Chapter 4
Interim Options

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The U.S. Government's "Best Buy" is the Interim option with . . .

1) . . . Titan IV and more manufacturing and launch facilities if the Nation wishes to increase U.S. launch capabilities but does not wish to incur the high development costs associated with new launch systems. Building more launchpads would also insure against launch failures that could destroy pads and limit the Nation's access to space. Resiliency concerns and limitations on available land for building more pads may make this option difficult to implement.

2) . . . **Titan V** if the Nation wants a vehicle to launch heavy payloads infrequently and wishes to limit development costs. Titan V would not be economical at high flight rates, and thus might be unsuitable for SDI deployment or a highly aggressive civilian space program.

3)... **Shuttle-C** if the Nation wants a new heavy lift launcher at a relatively low development cost to support the Space Station, space science payloads, polar platforms, or backup Air Force missions. Shuttle-C would not be economical at high flight rates, and thus might be unsuitable for SDI deployment or a highly aggressive civilian space program.

4) . . . **A Transition Launch System** if long-range plans indicate a need for increased launch capability by the mid to late 1990s and the Nation is willing to invest money now to lower launch costs or increase reliability to meet that demand.

INTERIM OPTION WITH TITAN IV

As one interim solution, the United States could build as many Titan IVs and Titan IV launch facilities as necessary to accommodate peak launch demand. Aggressively building new launch and manufacturing facilities would require investments of time and money comparable to those required for developing new vehicles. OTA chose the Titan IV for this option because it will have the heaviest payload capacity of all U.S. ELVs when it becomes operational.

The current Titan IV production rate is ten per year; there are two Titan IV launch pads. To meet the Expanded mission model in chapter 7 using Titan IVs would require increasing the production rate to 66 per year and building 12 additional Titan IV launch pads. Another approach would be to build fewer, high launch-rate pads, using an integrate-transfer-launch concept.[1]

Building additional launch facilities would also provide launch insurance against pad shut-downs due to launch vehicle lift-off failures. On April 18, 1986, a Titan 34D exploded shortly after liftoff raining 1.4 million pounds of debris on Vandenberg Space Launch Complex 4. Two launch pads were damaged and required almost a year to repair. Basing a space transportation strategy on an abundance of launch pads may be a

1 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), discusses various launch pad operational philosophies.

good way to ensure that the Nation can maintain access to space despite the possibility of catastrophic launch failures.

However, the Nation will face difficulties in finding sites for new launch facilities. A recent Aerospace Corporation study noted that the main problem is a lack of usable land:

> Suitable sites for processing and launching large space launch vehicles are very scarce . . . The hazards involved in overflying populated areas restrict acceptable sites to sea coast regions, the best of which are at . . . [Cape Canaveral Air Force Station, Kennedy Space Center, and Vandenberg Air Force Base]. Most of the existing launch pads were originally built in the 1950s and 1960s when environmental and social restrictions were much less severe. Satisfying the current restrictions on new construction in these environmentally sensitive areas is a complex expensive, and time-consuming task.[2]

The study pointed out that only four suitable sites remain for constructing large launch pads at existing launch bases: two at Cape Canaveral, one at Kennedy Space Center, and one at Vandenberg. Furthermore, the sites at Kennedy Space Center and Vandenberg present difficult construction problems because of the terrain and environmental restrictions.

In response to these real estate limitations, the Rowan Companies, Inc. of Houston recently proposed developing large off-shore launch platforms based on oil rig technology. The Italians currently launch small Scout rockets from such offshore platforms. However, using such platforms for large boosters would require the resolution of a variety of technical issues such as safety and fueling at sea.[3]

A simple resiliency analysis demonstrates the problem in attempting to launch large numbers of current vehicles. Titan IV launch rates of 60 per year are inconceivable given current levels of reliability (around 95 percent) and current down times following failure (6 months). At a reliability of 1 failure in 20 flights (95 percent), 60 flights per year would result in an average of 3 failures per year. If each failure required a 6 month standdown for an investigation, the system could not approach its flight rate goal.

OTA calculations in chapter 7 indicate that this option is competitive with all other options for the Low-Growth mission model. However, it is substantially less financially attractive for the Growth or Expanded mission models. In addition, this option must be regarded as infeasible at the high launch rates implied by the Growth or Expanded mission models unless appropriate launch sites can be found and resiliency improved.

