Chapter 3
Enhanced Baseline

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The ENHANCED BASELINE option is the U.S. Government's "Best Buy" if . . . it desires a space program with current or slightly greater levels of activity. By making incremental improvements to existing launch vehicles, production and launch facilities, the U.S. could increase its launch capacity to about 1.4 million pounds per year to LEO. The investment required would be low compared to building new vehicles; however, the adequacy of the resulting fleet resiliency and dependability is uncertain. This option would not provide the low launch costs (e.g. 10 percent of current costs) sought for SDI deployment or an aggressive civilian space initiative, like a piloted mission to Mars,

IMPROVING THE SHUTTLE

The Shuttle, though a remarkable technological achievement, never achieved its intended payload capacity and recent safety modifications have further degraded its performance by approximately 4,800 pounds. Advanced Solid Rocket Motors (ASRMs) or Liquid Rocket Boosters (LRBs) have the potential to restore some of this performance; studies on both are underway. Other possible options include manufacturing the Shuttle External Tank (ET) out of lighter materials, and improving the Shuttle ground processing flow to increase the Shuttle's launch rate.

Advanced Solid Rocket Motors (ASRMs)

The ASRM program goals are to improve Shuttle safety and performance significantly by:

- designing the field joints to close rather than open when pressurized,
- reducing the number of factory joints and the number of parts,
- designing the ASRMs so that the Space Shuttle Main Engines no longer need to be throttled during the region of maximum dynamic pressure,
- replacing asbestos-bearing materials,
- incorporating process controls and automation to eliminate labor intensive operations and improve motor quality, reproducibility, and safety.[1]

An example of the savings potential offered by improved process control is Hercules' new, automated, solid rocket motor manufacturing facility for the Titan IV solid rocket motors. Compared to an older United Technologies facility where the workforce is around 35, Hercules can cast four times the propellant at a time with one-tenth the personnel.[2]

1 RADM Richard Truly, NASA Associate Administrator, Office of Space Flight, testimony before the House Committee on Science, Space, and Technology, Subcommittee on Space Science and Applications, on Advanced Solid Rocket Motors, April 1988.

2 Air Force Space Division, Los Angeles, CA, Briefing to OTA, Dec. 4, 1987.

ASRMs would add an estimated 12,000 pounds of lift to the Shuttle, allowing it to lift 61,000 pounds to a 150 nm orbit.[3] At the proposed Space Station orbit (220 rim), ASRMs could allow a Shuttle to lift 58,000 pounds instead of 46,000 pounds, significantly aiding Space Station deployment. The first phase of Space Station deployment is presently scheduled to take about three years and 19 Shuttle flights. With ASRMs this could be accomplished with five fewer flights in four fewer months.[4] Furthermore, if even more capability were desired, NASA could decide to develop LRBs or ASRMs capable of lifting 15,000 rather than 12,000 additional pounds.

NASA believes that ASRMs would require about 5 years and $1 to $1.5 billion for design, development, test, and evaluation. A set of ASRMs could cost $40 to $50 million, or slightly more than the cost of present Solid Rocket Boosters.[5]

Liquid Rocket Boosters (LRBs)

In parallel with the ASRM studies, NASA is studying ways to enhance the Shuttle's performance by replacing the SRBs with LRBs. Like ASRMs, LRBs could be designed to provide an additional 12,000 pounds of lift over present SRBs. In September 1987 General Dynamics and Martin Marietta began LRB conceptual design studies. The analyses will consider performance, safety, reliability, costs, environmental impact, and ease of integration with the Shuttle and launch facilities. In the early 1970s NASA compared solid and liquid booster technology for use on the Shuttle. NASA chose solids because it estimated that the liquid booster would cost from $0.5 to 1.0 billion more to develop than a solid rocket motor.[6]

LRBs should have several advantages over SRBs. A flight-ready set of LRBs could be test-fired before they were actually used on a mission. LRBs might also improve the range of launch abort options for the Shuttle, compared with existing SRBs or ASRMs. LRBs can be instrumented and computerized to detect imminent failure and to select the safest available course of action. Unlike solid boosters, that burn their fuel until spent once ignited, LRBs could be shut down or throttled up if necessary to abort a launch safely. Launch operators could also change the thrust profiles of LRBs if mission requirements dictated, while SRB segments follow a specific thrust profile once cast. One-piece LRBs should have shorter processing times than segmented SRBs, which needed about 21 days for stacking before the Challenger accident, and around 70 days for the first post-Challenger flight. LRBs might provide a more benign payload environment than SRBs as a result of their more gradual start and lower acoustic levels. These factors may also extend the orbiters' lifetimes by reducing structural stress induced by lift-off noise and vibration. LRBs would also produce less environmentally contaminating exhaust products than current SRBs and would eliminate operations involving hazardous propellants in the Vehicle Assembly Build-

