Chapter 4

Existing Launch Systems

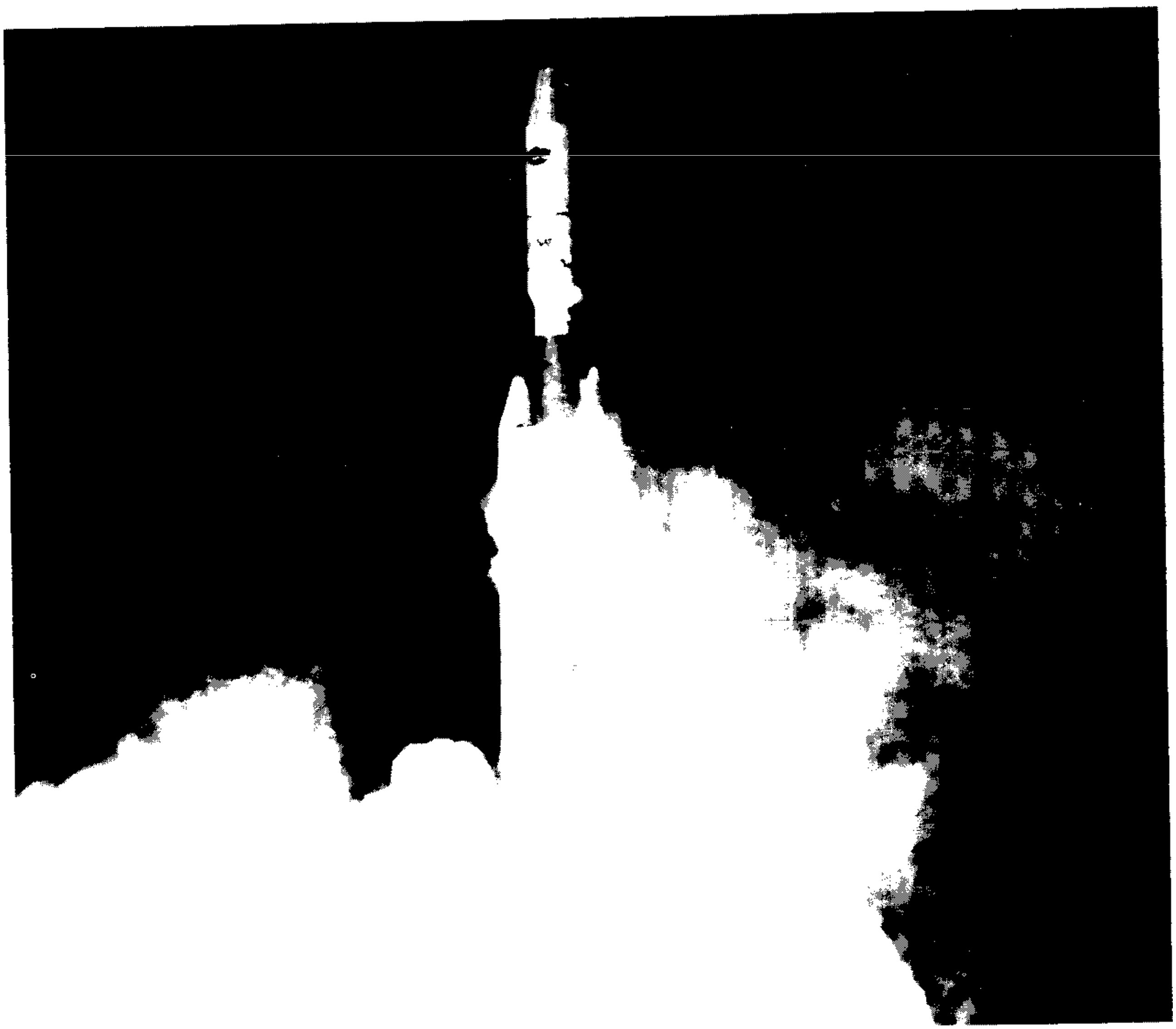


Photo credit: U.S. Air Force

The first commercialTitan lifts off from space launch complex 40 at Cape Canaveral Air Force Station. This commercial Titan carried a Japanese communications satellite and a Skynet communications satellite for the British Defense Ministry.

Chapter 4

Existing Launch Systems

EXPENDABLE LAUNCHERS

Originally developed in the 1960s from intermediate-range ballistic missiles (IRBMs) and intercontinental ballistic missiles (ICBMs), the three primary U.S. expendable launch vehicles (ELVs) have evolved into launchers capable of launching payloads of 7,600 pounds to 39,000 pounds into low Earth orbit (LEO)-(figure 1-1).[1] Though the Delta II, Atlas II, and Titan 111 were developed with Government funds, commercial versions of these vehicles are now owned and operated by private fins, which sell launch services to the Government and other domestic and foreign buyers (box 4-A). The U.S. Air Force owns and launches the Titan N. The Air Force also operates the launch complexes for all medium-lift ELVs, whether for Government or commercial launches.[2]

