Chapter 2

Current Launch Systems

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CAPABILITIES OF CURRENT LAUNCH SYSTEMS

In the early 1980s, the United States began to implement a policy that would have eventually resulted in the United States relying solely on the Space Shuttle for access to space. The Challenger disaster ensured that ELVs will again play an important role in our national launch strategy. In various stages of production are the replacement Shuttle orbiter[1] and 57 ELVs ordered by the Air Force: 23 Titan IVs, 20 Delta IIs, and 14 Titan IIs. The Air Force has reassessed its launch needs through 1995 and anticipates (as of June 1988) a need for an additional 45 ELVs –20 Titan IVS, 11 Delta IIs, 11 MLV IIs, and 3 Titan IIs. NASA plans 35 ELV and 53 Shuttle flights by the end of 1993.[2] This chapter provides a "snapshot" of current launch systems and their capabilities so that the launch system options discussed in chapters 3-5 can be compared to a baseline.

These planned flight rates represent a considerable launch capability if they can actually be achieved. Launch capacity depends not only on the lift capabilities of existing United States launch vehicles, but on their maximum production rates using present manufacturing facilities, and their maximum sustainable (steady state) flight rates at existing launch facilities.[3] As shown in table 2-1, existing manufacturing and launch facilities have sufficient capacity to meet planned flight rates for NASA and DoD ELVs, with the possible exception of the Titan IV. The Air Force has requested funds to augment Titan IV production and launch capability.

The amount of lift capacity provided by the Space Shuttle depends on how many orbiters are in the fleet and the maximum Shuttle flight rate. The calculation in table 2-1 evaluates the capabilities of a three-orbiter Shuttle fleet with a maximum annual flight rate of nine.[4]

The amount of lift capacity provided by ELVs is limited by the lower of their maximum annual production rates and their maximum launch rates. Currently, these rates limit the United States to about 12 Scout, 12 Delta II, 4 Atlas/Centaur, 5 Titan II, 4 Titan 111, and 6 Titan IV launches per year. This includes NASA, DoD, and commercial launches.

Table 2-1 shows that the maximum space launch capacity available to the U.S. using existing vehicles, facilities, and factories is roughly 860,000 pounds per year to low-Earth

1 The first flight of OV 105, the replacement fourth orbiter, is scheduled for January 1992.

2 Thirteen of those Shuttle flights are resewed for DoD payloads. U.S. National Aeronautics and Space Administration, "Payload Flight Assignments" (Washington, DC: Office of Space Flight, March 1988).

3 Launch vehicles typically come in several versions with different capabilities depending on the upper stages used. Although the launch vehicles in this figure are representative examples, they do not provide a comprehensive catalog. The performance figures cited refer to a specific version. All values are normalized to a common reference orbit; performance to other orbits will vary depending on the orbit selected.

4 Because of bottlenecks in the Shuttle processing flow, the National Research Council estimated the maximum sustainable Shuttle flight rate with a three orbiter fleet to be 8-10, and 11-13 with a four orbiter fleet. See National Research Council, Committee on NASA Scientific and Technological Program Review, Post-Challenger Assessment of Space Shuttle Flight Rates and Utilization (Washington DC: National Academy Press, October 1986).

orbit (LEO). To put this number in perspective, the United States launched about 600,000 pounds per year in the two years prior to the Challenger disaster (1984 and 1985).[5] Thus, current unimproved facilities give the United States room for limited expansion of its space launch activity.

Table 2-1. - Maximum Lift Capability of U.S. Launch Vehicles Using Existing Manufacturing and Launch Facilities

launch vehicle	**mass** delivered	**production** rate	**launch** rate[c]	capability
scout	570	12	18	6,840
Titan II	5,500	5[e]	5	27,500
Delta II (3920)	7,600	12	18	91,200
Atlas/Centaur	13,500	5	4	**54,000**
Titan 111	27,600	10	4	110,400
Titan IV	39,000	6	6	234,000
Space Shuttle	48,000[f]	n.a.[g]	9	432,000

total = 956,000 pounds

x 90 percent manifesting efficiency[h] = 860,000 pounds

[a] pounds delivered to a 100 nm circular orbit at 28.50 inclination unless otherwise noted.

[b] maximum sustainable production rate with current facilities in vehicles per year.

[c] maximum sustainable launch rate with current facilities in vehicles per year

[d] mass delivered times the lessor of the maximum production rate or the maximum launch rate

[e] In July 1988 the first of 14 planned Titan IIs (retired ICBMs converted into space launch vehicles) is scheduled for launch, with 41 other Titan IIs remaining in storage for potential conversion. Launch Vehicle Overview, Martin Marietta Launch Systems Company, Jan. 21,1988.

[f] This figure is an average of the three existing orbiters' performance to a 150 nm circular orbit (OV102: 45,600 pounds; OV103 and OV104: 49,100 pounds).

