SUMMARY

This background paper describes and examines a launch vehicle concept commonly known as the "Big Dumb Booster,"[1] a concept that derives from efforts first made in the 1960s to minimize costs of space launch systems.[2] Some launch system analysts believe that the use of this concept, when applied to existing technology, could markedly reduce space transportation costs. Other analysts disagree.

Low-cost space transportation is one of the keys to more effective exploration and exploitation of outer space. If space transportation costs were much lower, government agencies and firms with good ideas for using the space environment might be more willing to risk their investment capital. In this era of increased budget stringency, the high cost of space transportation has prompted analysts to examine a wide variety of ideas to reduce these costs.

This paper derives from a "Big Dumb Booster" workshop OTA conducted in December 1987, which was held to examine the Big Dumb Booster concept. It summarizes the findings of the workshop composed of a panel of industry and government aerospace experts, augmented by staff research and reviewers' comments on earlier drafts. The paper is part of a broad assessment of space transportation technologies requested by the House Committee on Science, Space, and Technology, and the Senate Committee on Commerce, Science, and Transportation.

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1 The term Big Dumb Booster has been applied to a wide variety of concepts for low-cost launch vehicles, especially those that would use "low technology" approaches to engines and propellant tanks in the booster stage. As used in this paper, it refers to the criterion of designing launch systems for minimum cost by using simplified subsystems where appropriate.

2 For example, Arthur Schnitt and F. Kniss, "Proposed Minimum Cost Space Launch Vehicle System," Aerospace Corporation, TOR-0158(3415)-1, July 18, 1966.

Previous publications in this assessment examined a variety of future launch options,[3] and possible reductions in the costs of launch operations.[4] Future publications will treat crew-carrying launch systems and payload design.

Origins of Today's Launch Vehicles

Current U.S. expendable launch vehicles (ELVs) were designed to meet stringent performance specifications. As a result, launch system designers gave relatively little priority to reducing launch costs. U.S. ELVs are derived from 1960s intercontinental ballistic missile designs that used high-performance engines and lightweight structures in order to minimize launch vehicle weight and maximize payload and range. Military requirements for storability in submarines or silos and the ability to be launched quickly drove their designs. These considerations, for example, led to the development of the Atlas rocket, with lightweight fuel tanks that taper in thickness to nearly a hundredth of an inch thick. Not only are such tanks expensive to manufacture, but they must be kept under pressure, like a balloon, to keep them from collapsing under their own weight.

Budgetary limitations during development as well as unforeseen technological challenges prevented Shuttle designers from building a system that minimized recurring launch costs. As a result, the Shuttle is extremely expensive to maintain and launch.[5] As the United States looks toward possible future launch systems, reducing space transportation costs would be a critical positive step in increasing the use of space resources.

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3 U.S. Congress, Office of Technology Assessment, OTA-ISC-383, *Launch Options for the Future: A Buyer's Guide* (Washington, DC: U.S. Government Printing Office, July 1988).

4 U.S. Congress, Office of Technology Assessment, OTA-TM-ISC-28, *Reducing Launch Operations Costs: New Technologies and Practices* (Washington, DC: U.S. Government Printing Office, September 1988).

5 U.S. Congress, Office of Technology Assessment, *Reducing Launch Operations Costs: New Technologies and Practices,* op.cit. The Shuttle program consumes approximately one-third of NASA's yearly budget. See U.S. Congress, Congressional Budget Office, *The NASA Program in the 1990s and Beyond* (Washington, DC: Congressional Budget Office, May 1988), p. 20.

A New Design Criterion

A 1966 Aerospace Corporation study first suggested that launch vehicles could be designed explicitly to minimize manufacturing and operational costs.[6] The new criterion, "Design for Minimum Cost" (DFMC), was based upon the understanding that in rocket design, minimum weight, maximum performance, and high reliability, taken together, are achieved only at high cost. Instead, these criteria must be examined with respect to one another and various technical design parameters traded off to produce a vehicle with the desired characteristics at minimum cost. Instead of pushing launch vehicle performance, the DFMC design criterion would accept lower performance in order to reduce the overall cost of the launch system.

Launch vehicles designed to achieve sharply reduced costs would be very different from today's launch vehicles. For example, according to the study, the first stages of a rocket should be relatively unsophisticated. It suggested that heavier hardware produced at lower unit costs by relaxing manufacturing tolerances should replace expensive, state-of-the-art, lightweight hardware. The former director of that study has explained the intuitive appeal of the concept: "[At the time] . . . we were designing every stage as if it went into space. For the top stage, which is small and extremely valuable, minimum-weight design made sense. For the lower stages it was nonsense. Why spend millions on high-efficiency engines when you could substitute a less efficient engine and simply make it bigger?"[7]

This concept assumes that the vehicle weight and fuel added by using heavier materials and less efficient designs would be more than offset by cost savings that accrued from the use of simpler, less costly technologies. One workshop participant drew an analogy to trucks and high-performance sports cars: despite the truck's heavy engine, fuel tank, and frame, it hauls cargo less expensively than a high-performance sports car. Although the fundamental technologies of both are the same, the greater manufacturing tolerances allowed on most trucks

6 Arthur Schnitt and F. Kniss, "Proposed Minimum Cost Space Launch Vehicle System," op. cit.

7 Arthur Schnitt, quoted by Gregg Easterbrook, "Big Dumb Rockets," *Newsweek*, Aug. 17, 1987, p. 48.

make them much less expensive per pound than sports cars. Engineering analyses suggested, for example, that relatively simple pressure-fed engines would be suitable for such a booster, replacing more complicated and expensive pump-fed engines.