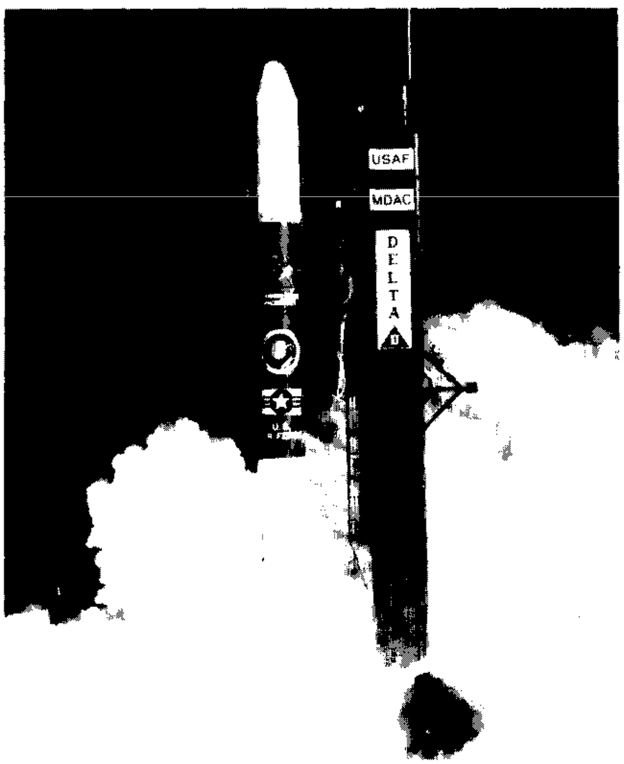


Photo credit: McDonnell Douglas Corp.

Delta expendable launch vehicle, lifting off from Cape Canaveral Air Force Station, carrying the Delta Star (Wooden Stake") Spacecraft for the Strategic Defense Initiative Organization.

Until the Shuttle was developed, these ELVs were the only means the United States had for placing payloads into orbit. During the early 1980s, when the United States was pursuing a policy to shift all payloads to the Shuttle, the Government decided to phase ELVs out of production. Although the Government had in theory turned its ELV fleet over to the private sector for commercial exploitation, it had priced Shuttle launch services so low that private launch companies were unable to make a profit competing with the Government.[3] However, following the loss of *Challenger*, policymakers realized that policies that forced reliance on a single launch system and prevented private launch companies from entering the market were unwise.[4] Hence, the Nation now follows a policy requiring a “mixed fleet” (both Shuttle and ELVs) to support Government needs, and a concomitant policy encouraging private ownership and operation of ELVs. The Commercial Space Launch Act of 1984 (Public Law 98-575), assigned the Department of Transportation (DOT) responsibility for overseeing commercial ELV operation.

THE SPACE SHUTTLE

Designed to carry crews as well as cargo to space, the Space Shuttle is a piloted vehicle capable of lifting 52,000 pounds to LE0.[5] It is the Nation’s largest cargo carrier. It was the world’s frost partially reusable Earth-to-orbit launch vehicle. Begun in 1972, the Space Shuttle was first launched in April 1981. As of February 15, 1990, NASA has launched the Shuttle 33 times, but experienced one tragic failure when one of *Challenger’s* Solid Rocket Boosters burned through in January 1986.

[1] For example, a series of upgrades has increased the Delta’s payload capability from several hundred pounds to 7,600 pounds (for the Delta 3920).

[2] The launch services companies reimburse the Air Force for use of the launch complexes for commercial launches.

[3] See the extensive discussion of Shuttle pricing in the mid-1980s and the contradictory policy of *encouraging* the *private* sector in: U.S. Congress, Office of Technology Assessment, *International Cooperation and Competition in Civilian Space Activities, OTA-ISC-239* (Springfield, VA: National Technical Information Service, July 1985), ch. 5.

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

[5] To a standard orbit 110 nautical miles high, at 28.5” inclination.

Box 4-A—US. Medium-Lift Expendable Launch Vehicles

- *Delta II is the* latest in a series of Delta ELVs manufactured by McDonnell Douglas. First launched in 1960, carrying a 137 pound payload (Echo IA), the Delta has undergone a long series of improvements that have increased its payload capacity to over 11,000 pounds to LEO, or 4,000 pounds to geosynchronous transfer orbit (GTO). It is powered by a liquid core engine (kerosene/liquid oxygen) and strap-on solids, Originally developed for NASA, the Delta launchers are now owned and operated by McDonnell Douglas as commercial launchers. McDonnell Douglas carried out the first U.S. commercial satellite launch on August 27, 1989, by launching the Marcapolo I direct broadcast satellite for British Satellite Broadcasting on a Delta 4925. It plans seven commercial launches in 1990.
- *Atlas 11* ELVs are manufactured by General Dynamics for the Air Force. The Atlas II can place about 14,500 pounds in LEO and over 6,000 pounds in GTO. A commercial version of the Atlas, designated the Atlas I, is also available. Both versions are powered by a first-stage liquid engine burning kerosene (RP-1), and a second-stage liquid hydrogen/liquid oxygen Centaur engine. Solid motor strap-on boosters provide extra lift for the Atlas II. The first commercial Atlas is expected to be launched in the summer of 1990, carrying a NASA payload—the Combined Release and Radiation Effects Satellite.
- Titan III is the commercial version of the Titan III originally built to Air Force specifications by Martin Marietta. The Titan III design derives directly from Titan II, which was used as an intercontinental ballistic missile by the Air Force, his propelled by a liquid core motor using hyperbolic liquids and two solid rocket motors mounted on either side. Titan III is capable of delivering 32,500 pounds to LEO, and about 4,000 pounds to geosynchronous orbit, In the near future, Martin Marietta plans to increase the thrust of the solid rocket boosters to allow delivery of 40,000 pounds to LEO. The relatively high capacity of the Titan IIIq makes it possible to launch two communications satellites to geosynchronous orbit Commercial Titan, Inc., a division of Martin Marietta, markets the Titan III. It uses Air Force launch facilities at Cape Canaveral (on a cost-reimbursable basis). The first commercial Titan III flight took place December 31, 1989, and sent two communications satellites to GTO.
- Titan IV is an ungraded version of the Titan III launch vehicle, manufactured for the Air Force by Martin Marietta. Capable of carrying 39,000 pounds of payload to LEO, the Titan IV is also powered by a liquid main engine and two solid rocket motors. The Titan IV successfully completed its maiden flight on June 14, 1989. In 1992, the Air Force plans to add improved solid rocket motors that will boost Titan IV performance to 48,000 pounds.

