BIG DUMB BOOSTER TECHNOLOGIES

This section examines representative technologies that have been proposed for use in a Big Dumb Booster. Although these technologies may contribute to low-cost design, minimizing the costs of a launch system requires comparing different approaches in detail, and making choices among such technologies depending on their effects on overall launcher design.

Engines

Rocket engines and tanks provide obvious targets for cost-cutting by relaxing weight constraints. The Aerospace Corporation's analysis[17] suggested that relatively simple pressure-fed engines would be suitable for a Big Dumb Booster's first stage, instead of more complex pump-fed engines like the Space Shuttle main engines (SSMEs) and the engines on all current ELVs. A turbopump increases the pressure of the propellants fed into the rocket engine, and thus permits much lower tank pressures than required by pressure-fed engines; besides the savings in tank weights, higher chamber pressures result in slightly higher propulsion efficiencies. However, a turbopump is complex, made of hundreds of rapidly moving parts under considerable stress. The pump typically accounts for about 20 percent of the cost of a pump-fed engine.

A major uncertainty is whether pressure-fed engines can be made large enough[18] to power a first stage. 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 engines of 250,000 pounds thrust.[19] A workshop participant noted that only the manufacture and demonstration of full-scale hardware can eliminate this and other uncertainties related to

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17 Arthur Schnitt, "Design for Minimum Cost-- A Review," Aerospace Corporation, F04695-67-C-0158.

18 Pressure-fed booster engines tend to be larger than traditional pump-fed engines for the same thrust level because the former typically operate at lower pressures. Higher engine pressures result in higher overall engine performance.

19 Using multiple engines could have other advantages: increased production volume, and better operating reliability (i.e., possible "engine-out" capability).

very large pressure-fed engines. "In my mind the largest of these uncertainties are the complexities of the pressurization system and the unknowns associated with combustion performance and stability," he added. Another participant noted that the perceived technical risk of scaling up pressure-fed liquid engines was a major reason that NASA chose solid boosters for the Shuttle.[20]

Tests performed on pressurization systems in 1969 did raise questions about the feasibility of scaling up pressurized tanks. A *2000* cubic foot tank was pressurized with rocket fuel and the fuel allowed to flow out. A workshop participant whose company conducted the test said, "a large [negative] shift in performance from previous small tank tests   noted."

The workshop participants generally agreed that scaling up large pressure-fed engines presented no obvious insurmountable obstacles, but still remained unproven. By contrast, pump-fed engines and cryogenic fuels are now mature technologies with a considerable experience base.. However, several ALS design studies are investigating the possibility of using clusters of smaller engines to achieve the necessary booster thrust. A pressure-fed booster might also be able to use such a strategy, rather than scaling-up the engine. Engine clusters are particularly attractive for adding an extra margin of safety. If one fails non-catastrophically, the remaining engines can be throttled up to compensate. Although engine-out capability is currently being studied as a goal for clusters of pump-fed liquid engines, the principle can be applied in part to pressure-fed systems by including multiple (clustered) pressurization sources in addition to the clustered combustors.[21]

Engine cooling is another area where weight might be added in exchange for lower costs. Current engines are cooled by complex, mechanical systems that allow engines to operate at higher pressures, making them more efficient. Lower-performance engines might use heavier, but simpler, ablative protection, similar to the heat shield on the Apollo capsule. Ablative coatings would protect the engine nozzle by gradually burning away as the engine heats up during firing.

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20 The cost of risk played an important role. Designers had the experience of the large solid rocket motors on the Titan 111 on which to build.

21 All ALS contractors have ranked the capability for engine-out high on their list for enhancing launcher reliability.

Two engines in the 10,000 pound thrust class, the Lunar Excursion Module Descent Engine and the Transtage engine on the Titan III, used ablative materials for their thrust chambers and both were pressure-fed. The Transtage engine is still used to power the third stage of the Delta II and Titan III.

Propellant Tanks

Early Big Dumb Booster studies also proposed that low-cost fuel tanks could be made of welded steel instead of titanium or beryllium/aluminum. These studies reasoned that welded steel tanks might reduce fabrication costs by eliminating the precision manufacturing needed to produce the thin, lightweight, expensive structures now used.

Although welding tanks and structures made of steel is less capital- and labor-intensive than manufacturing techniques now used for these components, inspection costs would remain high because every weld would have to be inspected for quality control.[22] Furthermore, the United States no longer manufactures the HY140 and HY150 steels proposed for use in Big Dumb Boosters, introducing an additional uncertainty in using these materials.