INTERIM OPTION WITH TITAN V

Titan IV will be the United States' heaviest ELV and thus would be a likely candidate for growing into a heavy lift launcher.[4] Martin Marietta, Titan's manufacturer, has identified several growth options for Titan IV. Possible modifications include enlarging the booster's core diameter, adding additional first stage liquid rocket engines and additional solid rocket motors. Table 4-1 summarizes some potential options for Titan growth.

Any version of a Titan V would require some new hardware. Enlarging the core diameter would require anew core structure; adding additional liquid rocket engines and

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2 Aerospace Corporation, "Air Force-Focused Space Transportation Architecture Study," Report No. TOR-0086A(2460-01)-2, August 1987, p. 66.

3 Rowan Company Briefing to OTA staff, Feb. 25, 1988.

4 OTA has not conducted a detailed analysis of the growth potential of all existing launch vehicles. "Growing" other existing launch vehicles might have advantages. However, this subject is beyond the scope of this report.

solid rocket motors would require new thrust structures, interfaces, and analyses. In fact, transforming the Titan IV directly into a vehicle capable of placing 150,000 pounds in orbit (almost four times Titan IV's capacity) would pose systems development challenges akin to those of a brand new launch vehicle.

The low-Earth orbit payload capacities of the above vehicles range from 60,000 to 150,000 pounds, almost four times the existing Titan IV's payload capacity. While going directly from the Titan IV to a 150,000 pound payload class vehicle might pose considerable technical and schedule risk, the less dramatic upgrades should have relatively predictable development costs and schedules. Martin estimates that the time required to develop a Titan V would be between 3 1/2 and 5 years depending on which growth path is taken.[5] This might permit development of a Titan-derived heavy lift launcher sooner than either a Shuttle-C or a new ELV like the Transition launch system.

The environmental effects of the large quantities of storable liquid propellants (N_2O_4/UDMH) burned by the large core engines of a Titan V could present formidable obstacles to the acceptability of the concept.[6] Although these are the same propellants used in the other Titan vehicles, shipping and handling the large quantities necessary for the Titan V, could strain current propellant technology and create environmental concerns. Furthermore, a Titan V would not be an ideal back-up for the Titan IV and its heavy payloads because of the likely technological commonality between the two vehicles. Although such technological heritage means that a new Titan would probably share the demonstrated reliability of existing Titans, it also means problems generic to the Titan family would ground the Titan V.

Cost estimates for a Titan V are not as mature as those for Shuttle-C because the Air Force is not sponsoring Titan V studies. Accordingly, the Aerospace Corporation estimated a Titan V's development cost to range from $800 million to $3.5 billion, depending on the vehicle's size.[7] In chapter 7, OTA estimated it would cost about $1.2 billion to develop Titan V. The cost analysis of chapter 7 shows that, at the high launch rates of the Expanded mission model, this option would be generally superior to Shuttle-C and Titan IV options, but inferior to the Transition launch system or the ALS. At the launch rates found in the Low Growth and Growth mission models. the Titan V is roughlv competitive with all other options considered.

Table 4-1. -Titan Growth Options

Vehicle	Core Diameter	Liquid Rocket Engines	Solid Rocket Motors	Performance[a]
Titan IV	3 meters	2	2	40,000
Growth 1	4 meters	3	2-3	60-80,000
Growth 2	5 meters	4-5	3-5	80-130,000
Growth 3	6 meters	5-6	5-6	130-150,000

[a] in pounds to a 100 nautical mile orbit inclined 28.5°

SOURCE: Martin Marietta Space Launch Systems Company.

5 "Developments in Space Launch System Technology," Martin Marietta Denver Aerospace briefing to OTA, July 11, 1986, Washington, DC.

6 Co]. Jack Wormington, ALS Program Manager, U.S. Air Force Space Division Headquarters, Los Angeles AFS, CA.

7 Aerospace Corporation, "Air Force-Focused Space Transportation Architecture Study," Report No. TOR-0086A(2460-01)-2, August 1987, p. 53.