SOURCE: Office of Technology Assessment, 1990.

The United States today depends entirely on the Space Shuttle for transporting crews to and from space. In space, the Shuttle functions as a vehicle for launching spacecraft, and also serves as a platform for experiments in science and engineering. During the late 1990s, 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 section summarizes the major issues related to maintaining and improving the Space Shuttle.

Shortcomings of the Space Shuttle

The heavy U.S. dependence on the Space Shuttle raises questions concerning the longevity of the Shuttle fleet and the risk that orbiters might be unavailable when needed.

- *NASA Flight Schedule.* NASA has estimated that 14 Shuttles can be launched per year from the Kennedy Space Center with existing facilities,[6] yet it has never launched more than 9 Shuttles per year. Some experts[7] doubt that 14 launches per year can be sustained with a 4-orbiter fleet without adding new facilities and launch operations staff.

[6] Enclosure t. letter from Darrell R, Branscome, NASA Headquarters, to Richard DalBello, Office of Technology Assessment, Mm. 31, 1988.

[7] National Research Council, Committee on NASA Scientific and Technological Program Reviews, Post-Challenger *Assessment of Space Shuttle Flight Rates and Utilization* (Washington, DC: National Academy Press, October 1986), p. 15; Aerospace Safety Advisory Panel, *Annual Report* (Washington, DC: NASA Headquarters, Code Q-1, March 1989), p. iv.

Keeping the "turnaround time," or total shifts required to prepare an orbiter again for launch after a flight, short is essential for reducing the cost per flight and increasing the sustainable flight rate. NASA will have difficulty reaching and sustaining a rate of 14 flights per year unless it is able to find ways of sharply reducing its current turnaround time.[8] Its present goal of 14 flights per year assumes a processing schedule having little margin for contingencies. Yet NASA is not achieving the reductions of turnaround time it had anticipated, especially for the orbiter.[9] In addition, some NASA officials have expressed concern that the planned 90-day standdown for each orbiter every 3 years, to make structural inspections and modifications, may not be sufficient to accomplish all necessary work.

- *lnflexibility.* If NASA were to prove capable of launching 14 Shuttle flights per year, scheduling launches at the maximum sustainable launch rate would leave no margin to accommodate a sudden change in launch plans or to fly extra missions on a surge basis.[10] If more margin were reserved in Shuttle launch schedules, an orbiter could be on hand to be outfitted quickly for an unplanned mission. However, even with more margin, preparing an orbiter for an unscheduled mission, such as a Space Station rescue, could take as long as a few months because of the lead time required for mission planning, orbiter processing, and crew training.[11] **If the Nation wishes to improve the safety of its crew-carrying space flight program while increasing its flexibility, NASA and the Defense Department will have to allow more margin in Shuttle launch schedules (which implies fewer launches per year) and provide alternative ELVs.**
- *Risk of Attrition.* Each time NASA launches the Shuttle it incurs a risk of losing an orbiter from equipment failure or human error. The Shuttle's success rate is 32 out of 33 flights, or 97 percent (table 2-2).[12] Estimates of Shuttle reliability generally vary between 97 and 99 percent. For example, the late Richard Feynman, a member of the Presidential Commission appointed to investigate the *Challenger* accident, called the Shuttle ". . .relatively unsafe. . . . with a chance of failure on the order of a percent."[13] A **NASA contractor estimated that** *post-Challenger* Shuttle reliability lies between 97 and 98.6 percent, with the most likely cause of failures identified as propulsion failures during ascent.[14] One NASA division estimated that on the Galileo mission, which was launched October 1989, the orbiter had a 99.361 percent probability of remaining intact until deployment of the Jupiter-bound Galileo space probe began,[15] yet another NASA division estimated the probability would likely lie between 35 in 36 (97.2 percent) and 167 in 168 (99.4 percent).[16] **If Shuttle reliability is 98 percent, launching Shuttles at the rates now planned would make it unlikely that Space Station assembly could begin before another orbiter is lost (figure 4-l).**

Options for Reducing the Risks of Depending on the Shuttle

- *Reduce the Shuttle flight rate. The* Nation could restrict Shuttle payloads to those requiring human intervention, and fly other payloads on ELVs.

[8] For instance, NASA is designing the Advanced Solid Rocket Motor, which is now under development, to be capable of much quicker assembly than the existing redesigned solid rocket motors.

