Chapter 7

Potential Future Launch Systems

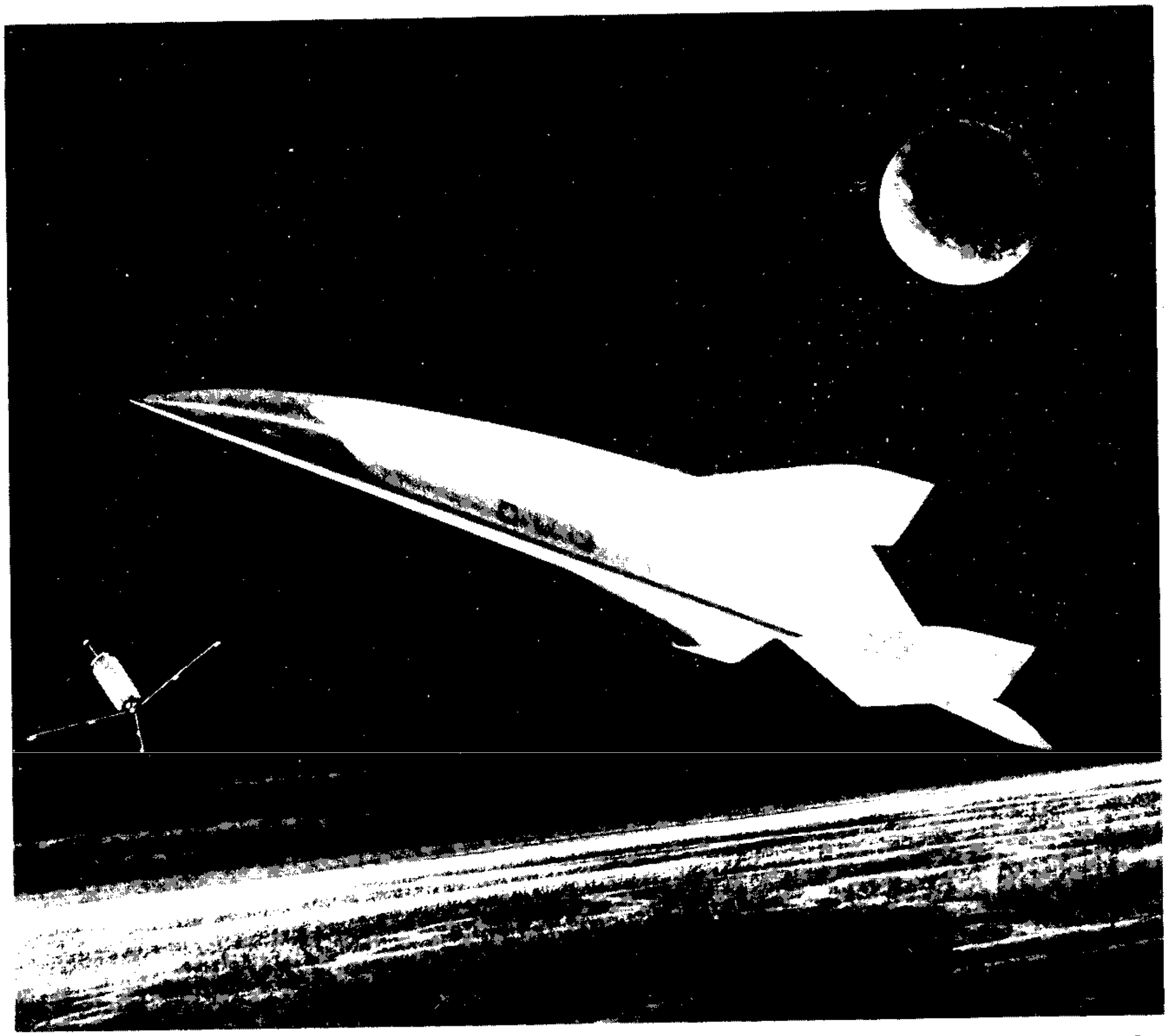


Photo credit: McDonnell Douglas Corp.

Artist's conception of an X-30 aerospace plane

Chapter 7

Potential Future Launch Systems

The Space Transportation Architecture Study (STAS)[1] and later studies conducted by NASA and the Air Force identified a wide range of technologies and management practices that could reduce the costs of space transportation and also increase reliability and operability. This chapter describes several options for meeting future space transportation demand.