INTERIM OPTION WITH SHUTTLE-C

NASA envisions Shuttle-C as a reliable, unpiloted, cargo vehicle with a 100,000 to 150,000 pound payload capability to a 220 nm, 28.5° inclination orbit. It would use the External Tank (expendable) and Solid Rocket Boosters (reusable)[8] of the current Shuttle, but replace the Orbiter with an expendable cargo carrier.[9] The cargo carrier would consist of a payload shroud, two or three Space Shuttle Main Engines (SSMEs), and a portion of the Orbital Maneuvering System, the Shuttle's on-orbit maneuvering thrusters.

NASA believes that the evolutionary nature of Shuttle-C would allow it to be developed in about four years. The major milestones include tests of cargo carrier structural loads, cargo carrier separation, vibro acoustics, and propulsion tests. Some observers feel that using Shuttle-C in the vicinity of the Space Station would require developing an automatic docking system in addition to the unpiloted cargo vehicle. However, NASA's current plans are to use the Orbital Maneuvering Vehicle (OMV) presently under development for Space Station rendezvous and proximity operations.

NASA expects Shuttle-C's reliability to be comparable to that of the Shuttle because both vehicles would employ common components. NASA sees Shuttle-C's commonality with the Shuttle as a benefit, because it would allow Shuttle-C to profit from the Shuttle's "learning curve" and avoid the "infant mortality" problems and schedule slippages normally associated with a new vehicle.[10]

The Air Force, on the other hand, has expressed concern that such commonality could be a liability because it "places all our eggs in one basket." For example, if an SSME failed and required the grounding of the Shuttle fleet, Shuttle-C would be grounded as well because it would employ the same engines. Similarly, a major accident in launch processing could ground both vehicles.

The current Shuttle-C design would place 100,000 pounds in an equatorial LEO orbit (220 nm, 28.5°), 94,000 pounds in a polar LEO orbit (160 rim), or 20,000 pounds in GEO using an existing upper stage. In addition to applications generic to all heavy lift vehicles (see box 4-l), such as launching large space science payloads, polar platforms, Shuttle-C could also serve as a test-bed for flying new Space Shuttle elements such as ASRMs, LRBs, or variants of the SSME without risking lives or a reusable orbiter. Because the Shuttle-C could carry the Centaur upper stage, it would provide alternative access to space for heavy planetary payloads, or certain national security payloads, which currently can only fly on the Titan IV.

Perhaps Shuttle-C's strongest selling point is its contribution to deployment of the Space Station. Use of Shuttle-C could reduce the time required to deploy the Space Station from 36 months to 19 months by carrying more payload per flight. It would allow compression of nineteen Shuttle flights into seven Shuttle flights plus five Shuttle-C flights.[11] Using Shuttle-C to deploy the Space Station could also increase the amount of equipment

8 If ASRMs were also available, Shuttle-C could usc them in place of SRMs.

9 One possibility is to recover the aft end of the cargo container, which would carry the expensive propulsion and avionics systems, by parachute.

10 Infant mortality refers to the comparatively large number of launch vehicle failures that typically occur in the first years of operating a new launch vehicle. As flaws are discovered and corrected a launch vehicle's reliability tends to improve rapidly and then level off.

11 A Shuttle-C could also be used in concert with a space shuttle augmented by ASRMs. In that case the payloads of the 19 shuttle flights could be compressed into 7 shuttle/ASRM flights plus 4 Shuttle-C flights. See NASA Office of Space Flight, Space Transportation for the Space Station, A NASA Report to Congress (Washington, DC, January 1988); and National Research Council, Report of the Committee on the Space Station (Washington DC: National Academy Press, .September 1987), p. 22.

Box 4-1. – Heavy-Lift Launch Vehicles: Advantages and Disadvantages

Much of the debate over new launch systems has focused on the desirability of building vehicles with greatly improved lift capacity, The largest capacity vehicle now in the U.S. inventory is the Titan IV, which is designed to launch about 40,000 pounds to low-Earth orbit. The new unpiloted launch systems currently being examined – Shuttle-C, Titan V, Transition launch vehicle, and ALS – could have a lift capacity of 100,000 to 150,000 pounds to low-Earth orbit.

Advantages

A new high-capacity launch vehicle would, of course, give the United States the ability to launch large, monolithic payloads. Space Station modules, large planetary spacecraft, or SDI systems could be launched fully assembled, thereby reducing the number of required launches, assembly time, and amount of extravehicular activity, while possibly increasing reliability. Since a considerable amount of money currently is spent trying to limit the weight of even our largest payloads, increasing the capability of the launch vehicle would relax these weight constraints and help to reduce the high cost of payloads.