[9] NASA Kennedy Space Center briefing, Apr. 26, 1989.

[10] When a launch accident or other incident causes a long delay in spacecraft launches, it may become necessary or prudent to fly off any backlog of payloads as quickly as possible after recovery in a "surge" of launches.

[11] Normally, Shuttle crews, payloads, and specific orbiter are chosen up to 2 years prior to a flight, in order to provide enough time fOr payload integration and crew training.

[12] For comparison, success rates experienced by expendable launch vehicles range between 85 and 95 percent (table 2-2).

[13] "Report of the Presidential Commission on the Space Shuttle *Challenger* Accident," app. F. (Washington, DC: U.S. Government Printing Office, 1986); R.P. Feynman, *What Do You Care What Other People Think? (New York, NY:* W.W. Norton & Co., 1988), p. 236.

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

[15] General Electric Astro Space Division, *Final Safety Analysis Report II for the Galileo Mission,* doc. 87 SDS4213 (Valley Forge, PA: General Electric Astro Space Division, August 1988). However, NASA supplied no rationale for its estimates of failure probabilities from which General Electric calculated this probability, and NASA instructions had the effect of masking the overall uncertainty.

[16] NASA Headquarters, Code QS, *Independent Assessment of Shuttle Accident Scenario Probabilities for the Galileo Mission,* vol. 1, April 1989. The probability of orbiter recovery after the Galileo mission would k comparable to the mission success probability, because the most likely causes of a mission failure would probably destroy the orbiter,

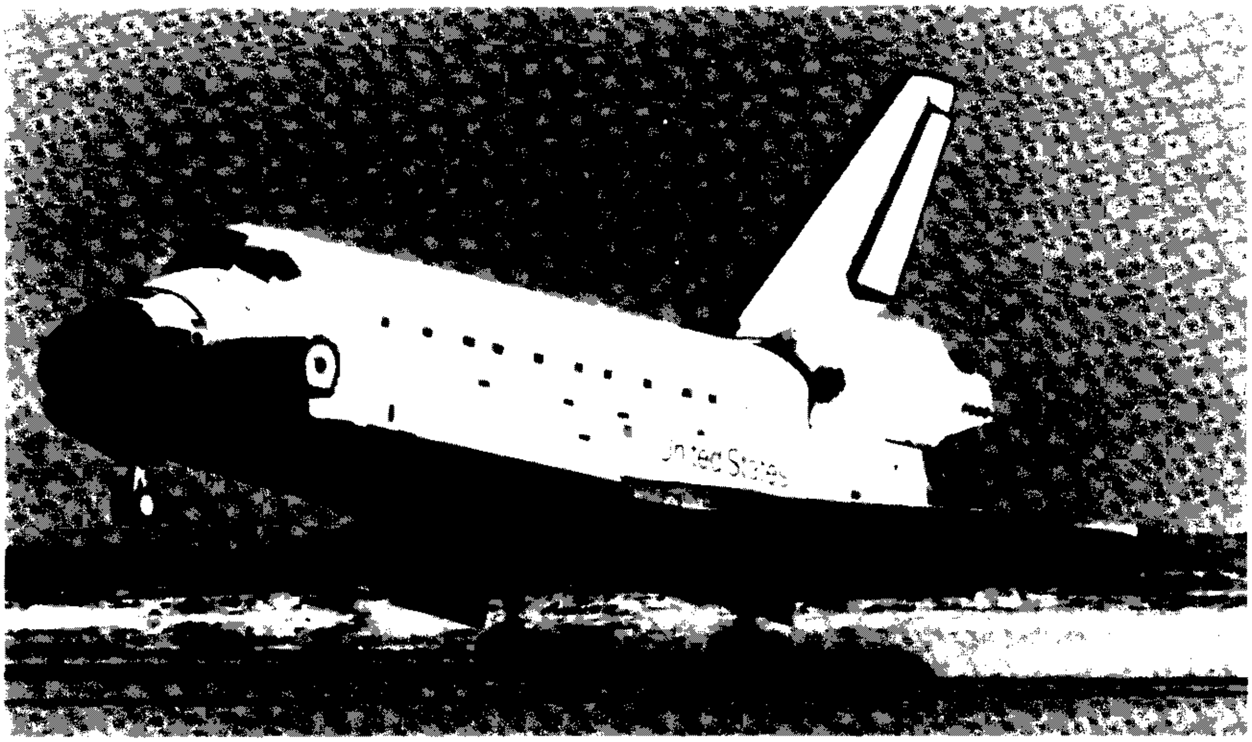


Photo credit: National Aeronautics and Space Administration

Space Shuttle orbiter *Atlantis* lands at Edwards Air Force Base after completing a successful 5-day mission in which astronauts deployed the Galileo planetary spacecraft, destined for Jupiter.

This would reduce the Shuttle flight rate and orbiter attrition. For example, the recently launched Galileo spacecraft, which is destined to explore Jupiter's atmosphere and moons,[17] could have been launched on a Titan III or Titan IV. Except for many materials processing or life science experiments, which require human attention, most payloads could be launched on unpiloted vehicles. The Air Force has now remanifested most of its payloads previously scheduled for the Shuttle on the Titan IV, which made its maiden flight on June 14, 1989.[18]

- *Purchase one or more additional orbiters.* If it is judged more important to have four orbiters available in the mid-1990s than to have high launch rates now, Congress may wish to allow for the potential loss of an orbiter by ordering one or more additional orbiters as soon as possible and limiting Shuttle launch rates.

