Chapter 2

Issues and Options

Photo credit: National Aeronautics and Space Administration

Space Shuttle Challenger lifts off from Kennedy Space Center on its second flight, June 18, 1983.

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The United States today depends entirely on the Space Shuttle for transporting crews to and from space. Not only does the Shuttle function as a vehicle for launching spacecraft, it also serves as a platform for experiments in science and engineering. In the future, NASA intends to use the Space Shuttle to deploy and service the planned Space Station. As the Nation looks toward the future of piloted spaceflight, it may wish to improve the Shuttle's reliability, performance, and operational efficiency. Eventually, additions to the Shuttle fleet or replacement Shuttles will likely be desirable. This chapter summarizes the major issues of maintaining and improving the Space Shuttle and developing advanced crew-carrying launchers. It also presents a range of congressional options for responding to these issues.

LAUNCHING HUMANS TO SPACE

One of the distinguishing characteristics of the U.S. civilian space program is its emphasis on people in space, to demonstrate U.S. leadership in the development and application of high technology. Since the early days of the Apollo program, the ''manned' space effort.. of the National Aeronautics and Space Administration (NASA) have served as a major driver of the direction and spending of its space activities. Today, NASA's projects involving people in space, primarily the Space Shuttle and Space Station programs, consume between 65 and 70 percent of NASA's budget (table 2-l).

Critics of NASA's emphasis on humans in space, especially critics in the space science community, have questioned the wisdom of continuing to emphasize these activities because of the heavy explicit and implicit demands they place on the civilian space budget. In particular, critics note that using the Shuttle to launch the Hubble Space Telescope and large solar system probes, like Galileo and Ulysses, subjects space science to unnecessary reliance on the Shuttle's ability to meet a launch schedule.[1] These critics point out that Europe and Japan, while spending considerably less on space than the United States, have nevertheless achieved noteworthy scientific and technological results. However, supporters of maintaining the human presence in space argue that such activities provide essential visibility for the U.S. space program and underscore America's international technological leadership:

> The [manned] space[flight] program is a visible symbol of U.S. world leadership; its challenges and accomplishments motivate scientific and technical excellence among U.S. students; and it provides for a diverse American population a sense of common national accomplishment and shared pride in American achievement.[2]

Current space policy calls for demonstrating U.S. leadership by expanding "human presence and activity beyond Earth orbit into the solar system, ' and "continuing our national commitment to a permanently manned Space Station."[3] U.S. space policy directs NASA to improve the Space Shuttle system and start the Space Station by the mid- 1990s. It also directs NASA to establish sustainable Shuttle flight rates for use in planning and budgeting Government space programs, and to pursue appropriate enhancements to Shuttle operational capabilities, upper stages, and systems for deploying, servicing, and retrieving spacecraft as national requirements are defined.[4]

Achieving all of these goals would be expensive. In the Apollo era, the Nation had the well-defined political goal to land a man on the Moon within a decade and return him, a goal that carried the rest of the space program and a large budget commitment with it. If the budget for space activities were unlimited and if the needs of the various space interests could all be met equally well, then many space program goals might be usefully pursued at the same time. The United States could maintain its

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[1] Robert Bless, ''Sp=e Science: What Wrong at NASA," *Issues in Science and Technology,* winter *1988-89,* pp. 67-73; Bruce Murray, ''Civilian Space: In Search of Presidential Goals, " Issues *in Science and Technology*, spring 1986, pp. 25-37.

[2] John M. Logsdon, "A Sustainable Rationale for Manned Space Flight," *Space Policy*, *vol.* 5, 1989, pp. 3-6.

[3] The WhiteHouse, Office of the Press Secretary, *"The* Resident's Space Policy and Commercial Space Initiative to Begin the Next Century,' Fact Sheet, Feb. 11, 1989.

[4] Ibid.

Table 2-l-National Aeronautics and Space Administration Fiscal Year 1990 Budget Summary for Space[a] (millions of current-year dollars)

	Budget Plan		
	1988	1989	1990
Research and Development	*2,922.0*	*3,862.4*	*5,288.8*
Space Station	392.3	**900.0**	**2,050.2**
Space transportation capability development	593.4	681.0	639.0
Space science and applications	1,581.8	1,830.2	1,995.3
Technology utilization	**19.0**	**16.5**	**22.7**
Commercial use of space	29.7	28.2	38.3
Transatmospheric research and technology	52.5	69.4	127.0
Space research and technology	221.3	295.9	338.1
Safety, reliability, and quality assurance	14.1	22.4	23.3
University space science and technology academic program	(21.6)	(22.3)	35.0
Tracking and data advanced systems	17.9	18.8	19.9
Space Flight, Control, and Data Communications	3,805.7	4,484.2	5,139.6
Shuttle production and capability	1,092.7	1,128.2	1,305.3
Space transportation operations	1,833.6	2,390.7	2,732.2
Space and ground networks communications and data systems	879.4	945.3	1,102.1
Construction of Facilities	178.3	275.1	341.8
Research and Program Management	1,762.2	1,891.6	2,032.2
Total Budget Summary	9,001.1	10,493.3	12,804.4

