.

[b] General Dynamics Space Systems Division, “Space Transportation Architecture Study,” Special Report - Interim Study Results, vol. 2, book 3, July 10, 1987, p. 7-90,7-91.

4 See, for example, John M. Logsdon, “The Space Shuttle Program: A Policy Failure?” Science, vol. 232, pp. 1099-1105.

5 One concept for reducing operations costs is to adopt standardized mission profiles and payload interfaces, which could be possible using the AlS's “excess lift capacity.” Such standardization could reduce the difficulties of launching several payloads at once.

SHUTTLE II

Shuttle II, presently the subject of limited design studies, would be a second generation Space Shuttle that could be used to service the Space Station and other future programs requiring astronauts in space. It is not seen as a heavy-lift launch vehicle. NASA envisions Shuttle 11 as a post-2000, piloted, two-stage fully reusable rocket-powered vehicle capable of launching between 20,000 and 65,000 pounds to low inclination LEO.

In some respects the Shuttle 11 is meant to be what the present Shuttle never became: a space transportation system that is relatively inexpensive, dependable, flexible, and capable of being turned around quickly. NASA planners expect Shuttle 11 to include light-weight primary structures, durable thermal protection systems, reusable cryogenic propellant tanks, reusable low-cost hydrocarbon and hydrogen propulsion, expert systems for decision making, robotics, and fault-tolerant, self-testing subsystems. Shuttle II could benefit from the structure and avionics advances of NASP and the production and operations advances of ALS.

As an advanced piloted vehicle, the Shuttle 11 could be used to support the Space Station or for self-contained experiments. NASA hopes to begin development in the mid-1990s and achieve a first flight around 2005.

Reduced launch costs would be sought by using advanced flight control systems and artificial intelligence, increasing automation, and minimizing launch and ground support. For example, one conceptual design has explored reducing ground operations costs by erecting the vehicle from a self-contained transporter after servicing it much like an ah-craft. As with Soviet launch practices, there would be no need for elaborate launch towers.

As with other advanced vehicles, the primary limitations to Shuttle II are its high development cost and uncertain development timetables. Because it would carry passengers, Shuttle 11's testing and certification requirements would be stringent. Also, current Shuttle 11 conceptual designs incorporate two high-value reusable vehicles; therefore, it would require high reliability to reduce the cost of failure. In case of failure of either reusable vehicle, standdowns could be drawn-out.

NATIONAL AEROSPACE PLANE (NASP)

The NASP program is a high-risk program with a potentially high payoff that might someday lead to a new family of aerospace vehicles[6] capable of taking off horizontally like a conventional airplane and flying all the way to Earth orbit. The principal technical hurdle is the development of a "scramjet"[7] engine capable of operating both in the atmosphere and in space. The NASP program must also solve several additional technical issues:

6 See for example, U.S. Congress, General Accounting Office, National Aero-Space Plane: A Technology Development and Demonstration Program to Build the X-30, GAO/NSIAD-88-122 (Washington, DC: U.S. General Accounting Office, April 1988).

7 A scramjet is an engine in which air flows through the combustion chamber at supersonic speeds, ignites hydrogen fuel, and is expelled through the exhaust, producing thrust. Scramjets maybe able to operate at speeds ranging from 4 to 25 times the speed of sound.

- Propulsion/Airframe Integration
- Aerodynamics and Computational Methods
- Materials and Structures

The joint NASA/DoD program, managed by the Air Force, is aimed at developing these critical technologies and ground testing NASP engines by 1990.[8] If the Government decides to continue the program through the design and fabrication stage, an experimental flight vehicle (the X-30) could be starting test flights in the mid to late 1990s. NASP program managers suggest that a NASP based on the results of that research could be operational by about 2010.

NASP capabilities are still uncertain, but experts assert that they will be similar to the Shuttle II. NASP's ability to take off from runways instead of large fixed launch sites and its great speed would provide unique mission flexibility and could make it useful to the military for reconnaissance or strike missions. NASP technologies may find application in civilian aircraft of the next century.

The principal uncertainties about NASP concern the feasibility of certain technologies, costs, and development and testing timeframes.[9] Although the program is designed to develop new technology as well as construct a test article, the current program emphasis on early demonstration flights could inhibit technology development. For example, the materials needed for airframe and engine components must be strong, lightweight and capable of withstanding operating temperatures of 1200°F to 1800°F while maintaining their strength. Yet the advanced metallic alloys and composites now available do not have these characteristics. Considerable research is also needed on the X-30'S aerodynamic stability above Mach 15. In addition, scramjet performance at the high Mach numbers needed to reach orbit is uncertain.