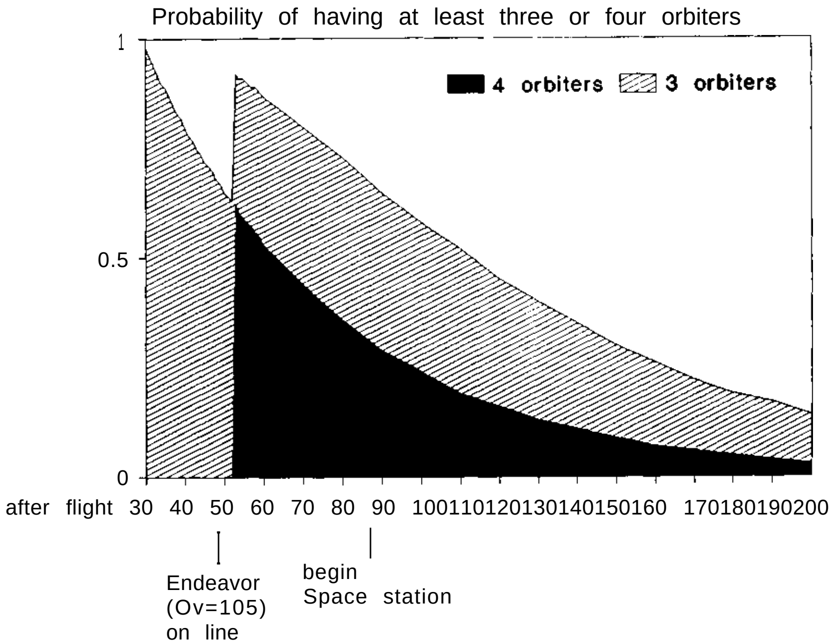
- *Improve the safety and reliability of Shuttle orbiter.* Purchasing an additional orbiter of the same design as *Endeavour (OV-1O5),* which is scheduled for delivery in 1991, would not reduce the risks to which Shuttle orbiters, crews, and payloads are now exposed. However, the safety and reliability of the orbiter could be improved (table 4-l). In addition, the orbiter could be modified to remain in orbit longer by adding additional life support equipment, and to carry additional payload by substituting lighter materials in current structures.

- *Improve the reliability of other Shuttle components.* As the *Challenger* loss demonstrated, the safety of the crew may depend critically on the reliability of systems other than the orbiter and on the practices and judgments of personnel. NASA has already improved the design of the solid rocket booster that failed during *Challenger's* last

[17]Launched on Oct. 18, 1989 on the orbiter *Atlantis*. Once Galileo was designed for launch on the Shuttle, changing it to allow launch on an ELV would have been prohibitively expensive.

[18]Considerable additional experience With assembling, processing, and launching Titan IV will be necessary before it will be considered an operational vehicle.

Figure 4-1-Probability of Retaining 3 or 4 Shuttle Orbiters Over Time



Shuttle reliability is uncertain, but has been estimated to range between 97 and 99 percent.[1] If the Shuttle reliability is 98 percent, there would be a 50-50 chance of losing an orbiter within 34 flights. At a rate of 11 flights per year, there would be a 50 percent probability of losing an orbiter in a period of just over 3 years. The probability of maintaining at least three orbiters in the Shuttle fleet declines to less than 50 percent after flight 113.

Although loss of an orbiter would not necessarily result in loss of life, it would severely impede the progress of the civilian space program, as it would likely lead to a long standdown of the orbiter fleet while the cause of the failure as determined and repaired.

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

SOURCE: Office of Technology Assessment, 1990

ascent and successfully employed the redesigned solid rocket motors (RSRMs) in 8 flights since September 1988. NASA is currently working on an Advanced Solid Rocket Motor (ASRM) that will replace the RSRM. It has also studied the feasibility of replacing the Shuttle's solid rocket motors with Liquid Rocket Boosters (LRBs). NASA's studies indicate that developing Shuttle LRBs might cost about twice as much ($3 billion) as developing ASRMs. Nevertheless, LRBs may be safer than ASRMs because liquid engines can be ignited and checked before lift-off, then shut off if faults appear.[19] If one, or even two, liquid engines were to fail after lift-off, they could be shut down, allowing the Shuttle to land at an alternative landing site. They can even be throttled during launch without incurring loss of life. Although a solid rocket motor could be designed to have its thrust terminated during flight, doing so on the Shuttle would lead to destructive thrust

Table 4-1-Selected Possible Improvements for New Orbiters

Safety end reliability
- Improved propulsion
- Simplified hydraulics
- Increased strength skins
- Improved attitude control
- Suppressed helium overpressure

Cost reductions
- Simplified cooling
- Modernized crew displays
- Improved tile durability
- Modernized telemetry

Performance
- Extended duration orbiter
- Weight reduction
- Local structure strengthening
- Global Positioning Satellite receiver-computer for navigation

SOURCE: Rockwell International Corp. and Office of Technology Assessment, 1990.