A heavy-lift launcher could also launch several smaller payloads at the same time, reducing the launch cost per payload and the total number of launches needed to meet program objectives. Finally, building launch vehicles with capabilities that far exceed those actually needed would allow them to be flown at less than their maximum potential. Flying launch vehicles below their maximum performance rating would lessen the strain on critical engine components and perhaps increase reliability. Such excess capacity would also ease the existing burden on flight software and reduce the impact of inadvertent growth of payload weight. By carrying more payload per flight and reducing the number of flights required, a heavy lift launcher could increase the ability to fly off excess capacity and therefore increase fleet resiliency.

Disadvantages

A heavy lift launch vehicle would have some drawbacks, though. A launcher capable of delivering 150,000 pounds to orbit might be inexpensive per pound when launched fully loaded, yet this may not always be possible. At present, few monolithic payloads have been identified that could take full advantage of a heavy-lift vehicle capability. On the other hand, launching multiple payloads of small or medium-size is extremely difficult to coordinate efficiently and to insure, if the payloads are commercial. Should the United States decide to deploy a space-based ballistic missile defense system, a heavy-lift vehicle would be very efficient, since many similar payloads could be launched together to common orbits. In this respect, SDI is unique in its requirements. Commercial users and space scientists might avoid using a large "bus," with limited operational flexibility, preferring instead a dedicated "taxi" able to respond to their individual needs.

that could be integrated into the modules and checked-out on the ground, increasing both reliability of the Space Station modules, and safety of the Shuttle crews assigned to space station assembly.

A fully instrumented Space Station lab module weighs about 69,300 pounds. Launching it on the Shuttle would require off-loading 29,800 pounds of instruments and other hardware, which would be launched on additional Shuttle flights, installed, and integrated on-orbit. Shuttle-C could launch the entire 69,300 pound lab module on one flight, reducing on-orbit assembly requirements, and possibly improving the reliability of the components. Furthermore, Shuttle-C's projected 100,000 pounds of payload capacity to Space Station orbit would satisfy about 55 percent of the Station's annual resupply requirements in one flight.

NASA plans to use Shuttle-C only two or three times per year, a rate limited by the availability of the SSMEs it would use. To keep development costs down, NASA plans to use SSMEs after they have flown on the Shuttle. SSMEs are qualified for 20 Shuttle flights but NASA plans to use them at most 10 times.[12] These SSMEs would then be fully inspected, refurbished, flown, and expended on the Shuttle-C.[13] To increase Shuttle-C's flight rate beyond a few flights a year, additional SSMEs would have to be procured. This would substantially increase Shuttle-C's cost, although larger SSME production runs should produce some unit cost reduction from the present cost of $40 million per engine.

The Shuttle-C would also have a limited flight rate because, unless additional Shuttle processing facilities were constructed, it would have to be merged into the Space Shuttle processing flow. NASA estimates that Kennedy Space Center facilities would have to be modified at a cost of $20-50 million to support a combined annual Shuttle/Shuttle-C flight rate of 14 (e.g. 11 Shuttles and 3 Shuttle-Cs) without unduly disrupting Space Shuttle processing.[14] If the combined Shuttle/Shuttle-C annual flight rates approached 20, an additional Mobile Launch Platform and an SRB Stacking Facility would be needed.

NASA estimates that Shuttle-C launches would cost about the same as the current Shuttle, though it would carry roughly three times the payload. This is about $240 million per launch divided by 120,000 pounds, or about $2,000 per pound.

NASA estimates of Shuttle-C development costs range from $740 million[15] to $1.5 billion,[16] excluding the costs of facilities modifications. If this estimate is correct, Shuttle-C would pay for itself after being used for Space Station deployment alone. Station deployment using Shuttle-C would require seven fewer launches at a cost of $240 million each for a savings of $1.7 billion.

The cost analysis of chapter 7 shows Shuttle-C to be uneconomical as the Nation's principal heavy lift launcher if there is a substantial long-term demand for such capability. However, it may be an attractive option for launching the Space Station deployment or a few large science or national security spacecraft.