CARGO ONLY

The Nation's existing fleet of expendable launch vehicles (ELVs) can carry payloads weighing up to 39,000 pounds (figure l-l) to low Earth orbit (LEO). Eventually, as cargoes gradually increase in size and weight, and as the Nation seeks to do more in space than it currently plans, new launch systems offering higher lift capacity will become attractive, if they can reduce costs while improving reliability and operability.

Some have argued that the Nation needs a heavy-lift launch vehicle (HLLV), similar in capacity to the Soviet *Energia,*[2] which can lift about 220,000 pounds to LEO. Indeed, for tasks requiring the launch of many pounds of cargo to space at one time in a single package, an HLLV would be necessary. If available, an HLLV would be useful for building large space structures, such as the Space Station, because launching pre-assembled structures would obviate much risky and expensive on-orbit assembly.

Some also argue that if the United States had an HLLV, the Government and the private sector would find a way to use it, for example, in bringing down launch and payload costs. OTA's analysis of future space transportation costs indicates that average cost *per pound* can be reduced substantially only if there is a marked increase in demand—that is, the number of pounds launched per year. Unless the Nation plans to increase investment in space activities significantly over current levels, development of an HLLV in order to reduce launch costs appears unwarranted.

Box 7-A—Potential Uses for Shuttle-C

- *Space Station Support*--*Shuttle-C* could reduce both the number of launches required to assemble the planned Space Station and the extravehicular work in space required to assemble and outfit the station.
- Science *and Applications* Payloads-Shuttle-C could launch large, heavy platforms for missions to planet Earth, and for the planetary sciences, astrophysics, and life sciences disciplines. If launched on the Shuttle, equivalent platforms might require on-orbit assembly by human crews.
- *Technology Test* Bed --Shtttde-C could be used **to test** new or modified systems, such as liquid rocket boosters, or new engines.
- *National security Applications* --Shuttle-C could place large payloads into polar orbit from Cape Canaveral, and Vandenberg Air Force Base.[1] It could place large payloads into retrograde orbits from Vandenberg Air Force Base.

[1] If the Shuttle launch complex (SLC-6) at Vandenberg AFB were reactivated.

SOURCE: Adapted from NASA Marshall Space Center, ''Shuttle-C Users Conference, Executive Summary," May 1989.

As noted earlier, if the Nation were to pursue the goals of building a permanent settlement on the Moon and/or sending explorers to Mars, one or more HLLVs would be required to carry the requisite fuel and other support infrastructure to LEO (box 7-A).[3]

Shuttle-C

NASA has investigated the potential for building a cargo-only HLLV, which would use Shuttle elements and technology. As envisioned by NASA, Shuttle-C could launch between 94,000 and 155,000 pounds to low Earth orbit (figure 7-1).[4] Such a system could lift large, heavy payloads if the risk or cost of using the Shuttle would be high as a result of