[a]Total NASA budget lass aeronautical research & technology
SOURCE: National Aeronautics and Space Administration.

preeminence in space transportation as well as in other space activities. However, as a result of the current budget stringency, Congress must choose among competing ideas for the United States to demonstrate its leadership rather than attempting to demonstrate leadership across the board.

In contrast to U.S. civilian activities, the military space program has spent relatively little on crews in space, despite numerous efforts over the years by some to identify military missions that would require crews. Indeed, DoD has recently reaffirmed that it has no requirements for crews in space. Production of a piloted aerospace plane for military use, such as is contemplated for a follow-on to the current National Aero-Space Plane Program, would reverse this historical stance.

An assessment of the appropriate mix of crew-carrying and robotic efforts for space science and exploration, or for military activities, is beyond the scope of this study. Expanded commitment to crews in space, as contemplated by NASA and the Air Force, would require increasing budgetary outlays and would likely require the development of new and costly crew-carrying space vehicles.

To illustrate the problem Congress faces, the Space Shuttle system and the Space Station, both of which require crews, dominate NASA's budget for the 1990s.[5] As noted in a 1988 Congressional Budget Office report, simply to maintain NASA's ''core program, ' which includes these major programs, but no large additional ones, will require NASA's overall budget to grow from $10.5 billion in fiscal year 1989 to about $14.4 billion in fiscal year 1995.16 NASA plans to spend about $2.5 billion per year for investment in its space transportation system, including improvements to the Shuttle, an advanced solid rocket motor, and in-orbit transportation vehicles. Operating the Shuttle will cost an additional $2.0 billion. Anything new, such as an

[5]Most of President Bush's 20 percent suggested budget increase for NASA for fiscal year 1990 derives from increases to build the Space Station, which is scheduled for permanent occupation in 1996.

[6]U.S. Congress, Congressional Budget Office, *The NASA Program in the 1990s and Beyond* (Washington, DC: May 1988), pp. x-xiv.

additional orbiter beyond OV-105, major modifications to the Shuttle, a Shuttle-C, a Personnel Launch System, or a crew return vehicle, will add to these costs.

Spaceflight is inherently risky. As noted in the next section and in chapter 3, the exact reliability of the Shuttle system is uncertain, but experts suggest it ranges between 97 and 99 percent. Therefore, the United States may expect to lose or severely damage one or more orbiters within the next decade, perhaps with loss of life, As America's reaction to the *Challenger* disaster demonstrated, the loss of another Shuttle crew in addition to an orbiter would likely result in another long standdown of the Space Shuttle system and could sharply reduce the productivity of the civilian space program. Loss of an orbiter would also certainly lead to a painful reexamination of the space program's purpose and direction.

One of the major challenges for the U.S. civilian space program will be to learn how to reconcile America's goals for the expansion of human presence in space with the ever present potential for loss of life. **In particular, if the United States wishes to send people into space on a routine basis, the Nation will have to accept the risks these activities entail. If such risks are perceived to be too high, the Nation may wish to reduce its emphasis on placing humans in space.**

DEPENDENCE ON THE SPACE SHUTTLE

U.S. dependence on the Space Shuttle for carrying crews to space raises questions concerning the longevity of the Shuttle fleet and the risks that orbiters might be unavailable when needed. These involve the inflexibility of the Shuttle system, especially when scheduled to fly at rates close to the maximum projected sustainable flight rate, and possible attrition of the Shuttle fleet.

Inflexibility

Although NASA has estimated that Kennedy Space Center can launch at most 14 Shuttles per year with existing facilities,[7] NASA has scheduled 14 Shuttle flights in 1993,[8] and plans to launch approximately 14 per year through the end of the century. Scheduling launches at the maximum sustainable launch rate leaves no margin to accommodate a sudden change in launch plans or to fly any missions that may be delayed by a future accident.