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3 Even though the unaugmented orbiters (OV103, OV104, and the replacement orbiter OV105) would be capable of lifting 54,000 pounds to orbit, landing weight constraints limit their payload capacity to 49,100 pounds. The earlier, heavier orbiter (OV102) is capable of lifting only 45,600 pounds to orbit.

4 National Research Council, Report of the Committee on the Space Station of the National Research Council (Washington, DC: National Academy Press, September 1987), and Space Transportation for the Space Station, A NASA Report to Congress, (Washington, DC: NASA Office of Space Flight, January 1988), p. 12.

5 A set of two new SRBs cost $88 million (1987 dollars) refurbished SRBs cost $35 million. (Gerald Smith, NASA, Office of Space Flight, "Solid Rocket Booster Project," presentation to OTA, Jun. 23, 1987.)

6 U.S. Congress, House Committee on Science, Space, and Technology, Subcommittee on Space Science and Applications, Space Shuttle Recovery Hearings, Apr. 29-30, 1987, vol. I, p. 64.

ing. Finally, LRBs could have applications beyond just the Space Shuttle, including Shuttle-C, an Advanced Launch System, or even as a new stand alone booster with a 50,000 to 80,000 pound lift capacity.[7]

Lighter Tanks

Another way to increase the Shuttle's capability would be to make the Shuttle's External Tank out of a new alloy, such as aluminum-lithium, instead of aluminum. Aluminum-lithium offers a 20 to 30 percent weight saving compared to the aluminum alloy now used in the External Tank.[8] If the External Tanks were made of aluminum-lithium and the inter-tanks were made of graphite epoxy, the Shuttle would weigh 12,000 pounds less at lift-off.[9] Since the External Tank is carried nearly all the way to orbit, reducing the weight of the External Tank by 12,000 pounds would translate into almost 12,000 pounds of increased payload capability.

Improving Shuttle Ground Operations

Introducing a number of new technologies and management strategies into Shuttle ground operations could make these operations more efficient, faster, and cheaper. For example, introducing computerized management information systems into launch and mission control facilities could sharply reduce the amount of human effort in making, distributing, and handling paper schedules and information. It could also reduce errors and speed up sign-off procedures.

Another strategy thought to have the potential to decrease Shuttle processing time is developing "mission reconfigurable software" to accommodate rapid, high quality mission-to-mission software changes. Software writing and rewriting is presently a constraint on the Shuttle's turn-around time and consequently, its flight rate. Other improvements to Shuttle ground operations include:

- reducing documentation and oversight,
- developing expert computer systems,
- providing adequate spares to reduce cannibalization of parts,
- developing an automated Shuttle tile inspection system, and
- creating better incentives for lowering costs.

IMPROVING EXISTING ELVs

Over the years, manufacturers have incrementally improved their ELVs, increasing both their payload capacity and reliability. This process continues today as the payload capacity of each major U.S. ELV family is now being increased.

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7 General Dynamics, Space Systems Division, "An Overview of the Liquid Rocket Booster System," April 1988.

8 Boeing Aerospace Company, "Space Transportation Architecture Study," Final Report, D524-10008-1, Nov. 30,1987, pp. 106-107.

9 Boeing presentation to OTA, February 1988.

10 U.S. Congress, Office of Technology Assessment, Reducing Launch Operations Costs: New Technologies and Practices, TM-ISC-28, (Washington, DC: U.S. Government Printing Office, August 1988), covers this topic in detail. The savings produced by these technologies and management strategies depends on the launch demand.