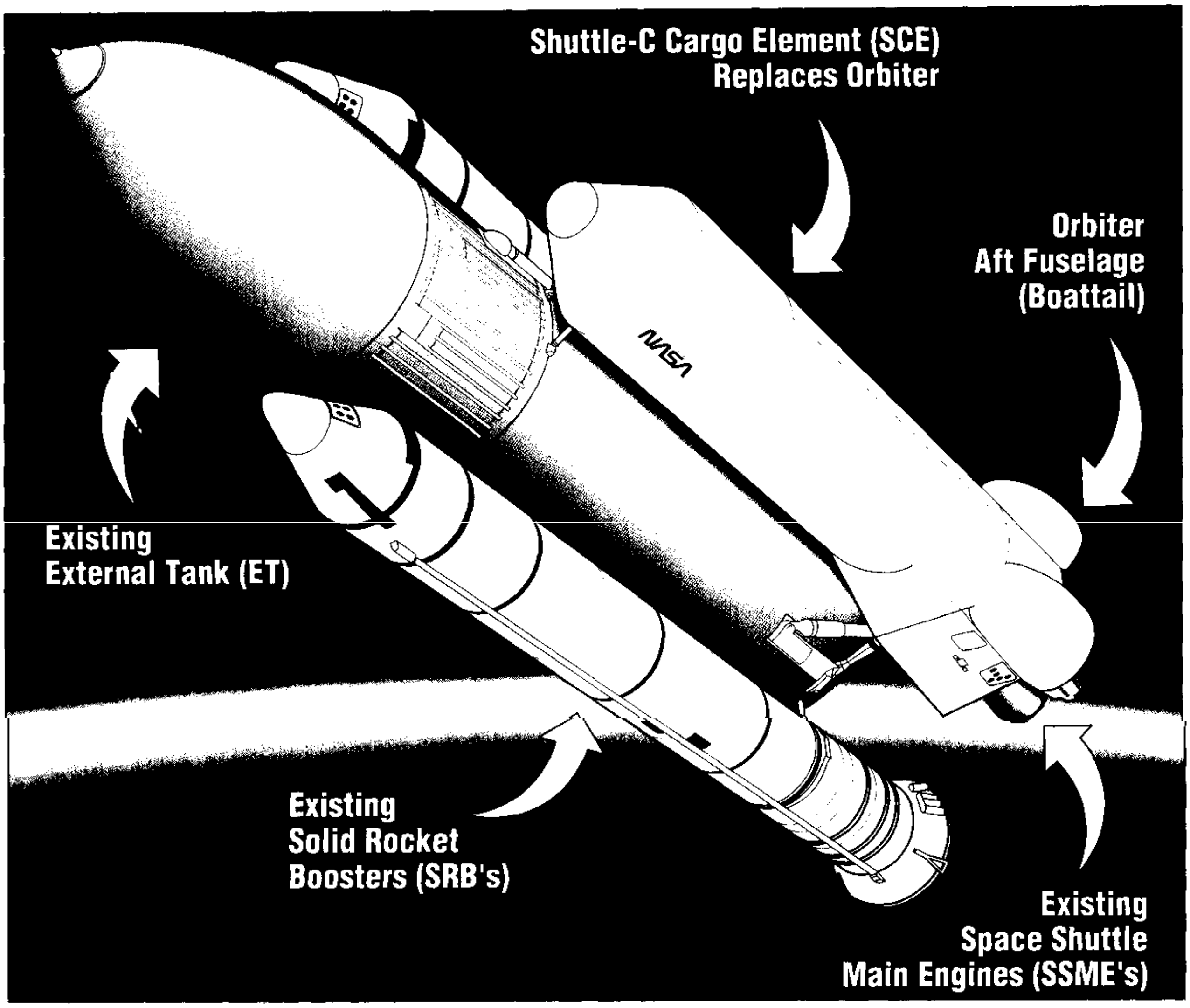
[1] U.S. Department of Defense and National Aeronautics and Space Administration, *National Space Transportation and Support St@ 1995-2010*, Summary Report of the Joint Steering Group, May 1986.

[2] The *Energia* can carry either cargo or the Soviet Shuttle into space, *Energia* may be used to lift elements of a new Soviet space station.

[3] Richard Truly, "Testimony before the Subcommittee on Space Sciences and Applications of the House Committee on Science, Space, and Technology, Sept. 26, 1989; National Aeronautics and Space Administration, *Report of the 90-Day Study on Human Exploration of the Moon & Mars,* November 1990.

[4] Shuttle is currently capable of lifting 52,()(XI pounds to 110 nautical miles above Kennedy Space Center.

Figure 7-1—Potential Shuttle-C Performance



Shuttle-C Ascent Performance Capability (lb)

		ETR				WTR
		220 nmi 28.5 deg.	110 nmi 28.5 deg.	110 nmi 98.7 deg.	30x200nmi 28.5 deg.	110 nmi 98.7 deg.
BASELINE DESIGN	**2** SSME @ 100%	82,750	93,700-	n/a	105,900	57,460
	@ 104%	88,180	99,100	n/a	112,40	62,800
	3 SSME @ 100%	141,300	151,100	53,200	162,900	111,000
	@ 104%	145,200	155,000	57,200	167,400	115,100
BASELINE + ASRM	**2** SSME @ 104%	99,620	110,540	13,900	124,400	74,300
	3SSME @ I04%	156,600	166,500	68,600	179,400	126,400

KEY: ETR = Eastern Test Range (Cape Canaveral); WTR = Western Test Range (Vandenberg Air Force Base)

SOURCE: National Aeronautics & Space Administration, 1989.

"orbital assembly or multiple Shuttle launches."[5] For example, it could enable the launch of large elements of the planned Space Station, already outfitted, reducing the risks that are associated with extensive on-orbit assembly using the Shuttle, or the Shuttle plus smaller ELVs (box 7-A).