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12 Letter from Dale Myers, NASA Deputy Administrator, to Robert K. Dawson, Associate Director for Natural Resources, Energy and Science, Office of Management and Budget, Jan. 20,1988.

13 See app. A for a discussion of how OTA treated. the costing of the SSMEs.

14 Darrell R. Branscome, NASA, letter to Richard DalBello, OTA, Mar. 31,1988.

15 Ibid.

16 James C. Fletcher, NASA Administrator, at hearing before the Senate Subcommittee on HUD and Independent Agencies of the Committee on Appropriations, June 8, 1988.

INTERIM OPTION WITH TRANSITION LAUNCH SYSTEM

The joint DoD-NASA Advanced Launch System (ALS) program seeks to make an order of magnitude reduction in launch costs by the late- 1990s using a launch system starting from a "clean sheet of paper." Initially, the Air Force suggested that it might be prudent to build an *Interim ALS* or *Transition launch system* to meet launch demand in the mid- 1990s, before the Advanced Launch System (ALS) would be operational. Such a Transition launch system would have been based primarily on existing technology. The Air Force expected to achieve a threefold reduction in operations costs. Fearing that a Transition launch system might make early deployment of space-based ballistic missile defenses more likely, Congress directed the Air Force to omit the notion of Transition launch system development from the ALS program,[17] and to concentrate instead on a program of system definition and technology development with the goal of achieving a factor of ten reduction in cost per pound.[18]

Before it was prohibited by Congress, some contractors had envisioned the Transition launch system as a modular vehicle with lift capacities ranging from 60,000 to 150,000 pounds. This range of capacity would be achieved by building a common core stage and varying the number of strap-on boosters, depending on the weight of the payload. They envisioned that a Transition launch system might therefore avoid payload coordination problems by being able to launch single or multiple payloads cost-effectively.

A precise Transition launch system cost estimate is not available because a specific design does not exist. Nevertheless, the ALS Program Director estimated that developing a Transition launch system would take about 7 years and cost about $5 billion.[19] Roughly $1 billion would be needed to develop a new engine, $2 billion for the rest of the launch vehicle, $0.5 billion for facilities construction, and $1.5 billion for ground support equipment. OTA has not had access to a detailed derivation of these cost estimates, but does not regard them as unreasonable.

Based on the estimated life-cycle cost of the particular version of the Transition launch system considered by OTA,[20] the Transition launch system appears to be one of the most cost-effective launch vehicles over the range of mission models from Low-growth to Expanded. In addition, depending on how different the Transition launch system was from today's launch vehicles, it could also provide a technologically independent, back-up means to orbit in case existing systems are grounded again because of failures.

Unlike the other three other launch systems described in this chapter, a Transition launch system would be brand new and have greater uncertainty regarding its ability to achieve goals for technical performance, schedule, cost, and flight rate. Therefore,

17 Concerns about SD I deployment prompted the Senate Appropriations Committee to include language in the Supplemental Appropriation bill funding the ALS that precluded the Air Force from further study of an Interim or Transition ALS. Senator J. Bennett Johnston (D-La) said the intent of the bill was to insure that "... the ALS design will not be sacrificed on the altar of early SDI deployment. We will proceed with the best rocket we can build using the most advanced technologies we can muster. We will not hamstring our engineers with an interim goal necessitating a hurry-up schedule for the sake of early SDI deploymen *Congressional Record*, July 1, 1987, S9138.

18 Public Law 100-180, Department of Defense Authorization Act, 1988/1989, Sec. 256 (101 Stat. 1066).

19 Col. John Wormington, ALS Program Director, Air Force Space Division, personal communication, December 1987.

20 The Transition launch systcm considered by OTA featured a proposed partially reusable unmanned launch vehicle with recoverable engines powered by liquid hydrogen and liquid oxygen.

comparisons of costs and capability between the Transition launch system and other systems must be treated with considerable caution. For that reason it may not be advisable to rely on it as a key element of another ambitious development project, such as the Space Station. NASA officials do not believe that a new launch vehicle would be initially reliable enough to launch one-of-a-kind Space Station modules.[21]

21 NASA Deputy Administrator Dale Myers has informed OTA that he "absolutely flat-out rejects" using a Transition launch system for Space Station deployment, October 1987.