[19] Richard DeMeis, "Liquid Lift for the Shuttle," *Aerospace America*, February 1989, pp. 22-25.

imbalance.[20] NASA is currently conducting studies to understand the potential benefits and drawbacks from substituting LRBs for solid rocket motors.

A Shuttle Improvement Program

Making major Shuttle enhancements on an individual project-by-project basis may not be the most efficient way to improve the Shuttle system. To choose one improvement may mean not pursuing another, worthwhile avenue. However, having a versatile, capable launch fleet that provides reliable human access to space will be essential if Congress wishes to maintain a policy of supporting the human presence in space. Hence, **Congress may want to consider an integrated approach to strengthening the Nation's space transportation capability by funding a Shuttle Improvement Program (table 4-2) lasting, for example, 10 years.** Such a program could include development of advanced solid rocket boosters, liquid rocket boosters, and the Shuttle-C, as well as additional, more modest, improvements summarized in box 4-B. To support this sort of program, which could cost as much as $850 million per year for 10 years above the current projected cost of the Shuttle program, would require finding extra space program funding, scaling down the Space Station program, or deferring other programs. In addition to leveling out budgetary requests for the 10-year period of the program, an integrated improvement program could lead to the development of technologies and systems that would be needed for new crew-carrying systems should Congress decide to pursue a more ambitious space program in the future.

SMALL LAUNCH SYSTEMS

Most of the Government's attention has focused on medium- or heavy-lift launch vehicles.[21] However, recent interest in lightweight spacecraft, designed for a range of specialized activities, such as store-forward communications, single-purpose remote sensing, and materials processing research, has generated a concomitant interest in small vehicles to launch them. Launchers of this class are particularly appropriate for private sector development, as the costs and risks are modest compared to higher capacity launch systems. If small payloads prove effective for a wide variety of military and civilian uses, the demand for small launchers could grow substantially.[22]

Photo credit: Orbital Sciences Corp. and Hercules Corp.

An artist's conception of the Pegasus air-launched vehicle ascending to orbit after being launched from an aircraft.

- *Scout.* Originally developed in the late 1950s and early 1960s, the Scout launcher is capable of carrying about 600 pounds to LEO. Scout is a four-stage vehicle, propelled by solid rocket motors, which is manufactured by the LTV corporation under contract to NASA. As soon as the remaining vehicles have been flown, NASA will retire it from service, unless LTV,

[20] See U.S. Congress, Office of Technology Assessment, Round Trip *to Orbit: Human Spaceflight Alternatives*, OTA-ISC-419 (Washington, DC: U.S. Government Printing Office, August 1989), pp. 45-48 and app. A, for a detailed comparison of solid and liquid engines.

[21] However, the relatively small Atlas-E (1,750 pounds to low-Earth Polar orbit) and Titan 11 (4,200 pounds to low-Earth Polar orbit) launchers, which originally served as intercontinental ballistic missiles, have been used to launch a variety of Government payloads. Neither of these vehicles are available for commercial use or for launching non-Government payloads.

[22] Lawrence H. Stern et. al., *An Assessment of Potential Markets for Small Satellites* (Herndon, VA: Center for Innovative Technology, November 1989); "Lightweight Launches to Low Orbit: Will a Market Develop?" *Space Markers,* Summer 1987, pp. 54-58.

Table 4-2-A Possible Shuttle Improvement Program

Options	Cost	Benefit
Orbiter improvements:		
Develop alternate turbopumps for Space Shuttle main engines	$228 million[a]	Safety andeoonomy
Automate orbiter for unpiloted flight	$200 million[b]	Safety
Extend orbiter flight duration	$120 million	Utility
Built-in test equipment[c]	[?][c]	Safety and economy
Booster improvements:		
Increase thrust of redesigned solid rocket motor (RSRM)	$50 to $60 million	More payload
Continue to develop advanced solid rocket motor (ASRM)	$1.3 to $1.8 billion	Safety and more payload
Develop liquid rocket booster (LRB)	$3.5 billion	Safety and more payload
Other elements:		
Develop lightweight external tank	[?]	More payload
Complementary Vehicles:		
Develop Shuttle-C	$1.5 billion	For cargo
Develop capsule or lifting body for Space Station escape	$0.7 to $2 billion	Safety

[a]Already funded by NASA.
[b]Only $30M to $40M for each additional orbiter.
[c]See OTA-TM-ISC-28, *Reducing Launch Operations Costs.*

NOTE: Most of these options would increase Shuttle payload capability, but by different amounts; their other benefits and their dates of availability would differ. Therefore, two or more options might be pursued, for example, ASRMS to increase Shuttle payload capability and LRBs for increased safety and reduced environmental impact.

SOURCE: Office of Technology Assessment, 1990.

or some other private firm, decides to offer it commercially .23 On a cost per pound basis, Scout offers a relatively expensive way to reach space ($12,000 per pound).

- *Pegasus. The* Lightsat program, initiated by the Defense Advanced Research Projects Agency (DARPA), has created a market for at least one new small launcher, the Pegasus, capable of launching between 600 and 900 pounds to LE0.[24] Pegasus is a three-stage, solid-fuel, inertially guided winged rocket that is launched from a large aircraft. It is the first all-new U.S. launch vehicle design since the 1970s, though it depends heavily on propulsion and systems originally developed for intercontinental ballistic missiles; it uses engines designed for the Midgetman ICBM.