Because the Shuttle-C would use most of the subsystems already proven on the Shuttle, NASA asserts that the Shuttle-C would cost about $1.8 billion to develop and could be ready for the first flight about 4 years after development begins. NASA planners suggest that it would serve to "bridge the gap" in launch services for large payloads between the mid-1990s and the beginning of the 21st century when an Advanced Launch System (ALS) could be available.[6]

Shuttle-C would avoid some costs by using Shuttle facilities and subsystems. For example, each Shuttle-C would use and expend two or three Space Shuttle Main Engines (SSMEs), but it could use SSMEs that had been used on the Shuttle until permitted only one more use by safety rules; these would be almost completely depreciated. However, Shuttle-C planners now propose to use SSMEs that have been used on the Shuttle only once; they would cost the Shuttle-C program $20 million each if they can be procured for $25 million each (versus $38 million currently) and refurbished for $15 million (fiscal year 1991 dollars), and if half the cost of two flights is allocated to Shuttle-C. In this case, the incremental cost per launch would be about 480 million fiscal year 1991 dollars[7] for a 3-engine Shuttle-C.[8]

Advanced Launch System (ALS)

In 1987 the Air Force and NASA began preliminary work on the (ALS), with the goals of dramatically reducing launch costs and improving vehicle reliability and operability. ALS program officials expect the ALS efforts to result in a modular family of cargo vehicles that would provide a broad range of payload capacity (figure 7-2). The ALS program estimates that development would cost about $7.3 billion (1989 dollars), and facilities would cost about $4 billion.

The ALS approach is to trade launch vehicle performance efficiency for low cost and high reliability by incorporating design and operating margins, and using redundant subsystems that are highly fault-tolerant. In addition, ALS designs would simplify and standardize interfaces, manufacturing processes, and operations procedures. New technologies would be developed and used only if they would further the goals of low cost and high reliability. ALS managers expect these approaches to improve the operability of the ALS compared to existing launch systems, by providing:

- high availability and reliability;
- high throughput and on-time performance; and
- standard vehicle-cargo operations

The ALS Program Office has defined a reference vehicle using liquid propulsion and capable of lifting between 80,000 and 120,000 pounds to LEO. It would use low-cost, 580,000-pound thrust engines that would be developed specifically for the ALS. The ALS program is also exploring the possible use of solid rockets for strap-on boosters.

Recent] y, the Department of Defense decided not to proceed with procurement of an ALS at this time, but to continue the program as a technology development effort. The primary thrust of the restructured ALS program would be to develop a new engine and other critical technologies for an ALS family of vehicles that could be started later in the decade if the need for such vehicles arises. The technology and subsystems developed for the ALS technology development program could provide the basis for building an HLLV system, if needed, in the early part of the 21st century. In the meantime, the program could provide important improvements for existing ELVs (table 7-l).

[5] NASA Marshall Space Center, "Shuttle-C Users Conference, Executive Summary," May 1989.

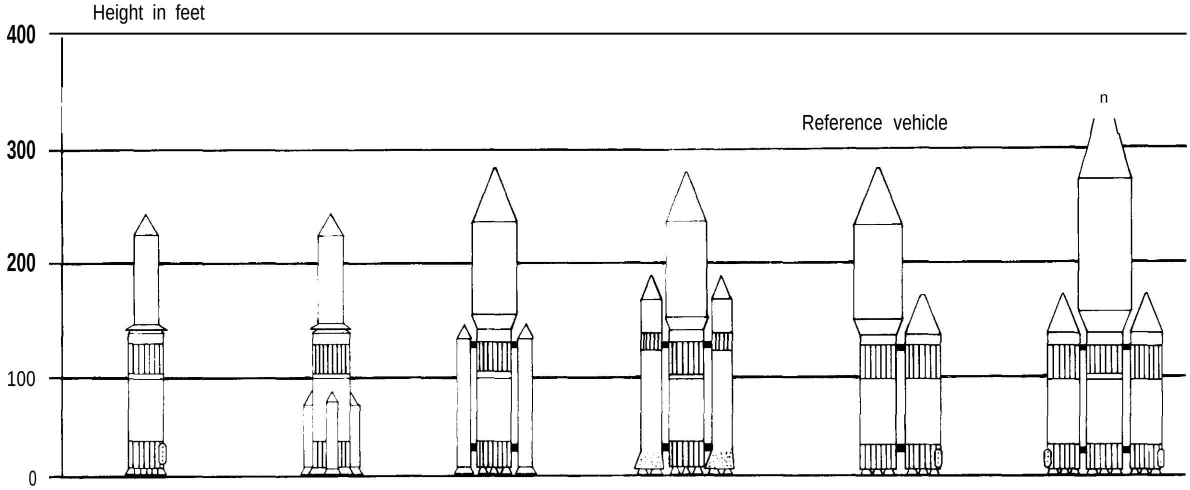
[6] Ibid.