Attrition

Whatever the launch rate, the fleet will be subject to a growing cumulative risk of attrition.[9] In 1988, a NASA contractor predicted *post-Challenger* Shuttle reliability would be between 97 and 98.6 percent and used 98 percent as a representative estimate.[10] A more recent NASA study estimated the chance of success on the Galileo mission would probably be between 1 in 36 (97.2 percent) and 1 in 168 (99.4 percent).[11] The probability of orbiter recovery after the Galileo mission would be comparable, because the most likely causes of a mission failure would probably destroy the orbiter. **If reliability is and remains 98 percent, there would be** a 50 **percent chance of losing an orbiter on the next 34 flights,** a 72 percent chance of losing an orbiter before the first Space Station assembly flight (if scheduled for flight 92), and an 88 percent chance of losing an orbiter before Space Station assembly is completed 42 flights later.

Because the construction of additional orbiters requires about 6 years, in the early 1990s the only way to increase the margin in the Shuttle launch schedule is to delay some missions already scheduled or launch them on expendable launchers. **To increase the probability that the Nation will have four operational orbiters in the mid-1990s, when NASA expects to start construction of the Space Station,** some missions now scheduled could be

7 Enclosure to letter from Darrell R. Branscome, NASA HQ, to Richard DalBello, OTA, Mar. 31, 1988. A National Research Council panel estimated that only 11 to 13 launches per year could be sustained. See *Post-Challenger Assessment of Space Shuttle Flight Rates and Utilization* (Washington, DC: National Academy Press, October 1986), p. 15.

8 NASA Headquarters, Transportation Services Office, *Payload Flight Assignments, NASA Mixed Fleet,* June 1989.

9 Viz. of not recovering an orbiter in refurbishable condition. This may differ from the risk faced by the crew, because the crew might escape in some situations in which the orbiter would be lost.

10 L-Systems, Inc., *Shuttle/Shuttle-C Operations, Risks, and Cost Analyses,* LSYS-88-008 (El Segundo, CA: L-Systems, Inc.) 1988).

11 NASA, Code Q, *Independent Assessment of Shuttle Accident Scenario Probabilities for the Galileo Mission,* vo1. 1, April 1989.

cancelled, delayed, or flown on expendable launchers. Ordering one or more orbiters now would increase the probability of having four operational orbiters after the mid-1990s. Unless additional orbiters are added to the fleet, attrition is likely to decrease fleet size, perhaps much more rapidly than NASA expected originally or now plans for (see ch. 3).

Wearout and Obsolescence

As time goes on, structural fatigue, wearout, and obsolescence will become more important. Existing Shuttle orbiters will be at least 15 years old in the mid-1990s, when Space Station operations are scheduled to begin. By that time, the designs of many Shuttle systems will be 25 years old. It will be economical to replace some systems, such as the Shuttle computers, before they wear out, because redesigned systems may be so much less expensive to maintain and operate that the cost of upgrading would be justified.[12]

Eventually, it will be economical to replace the entire orbiter fleet with a fleet of newly designed vehicles. As discussed in more detail in chapter 3, NASA is now estimating the costs of operating improved Shuttle orbiters and newly designed vehicles that would be used in an Advanced Manned Launch System (AMLS).

NASA, the Air Force, and their contractors are also estimating the costs of operating spaceplanes that could be built using technology to be demonstrated by the experimental X-30 spaceplane now being designed in the National Aero-Space Plane program. When these estimates are completed, comparisons of cost-effectiveness must be made to forecast economic dates for phasing out orbiters of existing design and introducing improved orbiters, an Advanced Manned Launch System, and/or operational spaceplanes incorporating X-30 technology.

IMMINENT DECISIONS

If the United States wishes to continue its strong dependence on the Space Shuttle, decisions about whether or not to purchase a new orbiter or to improve the Space Shuttle system should be be made in the next year or two. These issues are discussed in greater detail in chapter 3.

Order More Orbiters?

The United States must decide soon whether to order one or more Shuttle orbiters in addition to the one (OV-105) now under construction. Buying more orbiters would provide increased fleet capacity and flexibility and compensate for attrition. A new orbiter could be a copy of OV-105, or could be upgraded to improve safety, payload capability, endurance in orbit, or ease or economy of operation. It could be given a capability to fly automatically, with or without a crew aboard, like the Soviet space shuttle.

The longer a decision to order a "ship set" of spare parts or another orbiter is delayed, the greater will be the risk that the tooling or expertise needed to manufacture some parts will be lost, thereby leading to even longer lead times and greater cost.

Improve Existing Orbiters?