Delta

Various Delta configurations have successfully launched 170 spacecraft to orbit as of June 1988. Incremental growth of the Delta over the years has increased its lift capacity to LEO from several hundred to 8,000 pounds.[11] McDonnell Douglas is now considering the next steps in the Delta growth plan, including improved booster engines, stretched graphite epoxy solid rocket motors, extended fuel tanks, and wider payload fairings. These modifications reportedly could increase Delta's LEO payload capacity to 11,100 pounds by the mid- 1990s, while a new LOX-hydrogen second stage could almost double Delta's current lift.[12]

Atlas-Centaur

The Atlas-Centaur presently has a lift capacity to LEO of about 13,300 pounds or about 5,100 pounds to geosynchronous transfer orbit. The Atlas-Centaur II is to have an ability to launch 16,150 pounds to LEO, or about 6,100 pounds to geosynchronous transfer orbit. This performance enhancement of almost 3,000 pounds to LEO is to be achieved by increasing the thrust of the booster engines 10 percent, stretching the Atlas propellant tanks 9 feet, and stretching the Centaur tanks 3 feet.

Titan

Martin Marietta has produced over 500 Titans since 1959 and will maintain active production lines well into the 1990s. A new, light-weight, graphite-epoxy Hercules solid rocket motor, which will be operational by 1990, should boost Titan IV's lift capacity to LEO from 40,000 pounds to 48,000 pounds. Improved fault-tolerant avionics have the potential to increase reliability. Although existing manufacturing facilities can produce 20 Titan cores per year, only 10 payload fairings can be produced per year with existing facilities.[13]

The Air Force currently plans to launch four Titan IVs per year from complex 41 at Cape Canaveral with a surge capability of six launches per year. Duplicating the pad 41 modifications at pad 40 at the Cape would allow eight launches per year and a surge of 12 per year. Combined with 2 to 3 launches per year from the West Coast, these rates would allow the Titan IV roughly 10 launches per year, matching the Titan production rate.

CAPABILITY

Table 3-1 illustrates the net effect of proceeding with some of the enhancements described in this chapter. The result is that the United States could increase its launch capacity to about 1.4 million pounds per year to LEO, more than twice as much as the United States has ever launched in one year. The Enhanced Baseline option thus could provide a relatively low-cost means of increasing U.S. lift capabilities.

However, evolutionary enhancements to existing launch systems could not provide the low launch costs (e.g. 10 percent of current costs) sought for SDI deployment or an aggressive civilian space initiative, like a piloted mission to Mars. Furthermore, uncertainty

11 Using a Delta model 6920 to reach a 150 nm circular orbit, inclined 28.5°. Delta II Spacecraft User's Manual, McDonnell Douglas Astronautics Company, Huntington Beach, CA, July 1987.

12 Bruce Smith, "McDonnell Plans Rapid Buildup of Delta Launcher Fleet Aviation Week and Space Technology, Feb. 16, 1987.

13 H. Lange, Director, Special Space, McDonnell Douglas Astronautics Company, personal communication, Apr. 6, 1988.

14 Aerospace Corporation, "Air Force-Focused Space Transportation Architecture Study," Report No. TOR-0086A(2460-01)-2, August 1987.

remains about the adequacy of the resulting fleet resiliency and dependability. Unless vehicle reliabilities are improved, increasing vehicle flight rates would lead to more frequent launch failures.

In addition, none of the options described in this chapter would provide redundant access to polar orbit for Titan-class payloads. This option would also not lessen the environmental impact of high launch rates unless the current generation of solid rocket boosters were replaced with clean burning solid motors or liquid boosters.

Table 3-1. - Theoretical Lift Capability of Enhanced U.S. Launch Systems

launch vehicle	mass delivered	production rate[b]	launch rate[c]	capability
scout	570	12	18	6,840
Titan II	5,500	5	5	27,500
Delta II (model 8920)	11,000	12	18	132,000
Atlas/Centaur 11 (MLV II)	16,150	5	4	64,600
Titan III	27,600	10	4	110,400
Titan IV with new SRMs	48,000	10	10	480,000
Space Shuttle with ASRMs or LRBs	60,225[e]	n.a.	13	782,925

total = 1,600,000 pounds

x (9O percent manifesting efficiency = 1,440,000 Pounds

[a] pounds delivered to a 100 nm circular orbit at 28.5° inclination unless otherwise noted.

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

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

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

[e] figure obtained by averaging the future four orbiter fleet's performance to a 150 nm circular orbit (OV102: 45,600 pounds; OV103, OV104, and OV105: 49,100 pounds), and adding 12,000 pounds of additional capacity from the ASRMs.

SOURCE? OTA.