Further Studies and Hardware Developments

In the late 1960s, several aerospace companies performed system studies on minimum-cost launch vehicles, and the Government conducted some demonstration projects on Big Dumb Booster engines. The Air Force supported 120 ground tests of pressure-fed engines with up to 250,000 pounds of thrust. These studies and hardware developments prompted the Air Force in 1968 to start an R&D program for a minimum cost launch vehicle. However, the program was cancelled before a thorough analysis of the overall life-cycle costs[8] of such a booster could be performed. Most Big Dumb Booster research was officially abandoned in 1972 when President Nixon decided to develop the partially reusable Space Shuttle.

Continued Controversy

The Big Dumb Booster concept remains controversial. Supporters of the concept argue that it still has considerable merit and that it is not too late for the United States to adopt this rocket design philosophy. Opponents maintain that time and improved technology have passed it by. They further argue that technology choices that reduce cost in one area, such as engines and tanks, may drive up costs elsewhere. For example, larger, heavier tanks require larger launch pads and facilities. Supporters counter that in minimizing costs over a whole system, cost increases in one area, such as launch facilities, would be more than offset by decreases gained in operational simplicity, and that the concept merits further investigation. Further, some point out that boosters using pressure-fed engines would not necessarily be much larger than pump-fed vehicles if existing composite tank technology and advanced pressurization systems, or stage-mounted low pressure, commercial-type turbo pumps were used.

8 Life-cycle costs include not only the costs of manufacturing the launch vehicle, but also the costs of ground operations and launch facilities, developing and testing. It also includes the discounting of all these costs to reflect opportunity costs and inflation.

Big Dumb Booster design's primary uncertainty is whether pressure-fed engines, which are relatively inexpensive to manufacture, can be made extremely large. The largest pressure-fed engine ever tested produced 250,000 pounds of thrust. A Big Dumb Booster might need an engine with at least six times that thrust, or six 250,000 pound thrust engines. OTA workshop participants generally agreed that the task presented no obvious obstacles, but still remained to be accomplished.[9] By contrast, pump-fed engines and cryogenic fuels are now mature technologies with a considerable experience base, though they are expensive.

Some tout the large Soviet boosters, *Proton* and *Energia*, as examples of Big Dumb Booster designs because of their apparent simplicity and use of heavy steel structures. Furthermore, Soviet rocket assembly lines bear a closer resemblance to automobile factories than do their U.S. counterparts, which look more like operating rooms. On the other hand, large Soviet boosters do not use simple pressure-fed engines; they do use multiple combustion chambers (typically four), which are fed from a single turbopump. In addition, their new *Energia* heavy-lift launch system has many advanced features reminiscent of U.S. launch systems.[10] In any event, cost comparisons with U.S. boosters are extremely difficult to make because we have no objective measures of the true cost of Soviet launch vehicles.[11]

Payloads

Big Dumb Booster proponents claim that a high-capacity launcher that drastically reduced the cost of launching a pound of payload would generate a large synergistic cost saving by making cheaper spacecraft possible. However, one workshop participant with experience in developing communications satellites suggested that even if weight were not a constraint on payloads, satellite builders would probably use any added weight margins to continue to add

9 Nevertheless, the technology would still have to be thoroughly tested, as combustion stability and any unexpected problems would need to be addressed.

10 These include large, high chamber pressure, reusable, pump-fed, hydrocarbon-fuel booster engines; and fault-tolerant, advanced avionics.

11 One reviewer averred that using Soviet designs built and operated in the United States would be expensive and that, in any event, Soviet designs are not as simple as some of the low-cost Big Dumb Booster concepts.

capacity, redundancy, and lifetime at high cost, rather than attempting to apply Big Dumb Booster principles to satellite design. As some critics of current payload design practices point out, avoiding the temptation to add performance margins to payloads instead would require considerable management discipline.

Big Dumb Booster approaches are certain to meet pointed questioning from satellite owners and payload managers. Payload designers expect launch vehicles to provide services for the payload, including power, air conditioning, and fueling, along with custom-made interconnections. In order to meet goals of substantially reducing launch costs, Big Dumb Booster designers would wish to eliminate some of these services and custom-fittings, but payload managers are highly skeptical about designs that seek to reduce launch costs by placing greater requirements on the payload. Spacecraft owners must be convinced that if Big Dumb Boosters shift launch vehicle costs to the payload, they will be compensated by a greater reduction in launch costs, and acceptable reliability.

Conclusions

The Big Dumb Booster appears to be an attractive option in part because it seems intuitively obvious--make the first stage of a launcher simple to build and operate, large, and cheap, retaining any necessary complexity in the lighter upper stages. However, the technical community, which was divided over the soundness of the concept when it was first proposed in the 1960s, is still divided today. Nevertheless, attempting to determine who was "right" and who was "wrong" in a debate that occurred twenty years ago is beyond the scope of this paper. Nor would such an exercise contribute to an evacuation of the Big Dumb Booster concept in today's space program. Specific designs that might have been the minimum-cost solution two decades ago are certainly not today's minimum-cost design. Technology has advanced since the early Big Dumb Booster studies, significantly altering potential trade-offs among costs and technologies.

The critical issue is not whether the launch vehicle design is "dumb" or "smart," but whether the use of the minimum-cost criterion is capable of reducing launch vehicle costs--i. e., a 'Big Cheap Booster." Objective evaluation of the Big Dumb Booster concept would require systematic analysis, with attention to engineering details and costs. It would also involve some hardware development and testing. If a Big Dumb Booster study is done, it should be carried out as a systems study that integrates specific hardware choices with the entire system, including