[g] Not applicable since the orbiter is reusable. No orbiter production is currently planned beyond the Challenger replacement.

[h] Vehicles often fly carrying less than their full capacity. Manifesting efficiency is the amount of lift capability that is actually used by payloads or upper stages. Volume constraints, scheduling incompatibilities, or security considerations often account for payload bays less than full by weight.

SOURCE: OTA.

5 U.S. Congress, Congressional Budget Office, Setting Space Transportation Policy for the 1990s, A Special Study (Washington, DC: Congressional Budget Office, October 1986), p. 13.

LIMITS OF EXISTING LAUNCH SYSTEMS

The previous section examined theoretical launch rates and capabilities of current systems. However, merely examining "numbers of launches" or "pounds to orbit" does not tell the whole story because existing launch systems have some very important limitations:

A lack of "resiliency" - Simply stated, resiliency is the ability of a launch fleet to maintain schedules despite failures. The resiliency of existing launch fleets was called into question by the ELV and Shuttle launch failures in 1986. In order to increase space transportation resiliency, the Nation could develop new, more reliable launch systems. Alternatively, it could make existing vehicles more reliable, reduce the period of inactivity after failures, or increase the ability to "surge" by buying extra vehicles and payloads to launch at high rates following failure. In addition, the United States could design critical payloads to enable them to be flown on more than one launch vehicle, when possible. Box 2-1, "Improving The Resiliency of United States Launch Systems," describes these resiliency options in greater detail.

High launch costs - Current launch costs are between $3,000 and $6,000 per pound delivered to low-Earth orbit. Such costs limit the amount of civilian, military, and commercial space activity that the United States can reasonably afford. For example, payload sizes in some SDI mission models are compatible with today's launch vehicles, but launch costs using current vehicles would be unacceptably high because too many launches would be required. A baseline SDI Kinetic Energy Weapon architecture calling for lifting 40 million pounds into orbit would have a transportation cost alone of $120-240 billion using today's vehicles.[6] Similarly, civilian activities that would necessitate lifting millions of pounds to orbit, such as a human expedition to Mars, would require a reduction in launch costs to be affordable.

On the other hand, the costs of payloads, which can cost between $20,000 and $60,000 a pound, may prove the ultimate limitation on the exploitation of space. As pointed out in a recent report by the Congressional Budget Office,[7] dramatic increases in launch demand would require a concomitant increase in total budget outlays in order to pay for additional payloads.

Shuttle flight rate uncertainties - The Nation has far less experience with Shuttle processing than with ELV processing. Thus, planned Shuttle flight rates may be optimistic, as has been the case in the past. In 1989, as shown in table 2-1, NASA plans nine Shuttle flights, which would tie the record for the most flights ever made in a single year with three orbiters. The added check-out procedures instituted in response to the Challenger disaster could make a return to this launch rate unlikely in the near future.

Limits on payload size - Using the Shuttle, the United States has the ability to launch payloads up to 48,000 pounds into LEO, or aboout 10,000 pounds into geosynchronous orbit.[8] Both NASA and DoD space programs could benefit from a launch vehicle with a greater lift capacity.

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6 At a launch cost of $3,000 to $6,000 per pound.

7 See U.S. Congress, Congressional Budget Office, The NASA Program in the 1990s and Beyond (Washington, DC: Congressional Budget Office, May 1988).

8 For comparison, when the Soviet Energia becomes operational it will be capable of launching about 220,000 pounds into LEO, about as much as the Apollo program's Saturn V was able to lift.

Using the present Shuttle to launch Space Station laboratory and habitation modules will limit the amount of equipment that can be integrated within the modules on the ground. The rest of the equipment will have to go up separately and be installed on-orbit. This will require a substantial amount of difficult, and potentially hazardous, extravehicular activity (156 man-hours) and on-orbit outfitting. A new vehicle with greater lift capacity would also aid in the launch of large planetary missions. Using current vehilces, missions like the proposed Mars Sample Return, would require spacecraft to be launched in several segments and assembled in orbit.

Similarly, the trend of using increasingly larger communications, navigation, and reconnaissance satellites suggests that DoD could effectively employ a vehicle with greater lift capacity than current vehicles.[10]

Box 2-1. -Improving the Resiliency of U.S. Launch Systems

After the Shuttle and ELV launch failures in 1986, the Air Force developed a theory of space transportation "resiliency" to explain the impact that launch system failures have on payloads waiting for launch.[a]

A launch vehicle failure has two principal impacts. First, it can destroy unique, expensive payloads, such as the Hubble Space Telescope or critical national security satellites used to monitor arms control agreements. Second, after a launch failure, the government orders the fleet to "stand down" until the cause of the accident is determined and corrected. A standdown creates a backlog of payloads that slows programs, limits planned missions,[b] and generates unexpected expenses.[c] Reducing the backlog can require flying launch vehicles at a higher rate than normal which, in turn, can increase the probability of failure.