[7] About 424 million fiscal year 1989 dollars.

[8] The other half of the cost should be allocated to Shuttle operations. OTA's cost estimates for Shuttle assume 10 or more uses per SSME. See 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), p. 68, footnote 5.

[9] ALS Program Office briefing to OTA, September 1989.

Figure 7-2—Advanced Launch System: The ALS Famiiy



Payload (thousands of lbs)	40 to 80	40 to 80	80 to 110	100 to 251	80 to 120	120 to 300
Booster:						
Type	Stage & half	ALS-SRM	SRMU	STS LRB	ALS LRB	ALS LRB
Propellant	L O_2/ L H_2	Clean solid	Clean solid	L O_2/ L H_2	L O_2/ L H_2	L O_2/ L H_2
Number	N/A	3 to 8	2 to 4	2 to 6	1	2 to 4

KEY: **ALS** . Advanced Launch System; **LRB** = Liquid Rocket Booster; SRM = Solid Rocket Motor, **SRMU** = Solid Rocket Motor Unit; **STS** = Space **Transportation System.**

SOURCE: **Advanced** Launch System Program Office.

Unconventional Launch Systems

A number of launch systems have been proposed that would use "exotic" technologies to propel payloads into space. For example, a payload might ride to orbit on a plastic cylinder, the bottom of which is heated from below by the beam from a powerful ground-based laser. As the plastic on the bottom decomposes into vapor and expands, it will exert pressure on the cylinder, producing thrust. The SDIO estimates development and construction of a laser for launching 44-pound payloads would require about $550 million over 5 or 6 years. It estimates that a laser system could launch up to 100 payloads per day—more than 20 Shuttle loads per year-for about $200 per pound, assuming propulsive efficiencies 300 percent greater than those achieved in lab tests. The cost would be closer to $500 per pound if efficiency is not improved.

Railgun proponents predict a prototype railgun capable of launching 1,100-pound projectiles carrying 550 pounds of payload could be developed in about 9 years for between $900 million and $6 billion, including $500 million to $5 billion for development of projectiles and tracking technology. If produced and launched at a rate of 10,000 per year, the projectiles (less payload) might cost between $500 and $30,000 per pound (estimates differ). The cost of launching them might be as low as $20 per pound -—i.e., $40 per pound of payload.[10]

Several other gun-like launchers have been proposed. One is the ram cannon (or ram accelerator), the barrel of which would be filled with gaseous fuel and oxidizer. The projectile would fly through this mixture, which would be ignited by the shock wave of the passing projectile and would exert pressure on it, accelerating it. A ram cannon designed for space launch would be about 2 miles long.

Many uses have been proposed for such launch systems, but to date only the Strategic Defense Initiative Organization has identified a plausible

[10]Note, however, that such rates are more than 100 times the current launch rate.

Table 7-l—Potential ALS Technology Improvements to Existing Systems

Propulsion
- Simplified engine designs
- Low cost manufacturing processes
- Low cost, dean solid propellants
- Automated nondestructive testing for solid rocket motors
- Enhanced liquid propulsion performance

Avionics and software
- Highly reliable avionics
- Weather and mission adaptive guidance, navigation, and control
- Expert systems for vehicle/mission management
- Automated software production
- Electromechanical actuators

Aerothermodynamica
- Engine and avionics reuse
  - recovery
  - landing
  - maintenance
  - reentry systems

Structures, materials, and manufacturing
- Low weight materials for propellants
- Composite structures for shroud and innertank
- Low cost manufacturing
  - automation: welding
  - processes: spinning, casting, extrusion, forging

Operations
- Automated checkout and launch operations
- Paperless management
- Expert system monitoring and control
- Engine and avionics health monitoring
- Operational subsystems
  - pyrotechnic alternatives
  - hazardous gas detection
  - remote cable transducer

SOURCE: Advanced Launch System Program Office,

demand for high-rate launches of microspacecraft, which could use such systems economically. However, demand for launches of scientific, commercial, and other microspacecraft could increase, perhaps dramatically, if launch costs could be reduced to a few hundred dollars per pound.