Pegasus has been developed as a joint venture between Orbital Sciences Corp. (OSC) and Hercules Aerospace Co., and funded entirely with private capital. DARPA negotiated a price of $6 million per launch for a possible six launches. The Air Force has assumed responsibility for the oversight of the launch of Pegasus for Government payloads. To date, two launches have been ordered; the first one, which will carry two payloads, is scheduled for spring 1990.

A mobile launch system such as Pegasus could provide a survivable means for launching small military satellites in wartime to augment satellites launched in peacetime or replace any satellite damaged by anti-satellite weapons. However, the Department of Defense has not stated a need for a survivable launch capability. The first flights of Pegasus will employ a B-52 as the carrier. OSC plans to acquire a large commercial aircraft, such as a Lockeed L1011, to serve as a launch platform for commercial flights.[25]

- *Industrial Launch Vehicle,* The American Rocket Company (AMROC) is developing a family of suborbital and orbital rockets, called the Industrial Launch Vehicle, powered by a hybrid, solid-fuel/liquid-oxygen engine. AMROC's hybrid design uses liquid oxygen to burn nonexplosive solid propellant similar to tire rubber. Such hybrids would have some safety advantages and might be allowed in areas where conventional solid- or liquid-fuel rockets are not. They could, for example, be used to launch small satellites from mobile

23LTV and the Italian corporation SNIA BPD are discussing developing an upgraded Scout H, capable of launching about 1,200 pounds to LEO at a cost of about $15 million per mission.

24Joseph Alper, "Riding an Entrepreneurial Rocket to Financial Success," *The Scientist,* July 25, 1988, pp. 7-8.

25On a per-pound basis, Pegasus currently costs $6,000 to $10,000 perpound of payload, which is much higher than competing, larger launch systems. However, for some customers, the ability to launch from many different locations and relatively quickly (once the concept has been proven and operational procedures are streamlined) will outweigh the relatively high per pound cost of the Pegasus.

Box 4-B—Maintaining and Improving the Current Shuttle System

Buying Additional Orbiters

Three basic options are available:

- *Build a copy of OV-]05*
  The Challenger replacement (OV-1O5), already being built includes several important improvements:
  -addition of an escape hatch and pole;
  —improved heat shielding tiles, strengthened landing gear, wing structure, and engine pod;
  —more than 200 internal changes, including electrical rewiring and improvements in the braking and steering systems.
- Implement additional *improvements*
  —safety/reliability;
  -cost reduction; and
  —performance.
  (Some of these upgrades may involve structural changes, and therefore could not be made in existing vehicles.)
- Reduce *airframe* weight-Orbiter airframe weight reduction of 8,000 to 10,000 pounds could be achieved through the use of:
  -composite materials;
  —alloys;
  —*intermetallic* alloys; and
  —high-temperature metallics.

Incremental Changes

Some alterations to the Space Shuttle system have already been accomplished, or are already underway:

- *Redesigned Solid Rocket Motors (RSRMs)*
- *Space Shuttle Main Engine Improvements*—Specific efforts directed at longer life and higher reliability include improved:
  —welds;
  —manufacturing techniques;
  -nondestructive testing;
  —heat exchangers;
  --controllers;
  -engine health monitoring; and
  —-turbopumps.
- *On-Board Computer Upgrades-Specific efforts* include:
  —identical computer modules 'mass-produced" for economy,
  --connection by optical fibers, and
  —a high degree of fault-tolerance.

Other improvements NASA has considered or is now working on:

- *Extended Duration Orbiter* (EDO)-NASA is building in the capacity to extend on-orbit stays from the current 7 days to 16-28 days.
- *Automatic Orbiter Kit—An existing* Shuttle orbiter could be given the capability to fly an entire mission automatically without a crew.
- *Operation Improvements-Introducing* a numb&r of new technologies and management strategies to make Shuttle launch operations more efficient and cheaper, e.g., improved Shuttle tile inspection and repair, and expert systems for control.

Major Changes

Some candidates include:

- *Advanced Solid Rocket Motors (ASRMs)--These* would replace the existing RSRMs. Compared to the RSRMs, they offer:
  —up to 12,000 pounds additional lift capacity,
  --better manufacturing reproducibility,
  —reduced stress on the Space Shuttle Main Engines,
  —potentially higher reliability, and
  —potential for enhancing competition.
- *Improve Redesigned Solid Rocket Motors—l%* existing RSRMs could be improved further by redesigning them to increase their thrust. The Shuttle's payload capacity could be increased by 6,000 to 8,000 pounds by substituting a more energetic solid propellant and by making other requisite changes to the motors.
- *Liquid Rocket Boosters (LRBs)--They* would replace the solid boosters on the Shuttle. Compared to RSRMs, LRBs offer:
  —safer abort modes;
  -up to 20,000 pounds additional lift capacity;
  —long history, potentially greater mission reliability;
  -capability of changing mission profiles more easily;
  —safer Shuttle processing flow;
  —-potential application as an independent launch system; and
  —better environmental compatibility.
- *Materials improvements-'l'he* emphasis on improved materials has focused particularly on saving weight. For example, using aluminum-lithium (A1-Li) for the external tank instead of the present aluminum alloy could provide a 20 to 30 percent weight savings. Using composite materials in the orbiter wings and other parts could save an additional 10,000 pounds.
- *Crew Escape Module—This* would allow for safe escape over a larger portion of the liftoff regime than now possible. It would replace the escape pole system presently in place, but would be heavier and much more costly.