Existing Shuttle orbiters and OV-105 could be modified to have some, but not all, of the improvements of safety, payload capacity, endurance, economy, and operability that a new orbiter could have. This option could be chosen whether or not a new orbiter (beyond OV-105) is ordered. It would temporarily reduce the Shuttle flight rate, as making modifications to orbiters effectively removes them from the fleet for several months at a time.

Improve Other Shuttle Elements and Facilities?

Shuttle elements other than orbiters could also be upgraded. NASA and industry are considering many options, with several goals. Some options, for example, would increase the payload a Shuttle could carry to orbit. This would allow the Space Station to be assembled with fewer Shuttle flights and with less extra-vehicular activity (EVA) by astronauts; EVA is risky. It would also allow other payloads to be carried with fewer Shuttle flights, and it would allow heavier payloads to be carried on Shuttle flights.

[12] NASA has embarked on a program to replace the orbiters 'computers. However, because of the pace of improvements in computer technology, by the time they are installed in the early 1990s, these computers will not be state-of-the-art.

These options include:

- continued development of Advanced Solid Rocket Motors (ASRMs),
- modification of Redesigned Solid Rocket Motors (RSRMs) to increase their thrust,
- development of Liquid-fuel Rocket Boosters (LRBs), and
- development of lightweight External Tanks (ETs).

These would increase Shuttle payload capability by different amounts, and their other benefits and dates of availability would differ (see ch. 3). Therefore, two or more options might be pursued.

Alternatively, or in addition, NASA could develop complementary vehicles (e.g., Shuttle-C) to carry large payloads to orbit and reduce the Shuttle flight rate, thereby reducing the risk of Shuttle fleet attrition. The United States need not decide this year whether to proceed with one or more of these options. However, if such improvements are desired, more benefit will be reaped if they are begun sooner rather than later.

Develop Capsules or Gliders for Escape or Rescue?

Space Station crewmembers might become ill or be injured and need to return to Earth before a Shuttle could be prepared to rescue them. Although NASA's Aerospace Safety Advisory Panel has recommended that ''a single-purpose crew rescue vehicle or lifeboat should be an essential part of the Space Station's design,"[13] and although NASA's guidelines for "man-rating" space systems require the Space Station to have some sort of escape system (not necessarily single-purpose),[14] NASA has not yet decided to provide an escape system for the Space Station. NASA has not estimated the risk Station crewmembers will face, nor how much it could be reduced by the various escape systems NASA has considered developing.[15] Whatever the risk, it could be reduced to some degree, but not eliminated, by providing an escape system for the Space Station to complement safety measures already being pursued by NASA. 'G

NASA has considered several options for Space Station "lifeboats" (see ch. 6):

- a dedicated Shuttle orbiter docked to the Station;
- Apollo-like capsules; or
- gliders.

After the year 2000, NASA might rely on spacecraft being developed by foreign partners in the Space Station program *(Hermes*, HOPE, *Saenger*, or possibly Hotol), or on "NASP-derived" spaceplanes for crew rescue or escape. But these would not be available for the first years of Space Station operation, unless Space Station construction is delayed.

FUTURE DECISIONS

The United States need not decide now whether to develop an Advanced Manned Launch System along the lines now envisioned by NASA, or some other version, and whether to develop a single-stage-to-orbit aerospace plane. NASA and the Air Force have programs to develop technologies for such vehicles and to estimate their operational capabilities and costs. Industry is also advancing proposals. More technology development, design, and cost/benefit estimation must be done before an informed rational choice can be made in the early to mid-1990s.

Develop the Advanced Manned Launch System or a Different Advanced Rocket?

In its AMLS program, NASA is studying concepts for an advanced reusable crew-carrying orbiter (previously called Shuttle II) to succeed the Shuttle in 2005 or later. NASA is evaluating five concepts:

- an expendable two-stage rocket;
- a partially reusable rocket;
- a partially reusable ''drop-tank' rocket;
- a fully reusable rocket; or
- a fully reusable two-stage vehicle that uses airbreathing engines for the first stage.

[13] *Aerospace* Safety Advisory Panel, *Annual Report* (Washington, DC: NASA Headquarters, Code Q-1, March 1989), p. 7.

[14] National Aeronautics and Space Administration, *Guidelines for Man-Rating Space System,* JSC-23211, preliminary, September 1988.

[15] NASA has not routinely carried out quantitative risk assessments of its systems. See Trudy E. Bell and Karl Esch, "The Space Shuttle: A Case of Subjective Engineering," *IEEE Spectrum*, June 1989, pp. *42-46.*

[16] U.S. Congress, Congressional Budget Office, *The NASA Program in the 1990s and Beyond* (Washington, DC: May 1988), pp. x-xiv.