Most of these exotic launch technologies are still in the exploratory stage and therefore much less mature than rocket technology. Because of this, the costs cited must be regarded as highly speculative. Nevertheless, Congress may wish to fund continued research in order not to foreclose the opportunity exotics may pose for reducing future launch costs, especially for extremely small payloads such as the microspacecraft discussed in chapter *6--Reducing Space Space System Costs.*

CREW-CARRYING LAUNCH SYSTEMS

Even if the Shuttle is made more reliable, the Shuttle% high operational costs will eventually lead to a decision to replace it with a successor capable of more effectively fitting the needs of the Government's activities for people in space and reducing the recurring cost of launching piloted vehicles. The most important goal of each Shuttle mission is to return the reusable orbiter and crew safely to Earth.[11] This goal, an essential aspect of flying human crews and an expensive reusable vehicle, nevertheless adds to mission costs by requiring additional attention to payload integration, extra payload safety systems, and additional preflight payload handling. In addition, humans require special environments not needed by many payloads.

For the 1990s, the primary need for transporting people to and from outer space will be to operate the Shuttle orbiters and experiments aboard them, and to assemble and operate the Space Station. NASA now estimates that Phase I Space Station construction will require 29 Shuttle flights (including some logistics flights) and about 5.5 flights per year thereafter to service Space Station. If the Nation decides to build a lunar base or to send a crew-carrying mission to Mars, NASA estimates that additional crew-carrying capacity would be needed to supplement or replace the Shuttle.

NASA is studying several launch concepts that could supplement or replace the current Shuttle. Most could not be available before the turn of the century. NASA and the Air Force are collaborating on the development of an aerospace plane using advanced, airbreathing engines that could revolutionize spaceflight. However, even if development were pushed, an aerospace plane based on airbreathing technology is unlikely to be available for operational before 2005.

PERSONNEL CARRIER LAUNCHED ON UNPILOTED LAUNCH VEHICLES

NASA is exploring the possibility of developing a personnel launch system (PLS) that would use a

[11] Returning the orbiter and crew safely is not necessarily equivalent to completing the mission, although it is often confused with the same. NASA will abort the mission rather than knowingly risk crew safety, if problems appear. Launching payloads on unpiloted vehicles avoids the added complexity and cost provided by the human factor.

small reusable glider, capsule, or lifting body launched atop an expendable launch vehicle rated to carry crews.[12] This option would separate human transport from cargo delivery, and could, in principle, be made safer than the Shuttle. The Soviet Union,[13] The European Space Agency,[14] and Japan[15] have all adopted this approach to placing people in orbit. Candidate launchers could include a Titan III, a Titan IV, a Shuttle-C, or perhaps a new, as-yet undeveloped launcher such as the ALS.

The ALS Joint Program Office has recognized the potential benefit of having a flexible launch vehicle rated for launching crews. It has therefore required that contractor proposals for an ALS provide for a launch vehicle capable of meeting both the design and quality assurance criteria for carrying crews. Designing an ALS launch vehicle at the outset to provide additional structural strength would be much less expensive than redesigning, rebuilding, and retesting it after it is developed.[16] As currently envisioned, ALS would also provide previously unobtainable levels of safety by incorporating fault-tolerant subsystems and engine-out capability.

Having a crew-rated automated launcher in addition to a Shuttle has three strong advantages: 1) the crew-rated vehicle could launch new orbiters designed for launch with other boosters; 2) it could enhance crew safety (intact abort is a design requirement for the PLS); and 3) there may be cases where it will be necessary only to deliver personnel to the Space Station. In that case, there is no need to risk a Shuttle orbiter. Separation of crew- and cargo-carrying capabilities is especially important, as carrying both on the same vehicle adds to the payload costs and may reduce crew safety, **In view of the concerns over Shuttle fleet attrition, it may be important for NASA to investigate the potential for using a crew-rated ALS or other launcher to reduce the risk of losing crew-carrying capacity early in the next century.**

Advanced Manned Launch System (AMLS)

NASA's program investigating the set of concepts for an AMLS, previously called the Shuttle II, is studying new designs with the goal of replacing the Space Shuttle early in the next century. A vehicle significantly different from the existing Shuttle would result (box 7-B). If activities involving crews in space increase markedly in the next century, an AMLS using advanced technology might be needed. It could offer significant improvements in operational flexibility and reduced operations costs over the existing Shuttle. However, development, testing, and procurement of an AMLS fleet could cost $20 billion or more (1989 dollars).