launchers. AMROC's first attempted launch of its hybrid system on October 5, 1989 was aborted when a liquid oxygen valve failed to provide enough oxygen to support adequate thrust.[26] Significantly, the rocket neither exploded nor released toxic fumes, demonstrating one of the safety features of using hybrid systems. Instead, it burned on the pad, doing relatively little damage to the pad (between $1,000 and $2,000) or to the two payloads it was to carry on a suborbital flight. AMROC has several customers interested in its launch vehicle, but to date has no firm launch contracts.[27]

- *Standard Small Launch Vehicle (SSLV). The* SSLV is being developed by the Defense Advanced Research Projects Agency (DARPA). DARPA recently awarded a contract for purchase of SSLV launch services to Space Data Corp., a division of Orbital Sciences Corp. The first stage of Space Data's Taurus SSLV will be the first stage of an MX missile booster; the three upper stages of this vehicle will be the same solid rocket engines that power the Pegasus. Taurus is designed to carry a 1,500 pound satellite to a 400 nautical mile polar orbit, or a 3,000 pound spacecraft to LEO. It could even be used to launch an 830 pound satellite to geosynchronous transfer orbit.[28] Taurus will be fully transportable and capable of being launched quickly on a few months notice from a variety of launch sites. The first DARPA demonstration launch is scheduled for July 1991. DARPA holds options for four future flights on Taurus.
- *Conestoga.* Space Services Inc. (SSI) is developing a family of launch vehicles called Conestoga, which will use Castor solid rocket motors strapped together indifferent configurations to achieve payload lift capacities of 900 to 2,000 pounds to polar orbit and 1,300 to 5,000 pounds to LEO. Launch services to LEO will cost $10 million to *$20* million, depending on payload size and vehicle configuration. To date, SS1 has no firm orders for launch services on Conestoga, although it has several prospects. SSI successfully launched its Starfire I, the first U.S. commercial sounding rocket on March 29, 1989. However, on November 15, 1989, the second sounding rocket flight failed.
- *EPAC "S" Series.* E'Prime Aerospace Corp. (EPAC) is developing a series of ELVs propelled by rocket motors developed for the MX. EPAC is offering seven different launch vehicle configurations capable of placing payloads of up to 36,000 pounds in LEO. Prices charged commercial customers will range from $18 million (for 5,781 pounds to LEO) to $84 million (for 36,138 pounds to LEO). Government prices would be lower.[29] It plans to make its first orbital launch of the S-1 in 1991.

Other companies, both large established firms and smaller, startup companies, have offered small launch vehicle designs in the launch services market. Lockheed Missiles and Space Co. has designed a launch vehicle that would use Poseidon Fleet ballistic missile components to carry 850 pounds to polar orbit or 1,200 pounds to LEO. Pacific American Launch Services, Inc., is working on the design of a single-stage, liquid oxygen-hydrogen launcher that would carry 2,200 pounds to LEO.

In addition to these U.S. examples, several foreign firms are offering to sell launch services on small launchers. For example, a consortium in northern Europe is developing a small, solid rocket-powered launcher named LittleLeo. The Soviet Union has suggested converting some of its SS-20 mobile missiles for use as small commercial launchers.[30]

The market created by DARPA made possible the development of Pegasus and Taurus. At this time, it is unclear whether private sector demand for small spacecraft will be sufficient to support a truly commerical launch market for small launchers. However, several aerospace companies, including Orbital Sciences Corp., Hughes Aircraft Corp., and Ball Aerospace Co. are working on designs for small satellites for communications and remote sensing, which will test market potential over the next few

[26]The liquid oxygen valve failed to open sufficiently, probably as a result of heavy icing m the relatively humid climate of Vandenberg Air Force Base where the test launch was attempted. Michael A. Dornheim, "Amroc Retains Key Personnel Despite Cutbacks After Pad Fire, ''Aviation *Week and Space Technology,* Oct. 30, 1989, p. 20.

[27]James Bennett, AMROC, December 1989.

[28]"Pegasus, MX Boosters Combined for New Defense Launch Vehicle," *Aviation Week and Space Technology,* Sept. 18, 1989, pp. 47-48.

[29]Bob Davis, EPAC, Mar. 12, 1990.

[30]Marketed in the United States by Space Commerce Corporation.

years. The construction of non-Federal launch sites would assist the process of developing a market for small spacecraft and launchers.[31] Groups in the States of Florida, Hawaii, and Virginia have shown considerable interest in constructing launch sites for the private market.

Military demand for small launchers may be substantial, as some elements in the services are interested in developing small spacecraft for tactical surveillance and communciations. SDIO may have a near-term requirement for launching small spacecraft to support ballistic missile defense. Although the cost per pound of payload carried on small launchers is currently high, a large market for small launchers may help to bring costs down over time. However, private companies will have to amortize their development costs, which will tend to keep launch costs per pound of payload relatively high compared to larger systems for which the development costs were borne by the government years ago.

[31] However, additional launch sites might reduce the market for Pegasus by increasing availability of alternate launch sites.