The airbreathing vehicle would take off from a runway like art airplane, and both the unpiloted first stage and the piloted orbiter would land on a runway.

The program will compare the costs and benefits of an AMLS with the Shuttle evolution option under study by the Johnson Space Center. It would be prudent to defer a decision until NASA has completed preliminary designs of alternative vehicles in sufficient detail to estimate technological risk and life-cycle cost.

Develop a Single-Stage-to-Orbit Spaceplane?

The National Aero-Space Plane (NASP) program is designing and developing technology for an experimental single-stage-to-orbit air-breathing jet/rocket aerospace plane, the X-30. Two X-30s are to be built; they are intended to demonstrate the feasibility of taking off from a runway, entering orbit, reentering the atmosphere, landing on a runway, and being prepared for another sortie within 24 hours. If the X-30 is successful, the government will have a basis for greater confidence that operational aerospace planes ("NASP-derived vehicles," or NDVs) of similar design could be built to perform civilian and military missions, including space transportation. An NDV might serve as a space taxi between Earth and low orbit.

The value of NDVs for space transportation will depend in part on the importance of their unique capabilities (e.g., rapid turnaround[17]) and in part on the average cost per flight and per pound of payload. NDVs might be very economical compared to existing launch vehicles, and may compete in cost with the proposed Advanced Launch System (ALS). The NASP Joint Program Office is assessing the ability of NDVs to satisfy some of the Air Force needs[18] that the ALS is being developed to satisfy. However, in contrast to the ALS, a practical NDV would not be able to carry extremely heavy payloads (100,000 to 160,000 pounds to a low-altitude polar orbit).

Average cost would likely depend sensitively on maintenance man-hours per sortie (which is related to turnaround time) and useful life. Aircraft that push technology to the limit to increase speed and altitude to perform novel missions often have greater-than-predicted operating cost and shorter-than-predicted useful life (see ch. 5). The A-11, SR-71, and the Space Shuttle programs illustrated that maintenance man-hours per sortie for such aircraft cannot be estimated with confidence before considerable operational experience has been obtained, and useful life cannot be estimated with confidence before several vehicles have been retired or lost by attrition.

Even if NDVs were more costly than ALS for space transportation, they could be judged worthwhile if they are necessary or uniquely economical for military missions, such as surveillance from orbit. The NASP Joint Program is assessing the ability of NDVs to satisfy needs for a military aerospace vehicle for the Air Force Space Command and a military space flight capability for the Strategic Air Command.

The value and urgency of meeting these needs is difficult to quantify; earlier stated needs for military spaceplanes have gone unmet, with debatable but not catastrophic effect on national security. For example, in 1958 the Air Force proposed development of a rocket-powered spaceplane, the Dyna-Soar. It was to include 'a manned capsule with glide interceptor and satellite interceptor, together with global reconnaissance and global bombardment subsystems. The global bombardment capability was to augment the Atlas, Titan, and Thor missiles then in development. The Air Force Deputy Chief of Staff for Development wrote that the Dyna-Soar and four other proposed space programs, including a Lunar Base System and an Advanced Reconnaissance System with a crew-carrying space station, were "essential to the maintenance of our national position and prestige.' '[20] Development of the Dyna-Soar was approved, but in 1963, halfway through the program, Secretary of Defense Robert McNamara canceled the program, arguing that its objectives

[17] "Turnaround time" is the time between a landing and the next take-off of the same vehicle.

[18] Air Force Space Command, *AFSPACECOM Statement of Operational Need (SON) 005- 88 for an Advanced Launch System (AILS),* Aug. 12, 1988.

[19] In forthcoming analyses of the potential economic benefits of NDVs and (he ALS, it will be important to note whether, in estimating the savings achievable by using NDVs or the ALS instead of existing launch vehicles, the same payloads are assumed to be launched on both systems.

[20] M.E. Davies and W.R. Harris, *RAND's Role in the Evolution of Balloon and Satellite Observation Systems and Related U.S. Space Technology,* R-3692-RC (Santa Monica, CA: The RAND Corp., September 1988), p. 96.

could be met with the Manned Orbital Laboratory, which was then just beginning and was later canceled.[21] The value of NDVs will have to be weighed against the ability of other systems to accomplish the Nation's requirements for space transportation.

[21] Clarence J. Geiger, "The Strangled Infant: The Boeing X-20A Dyna-Soar," in Richard P. Hallion, *The* Hypersonic *Revolution, vol. 2* (Wright Patterson Air Force Base, OH: ASD Special Staff Office, 1987),