The timing of the development phase for an AMLS should depend on NASA'S need to replace the Shuttle fleet. It would also depend in part on progress reached with technologies being explored in the Advanced Launch System and National Aero-Space Plane (NASP) programs. In any event, a decision on AMLS will not have to be made for several more years. For example, if Congress decided that an operational AMLS was needed by 2010, the decision to start the early phases of development would have to be made by about 1995. By that time, Congress should have had adequate opportunity to assess the progress made in the NASP program (see below), which could be competitive with an AMLS.

An Aerospace Plane

Developing a reusable vehicle that could be operated like an airplane from conventional runways, but fly to Earth orbit powered by a single propulsion stage would provide a radically different approach to space launch and a major step in U.S. launch capability. However, building such a vehicle poses a much larger technical challenge than building a two-stage, rocket-propelled vehicle such as the AMLS. A successful aerospace plane might also provide greater benefits to industry and to U.S. technological competitive-

[12] A NASA or Air Force launch vehicle is said to be crew, or "man-rated," if it has been certified as meeting certain safety criteria. These include design criteria as well as quality assurance criteria.

[13] Although the Soviet Union has also developed a shuttle orbiter similar to the U.S. Space Shuttle, it will continue to rely on its *Soyuz* vehicle for transporting people to the *Mir* space station atop the Proton launcher, and on its *Progress* transport for launching cargo.

[14] The reusable, piloted *Hermes* spaceplane will be launched atop an Ariane V launcher sometime in the late 1990s. Ariane V is currently also under development.

[15] Japan plans to develop a small, unpiloted spaceplane, HOPE, that would be launched atop its H II launch vehicle, now under development. HOPE may experience its first flight in the early years of the next century.

[16] It would, however, add a small amount to the cost of each flight in which cargo only were carried.

Box 7-B—The Advanced Manned Launch System (AMLS)

The goal of the NASA AMLS program is to define advanced manned launch system concepts, including their development, system and operational characteristics, and technology requirements. A vehicle significantly different from the existing Shuttle would result. NASA is presently evaluating five concepts:

- an expendable in-line two-stage booster with a reusable piloted glider;
- a partially reusable vehicle with a glider atop a core stage;
- a partially reusable drop-tank vehicle similar to the fully reusable concept below but with expendable side-mounted drop tanks;
- a fully reusable rocket with a piloted orbiter parallel-mounted (side-by-side) to an unpiloted glideback booster;
- a two-stage horizontal takeoff and landing air-breather/rocket, which would be fully reusable.

Critical technology needs for all AMLS concepts include:

- light-weight primary structures,
- reusable cryogenic propellant tanks,
- low-maintenance thermal protection systems,
- reusable, low-cost hydrogen propulsion,
- electromechanical actuators,
- fault tolerant/self-test subsystems, and
- autonomous flight operations.

SOURCE: National Aeronautics and Space Administration.

Box 7-C-The National Aero-Space Plane Program (NASP)

NASP is a program to build the X-30, an experimental, hydrogen-fueled, piloted aerospace plane capable of taking off and landing horizontally and reaching Earth orbit with a single propulsiom stage. The design of the X-30 would incorporate advanced propulsion, materials, avionics, and control systems and make unprecedented use of supercomputers as a design aid and complement to ground test facilities. NASP is a technically risky program that, if successful, could spur the development of a revolutionary class of reusable, rapid turn-around hypersonic flight vehicles, that would be propelled primarily by air-breathing "scramjet" engines.

Operational follow-ons to the X-30: An aerospace plane derived from NASP technology offers the promise of dramatically reduced launch costs if the vehicle can truly be operated like an airplane using standard runways, with minimum refurbishing and maintenance between flights.

SOURCE: Office of Technology Assessment, 1990.

ness than an AMLS, as a result of the development of new materials and propulsion methods. The Department of Defense and NASA are jointly funding the NASP program to build the X-30 (box 7-C),[17] a research vehicle intended to demonstrate both single-stage access to space and endoatmospheric hypersonic cruise capabilities.