To increase the resilience of its launcher fleet, the United States could pursue one or more of the following alternatives:

- *Develop new, more reliable launch systems* – Some government and industry experts believe that technology available today could be incorporated into designs for new launch vehicles, making them more reliable and faster to prepare and launch than current vehicles. Of course, developing any new space launch vehicle is a challenging task involving significant technical and financial risk.

- *Increase the reliability of current launch systems* — Where possible, some subsystems on existing vehicles could be replaced with new, more reliable subsystems, increasing the systems' overall reliability and resilience, Efforts currently underway include developing fault-tolerant avionics and upgraded solid motors for the Titan IV, and Advanced Solid Rocket Motors for the Shuttle. Still, no launch system, including the Shuttle, can be made 100 percent reliable.[d]

- *Increase current ground facilities and buy more existing launch vehicles and payloads* – When a failure occurs, the United States tends to interrupt launch activities until the malfunction can be identified and corrected. Following this stand down, the launch system must "surge," that is, fly payloads more frequently than planned, to work off the accumulated backlog. Expanding ground facilities and building additional launch pads, launch vehicles, and payloads would improve resiliency by reducing the time it takes to fly off the backlog and return to normal operations.

9 National Research Council, Report of the Committee on the Space Station, (Washington, DC: National Academy Press, September 1987), p. 22.

10 An Aerospace Corporation study projects that by the mid-1990s the Air Force may seek to place payloads weighing 14,000 pounds into geosynchronous orbit. This would require the ability to deliver a minimum of 57,000 pounds to LEO. Aerospace Corporation, "Air Force-Focused Space Transportation Architecture Study," Report No. TOR-0086A(2460-01)-2, August 1987.

A decision to deploy space-based ballistic missile defenses would also require vehicles capable of launching large monolithic payloads to space.

Environmental concerns - Current solid rocket motors produce hydrochloric acid as a combustion byproduct. If the Nation were to continue to use these solid rocket boosters on its launch vehicles, environmental considerations would at some point limit their allowable launch rates.[11] However, as part of the ALS technology program, researchers at the Air Force Astronautics Laboratory are studying solid propellants that not only have clean exhausts, but improved performance and lower cost than the Shuttle propellants.

The highly toxic storable liquid propellants, such as the nitrogen tetroxide and monomethylhydrazine used used to power the core engines of Titan launchers, might

- *Change U.S. policy and cease to stand down after launch failures — When* a U.S. aircraft crashes, rarely is the entire fleet of similar models grounded. The Soviet Union has generally maintained an aircraft-like "launch after failure" philosophy while the U.S.–mainly because of the high cost and unique nature of certain payloads (including piloted flights) — tends to stand down. Not standing down means that no backlog is developed and no surge is necessary. Launch systems are flown at their normal, steady-state flight rate. Most aircraft failures do not result in standdowns because of the experience base and confidence we have in aircraft reliabilities. Until we have similar confidence in launch system reliabilities it may be difficult to change this standdown policy.

- *Design payloads for flight on several launch vehicles, when possible* — If payloads and launch vehicles had compatible, interchangeable interfaces, then operational flexibility would be increased and resiliency might be increased. A critical satellite manifested for a launch vehicle currently standing down could be remanifested for an operational launch vehicle. A limitation of this option is that payloads designed for the heaviest booster in the fleet would have no backup launch vehicle. Moreover, if the backup vehicle is less reliable than the primary vehicle, there would be a greater chance of payload loss.

[a] Harry Bernstein and A. Dwight Abbott, "Space Transportation Architecture Resiliency," Working Paper, (El Segundo, CA: The Aerospace Corporation, March 1987.) A specific mix of launch systems is considered resilient if it has the ability to recover rapidly from failures, and maintain launch schedules.

b Diminishing launch capacity *can cause* delays and cancellations of lower priority (commercial and research) payloads so that the most urgent payloads (national security and planetary payloads with critical launch windows) can be flown. About 70 Shuttle equivalent flights over ten years were eliminated from the Nation's launch plans as a result of the space transportation crisis. Source: NASA, Office of Space Flight, briefing to OTA, Feb. 8, 1988.

[c] One contractor estimated the cost of the Challenger accident (including the costs of replacing the orbiter, replacing the cargo, investigating the accident, redesigning the flawed parts, and delaying the launch schedule) to be upwards of $13.5 billion.

d A recent National Research Council report stated, "... the nation must realize that the Shuttle orbiter fleet is likely to continue to suffer occasional attrition." National Research Council, *Report of the Committee on the Space Station,* (Washington DC: National Academy Press, September 1987), p. 24. Rockets will fail occasionally, sometimes catastrophically.

11 OTA has not conducted an independent analysis of the environmental effects of using the current generation of solid rocket motors at high launch rates. It has also not studied the environmental effects of liquid propellants.

cause considerable environmental concern if used at very high launch rates. Other, less toxic liquid propellants, which also produce clean exhaust products, are being studied.