Its payload capacity could be relatively small since its main function would be to transport humans for civilian space needs or military operations. Successful development thus would improve resiliency for payloads of moderate weight or piloted missions. Unresolved questions about the NASP include cost, safety, storage of cryogenic fuels, and environmental effects, including sonic booms.

Of the three advanced technology launch systems described, the NASP represents the greatest technological leap. The present X-30 research program entails considerable technological risk. It could also be a significant driver of aerospace technology development because it requires major advances in propulsion, aerodynamics, and materials. Final costs and performance of NASP technology are uncertain and will continue to be for some time. For this reason, NASP was not included in the chapter 7 mission models and funding profiles.

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8 General Dynamics, McDonnell Douglas, and Rockwell International were each awarded $25.5 million contracts in October 1987 to continue technology development for the airframe competition. Rockwell's Rocketdyne Division and United Technologies' Pratt and Whitney Division were each awarded $85 million in September, 1987 to develop engines for the X-30.

9 See for example David C. Morrison, "Testing the Limits at Mach 25," Science, May 20,1988, pp. 973-975.

Box 5-2. – Unconventional Launch Technologies

Eventually launch methods may be developed that operate on physical principles other than conventional chemical propulsion. Some of these techniques would result in vast increases in launch capability. Areas of study include laser propulsion, direct launch (by cannons or coil guns), and anti-matter rockets, among others, Some "unconventional" launch methods involve extremely high accelerations. As a result, only cargo capable of tolerating high g forus could be transported. Currently most of the funding for examining the potential of these exotic technologies comes from the DOD. Although it is much too early to determine which, if any, of these concepts may become feasible, continued low-level funding support appears desirable because if even one of these concepts (or something different suggested by the research) proves useful, it could provide an inexpensive means for transporting supplies to space.

Laser Propulsion - Laser propulsion is a concept for obtaining propulsive force by beaming a laser from the ground to a launch vehicle. The laser beam would follow the craft during the entire ascent, heating a "working fluid" on the bottom of the craft. The laser pulses would produce a "laser-supported detonation" wave of hot, expanding vapor, which would produce thrust. Because the propulsive energy would come from the laser, the working fluid would be a propellant but not strictly speaking a fuel, and could be something as ordinary as reinforced ice placed beneath the payload. The routine use of lasers for propulsion would require resolving many issues, including high power levels, thruster efficiency, atmospheric propagation, beam quality, guidance and control, and environmental effects.

Ram Cannon for Cargo - A ram cannon uses a barrel filled with gaseous propellant and a projectile that flies through the propellant, igniting it like the centerbody of a ramjet engine. This reverses the usual situation as fuel is on the outside of the vehicle instead of on the inside. An experimental ram cannon has accelerated 0.1 pound projectiles at 20,000 g's to a velocity of 1.25 miles per second, about 20 percent of the velocity required to reach orbit. A full-scale ram cannon might be 2 miles long, built on the side of a mountain, and require about 50,000 tons of steel, about as much as the ocean liner Queen Elizabeth II. A ram cannon would be suitable only for payloads able to withstand extremely high accelerations. Propellants are potential payloads since they constitute more than half of current U.S. payload mass to low earth orbit.

Coilgun for Cargo - Electric catapults and guns have been studied since the 1930s, but electromagnetic devices for launching to space have been explored only relatively recently. A vertical electromagnetic coilgun in a 8 kilometer deep well might accelerate a one ton projectile to orbit under an acceleration of 1000 g's. It would require a coil to store and deliver roughly the output of atypical municipal power plant (1000 megawatts) in 90 seconds. Major questions about this technology involve energy storage costs and hightechnology switching systems. The impact and utilization of room-temperature superconducting material could be very significant and should be considered.

Anti-hydrogen Rocket - Anti-hydrogen has been considered for use in rocket propulsion because anti-matter converts all of its mass to energy upon annihilation with normal matter. It could serve as a fuel of tremendous energy density. For example, an aerospace plane weighing 120 tons at lift-off could carry 30 tons to LEO at Shuttle-like accelerations using only 35 milligrams of anti-hydrogen and several tons of ordinary hydrogen (for use as an inert propellant).

Anti-matter, whose existence was first proven in 1932, is being made and stored today, albeit in extremely small quantities. Production of 35 milligrams of anti-hydrogen would require 19 million years at present U.S. production rates, but might be produced in five weeks in a 10 gigawatt solar-powered orbital facility, according to one estimate. One recent study stated that relatively near-term methods existed to produce and store antimatter at about $10 million per milligram.

The high energy density of anti-hydrogen poses high risks as well. Accidental annihilation of 35 milligrams of anti-hydrogen would release the energy of 3 kilotons of TNT (comparable to a worst-case Shuttle explosion) and it might produce a large electromagnetic pulse.