NASP is a high-risk technology development program. Building the X-30 to achieve orbit with **a single stage would require major technological advances in materials and structures, propulsion systems, and computer simulation of aerodynamic and aerothermal effects from Mach 1 to Mach 25.[18] The** uncertainties in meeting design goals are compounded because a successful X-30 would require many of the key enabling technologies to work in concert with one another. Because ground test facilities cannot replicate all of the conditions that would be encountered in ascent to orbit, it is impossible to predict precisely how the X-30 would perform when pilots make the first attempts to push it far into the hypersonic realm.

If funded, the X-30 would be a research vehicle, not a prototype of an operational vehicle. To develop an operational vehicle would require an additional program beyond NASP. A development cycle that took full advantage of lessons learned in the X-30'S planned test program could not commence until the late 1990s at the earliest. An operational vehicle derived from the proposed X-30 would therefore be unlikely until approximately 2005 or later unless it were closely modeled on the X-30. However, if the X-30 were designed to provide the maximum data

17 Debates over NASP funding within the Administration and within Congress have left the long-term status of the program in doubt. In Spring 1989 DoD decided to cut its contribution to NASP by two-thirds for fiscal year 1990 and to terminate funding for it in subsequent years. A reexamination of the program by the National Space Council led 10 the replacement of program funds, but delayed the decision concerning whether or not to proceed with construction of the X-30 for2 years, to 1993. Congress decided to appropriate $254 million for NASP research in 1990 ($194 from DoD; $60 million from NASA).

18 Mach 1 is the speed of sound. Hypersonic usually refers to flight at speeds of at least Mach 5—five times the speed of sound, or about 4,000 miles per hour. Mach 25 (25 times Mach 1), is the speed necessary to reach Earth orbit.

about the feasibility of an operational aerospace plane, it would be unlikely to serve as an appropriate prototype of an operational vehicle. Although the X-30 would be piloted, aerospace planes based on the X-30 could be designed to carry cargo autonomously. [19]

If the X-30 proves successful, the frost operational vehicles that employ NASP technologies are likely to be built for military use, possibly followed by civilian space vehicles. Commercial hypersonic transports (the 'Orient Express") are a more distant possibility. Recent studies have shown that from an economic standpoint, commercial hypersonic transports would compare unfavorably with proposed slower, Mach 3 supersonic transports based on less exotic technology and conventional fuels. Therefore, the most economic route to commercial high-speed air transport is unlikely to be through the X-30 development program. However, the X-30 program could provide technical spin-offs to aerospace and other high-technology industries through its development of advanced materials and structures and through advances in computation and numerical simulation techniques. It is too early to judge the economic importance of such spinoffs.

Even assuming a rapid resolution of the myriad of technical issues facing the creation of an X-30 capable of reaching orbit with a single propulsion stage based on airbreathing technology, translating this technology into an operational spaceplane might come late in the period when an AMLS **could be ready, and perhaps after the time when replacements for the Shuttle would be necessary.** With their less exotic technologies, rocket propelled AMLS vehicles could probably be funded in the mid to late 1990s and still be developed in time to replace aging Shuttles. An AMLS program begun in this period would also benefit from the technical base being developed in the NASP program, which is exploring concepts based solely on rocket propulsion as well (see below). **However, the technical and economic uncertainties of both programs suggest that Congress would benefit from monitoring their progress and comparing the probability of success of each before committing development funds for operational vehicles in the mid-1990s. The development costs of each program, as well as other competing budget priorities, will play a major role in such a decision.**

Additional Reusable Launch Concepts

Routine flight to space with reusable vehicles offers tremendous economies if the United States can master the underlying technologies-materials, structures, propulsion, and avionics to produce a highly reliable and maintainable reusable vehicle.[20] The technologies needed for fully reusable space launch systems are being developed primarily by the NASP program, although the ALS and AMLS programs are also investing in reusable concepts. Future operational cargo systems may combine the best technologies developed by each program. Ranging from rocket-powered vehicles that might be available by the beginning of next century, to airbreathing propulsion systems that would be available later, such vehicles could support intermediate to near Shuttle-size payloads. Operated as fully reusable vehicles able to fly to orbit without an expendable stage, such vehicles offer some of the economies associated with aircraft.

[19] The Soviet shuttle *Buran* has demonstrated the feasibility of launching and landing a reusable space plane without a human crew.

[20] See app. A for a discussion of the effect of reliability on life-cycle cost estimates of future launch systems.