More important, technologies that have appeared since the early Big Dumb Booster studies could significantly change the analysis of this launch concept. For example, one workshop participant presented a rough analysis of the cost of various tank materials and suggested that graphite-epoxy could be used for about the same cost as HY140 steel.[23] Yet, graphite-epoxy is considerably lighter: a graphite-epoxy tank for one Big Dumb Booster design would weigh 38,000 pounds compared to 213,000 pounds for HY140. That would free up 175,000 pounds for other purposes, such as adding extra fuel or additional payload.

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22 One way to avoid costly inspections is to control the output of the manufacturing processes more effectively. The Air Force Reliability and Maintainability 2000 program has developed the variability reduction process to do that.

23 Graphite-epoxy technology has grown rapidly in the last decade (U.S. Congress, Office of Technology Assessment, *Advanced Materials By Design, OTA-E-351* (Washington, DC: U.S. Government Printing Office) p. 142.). It has been developed experimentally for application to Shuttle solid rocket booster casings. Yet, because the material has not been certified for use with cryogenic liquids, its use for cryogenic fuel tanks must remain speculative until more research is done.

This may indicate that the best approach to launch systems would be to design for minimum cost using proven, off-the-shelf "appropriate technology." Such an approach would use the Big Dumb Booster maxim of designing to minimum cost, but not necessarily rely on "boiler-plate" technology components often associated with it.

Propellants

Some conventional rockets use liquid hydrogen, a high-performance cryogenic fuel that requires insulated fuel tanks to maintain it at temperatures of 423 degrees below zero, Fahrenheit. Big Dumb Booster designs often call for use of lower-performance Nitrogen Tetroxide (N_2O_4) and Unsymmetrical Dimethyl Hydrazine (UDMH) as propellants because these fuels can be stored at room temperature in simple, welded-steel tanks. These high density fuels also require smaller tanks than liquid hydrogen, for example. The Titan family of vehicles uses these fuels, which ignite spontaneously when mixed.

However, these fuels can pose safety and environmental hazards, and they are relatively expensive. N_2O_4 is corrosive and UDMH is carcinogenic. Both propellants and others like them require special handling. Their transport by rail and truck is strictly regulated. Safety rules at Vandenberg Air Force Base limit the amount of such fuels that can be handled at one time so that a gas cloud from an accidental spill will not endanger neighboring communities. Titan launch operations at Vandenberg already approach the limit allowed by the rule. A much larger rocket would need an expanded safety zone, possibly requiring the development of offshore launching facilities.[24] Such marine launch pads could present their own fuel handling problems.

Pressure-fed engines can also be designed to burn other fuels, such as methane, propane, or kerosene, which do not require extraordinary handling and pose less environmental hazard. It may also be possible to use liquid hydrogen and liquid oxygen, although no engine tests have yet been made using these propellants.

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24 Offshore facilities may be developed for other reasons as well. See the discussion in *Reducing Launch Operations Costs: New Technologies and Practices, op.* cit., p.64.

Avionics

One area where today's technology is clearly superior to 1960s technology is avionics. Advances in electronics can greatly reduce the weight and cost of avionics equipment while also improving its performance. General Dynamics recently upgraded the 1960s vintage electronic components of the Atlas-Centaur rocket with new integrated circuits. As a result, the cost of the on-board computer fell fivefold; the weight of the inertial guidance system went from 150 pounds to 50 pounds; and performance improved by a factor of ten.

Launcher Reliability

Workshop participants disagreed on the reliability of low-cost designs. Proponents of simplified designs argue that reducing the number of moving parts and using heavier materials with conservative design margins decreases the possibility of malfunctions. They note that a pump-fed engine may have 15,000 parts compared with fewer than 100 in a pressure-fed engine. Simple designs, that decrease possibilities for human error and reduce special handling, would not only increase reliability, but also simplify trouble-shooting. "When a pump-fed engine fails you have a research project on your hands," said one workshop participant. In the words of the Shakers, "Tis a gift to be simple."

Another workshop participant pointed to the Shuttle's complexity and the Challenger accident: "you can't be in a position where when you have a failure you have to reconstitute the design team to figure out what went wrong."[25] Others disputed the view that simplicity equals reliability y. They argued that commercial jet aircraft are made reliable by their very sophistication. Still others drew attention to the high reliability of the pump-fed engine used on the **Atlas** Centaur, the RL-10, which has suffered no failures in over 150 flights and hundreds of ground tests since its first test flight in 1962.

The workshop participants generally agreed that while simplicity is a virtue in any design, it does not guarantee high reliability. Another path to reliability is through robust, redundant, autonomous subsystems with wide performance margins, capable of performing in

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25 Yet, in fact, the Challenger's problem was with one of the simplest systems on the Shuttle, the O-rings on the solid rocket boosters, not with the complex pump-fed engines as experts first speculated.

excess of normal demands. If a more complex design is better able to tolerate human errors and anomalous operating conditions, then the net reliability can be higher and lead to lower life cycle costs than in a simpler design.