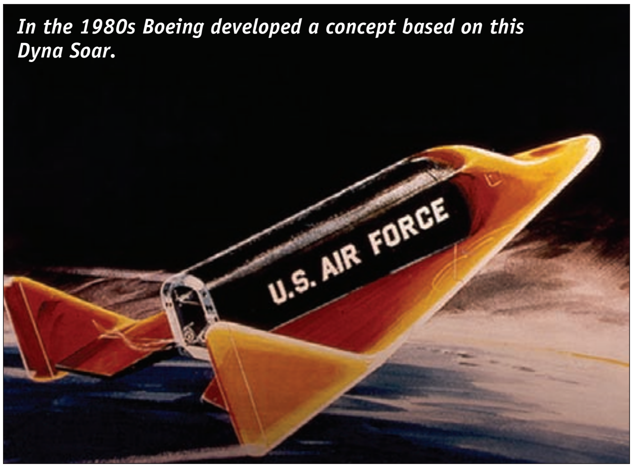
Designing a responsive space launch vehicle

Reducing the cost of space access, increasing reliability and safety, and providing operationally responsive space launch have long been the goals of future Earth-to-orbit space launch vehicle designers. In seeking to achieve them, NASA created the X-33 and X-34 programs—the X-33 to demonstrate rocket-powered single-stage-to-orbit technologies; the rocket-powered X-34 to demonstrate operational technologies and provide a test bed for them. Both were canceled before completion.

Requirements

A transatmospheric vehicle design concept based on legacy technology could be built today to to help develop and demonstrate future reusable launch vehicles that meet desired cost and operational goals. The two key technologies needed for reusability are a validated structural design concept, including a thermal protection system (TPS), and a suitable propulsion system. Both are available today. Equally important, however, is a vehicle design concept that offers both low cost and operational responsiveness.



In the 1980s Boeing developed a concept based on this Dyna Soar.

Both the Air Force and NASA have need for such a vehicle. In addition, the Air Force needs on-demand launch and a global strike capability. To meet dual-use requirements, Air Force Scientific Advisory Board studies have considered transatmospheric vehicles, hypersonic cruisers, and more conventional launch vehicle options. It is now possible to consider a vehicle design using legacy technology to demonstrate ground operations and flight performance with these dual-use capabilities. There are available rocket engines and validated structural-TPS concepts that could be used now to develop a ground and flight demonstration vehicle. Development of a demonstrator vehicle would be the initial spiral in a program whose objective is full operational capability.

If the flight speed of a near-term demonstrator is above Mach 10, the propulsion system of choice is a rocket engine. The flight speed of the proposed demonstrator is 7,200 m/sec, based on the velocity requirements for a single-stage unrefueled global range performance capability. There are several available rocket engines: an up-rated RL-10 derivative like that used on the DC-X, a modified space shuttle main engine, a Japanese LE-7A used on the H-IIA launcher, or the Russian RD-0120 used on the Energia heavy-lift booster.

To date, three structural-TPS concepts have been validated: the one used on the space shuttle, one developed in an Air Force program by Boeing during the 1980s (an all-metal honeycomb structural-TPS concept based on the Dyna Soar), and one McDonnell developed in a 1960s program for use on a Mach-17 air-launched reconnaissance aircraft.

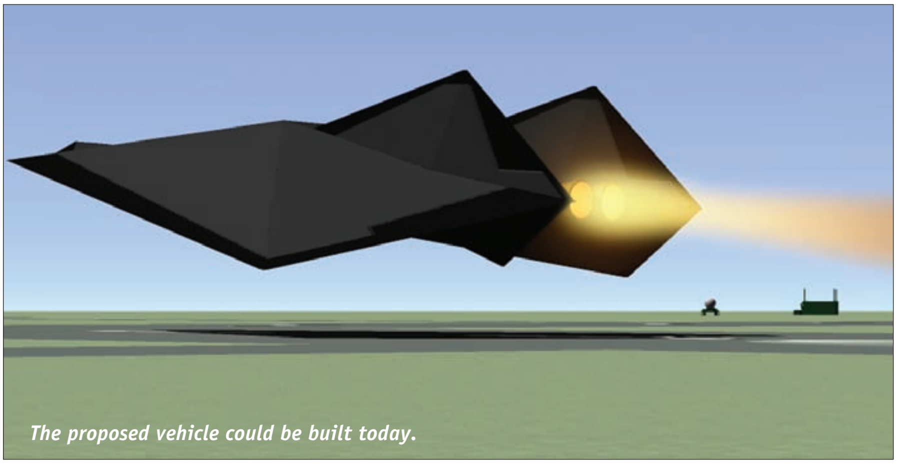
Only the shuttle has been flight-tested over the full range of operational requirements; the other two have been ground-tested under simulated ascent and reentry conditions.

The Boeing test article contained over 90% of the parts that would go into a full-scale vehicle, and the actual test article weight was lighter than the weight predicted by the structural design codes. The hot structure-TPS concept is less expensive to fabricate than more complicated structure-TPS concepts, especially if the hot structure-TPS concept is combined with vehicle designs based on flat surfaces and the McDonnell diffusion-bonded honeycomb. Originally the labor-intensive honeycomb was expensive to fabricate, but Rockwell developed a cheap way to manufacture it during the National Aero-Space Plane (NASP) program.

Design concept

The operationally responsive space launch demonstrator concept is a rocket-powered horizontal takeoff and landing design. The demonstrator gross weight would depend on the required performance capability and engine selection. Prior studies have indicated the advantage of horizontal takeoff and landing compared to vertical takeoff and either horizontal or vertical takeoff concepts.

The materials used would be those developed in the NASP program, to provide a stronger, lighter structure with higher weight margins. Prior studies have



The proposed vehicle could be built today.

indicated advantages for a horizontal takeoff design compared to a vertical takeoff design.

The demonstrator would have a cutoff velocity goal of 7,200 m/sec, which would enable the vehicle to fly around the world and return to the launch site using a boost-glide-skip flight profile. That cutoff velocity requires a usable propellant fraction of approximately 85%, whereas Boeing's structural test article was based on providing an 88% usable propellant loading fraction.

The proposed operating base for the demonstration vehicle is Vandenberg AFB, which has the necessary propellants, a launch command and control center, the 4,500-m runway originally planned for the space shuttle, and a shuttle processing facility. At Vandenberg, infrastructure costs for the demonstrator should not be a significant cost factor. In addition, space launches are common events there, so the local population would not become concerned about an additional launch.

This design concept attempts to minimize investment and operations and maintenance (O&M) costs while providing operationally responsive capability. Minimizing the infrastructure costs by using existing facilities and services can significantly reduce investment and operating costs.

The configuration is a modified wave rider using all flat surfaces to minimize construction costs. The hot structure-TPS concept does not use tiles, multilayer insulation, or separate propellant tanks. The vehicle takes off and lands horizontally. Ground operations are based on military aircraft O&M. Aircraft docking equipment is used for all maintenance and pre- and postflight operations.

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The current data and evaluation criteria may be insufficient today to make a clear decision regarding takeoff and landing modes for an operationally responsive reusable launch vehicle, but it is clear that the design of a horizontal takeoff vehicle has many beneficial attributes that have been considered in the formulation of the example design.

Selection of the preferred takeoff and landing mode becomes more complicated if the vehicle design requirements include factors other than performance and cost. Additional factors include consideration of multimission capability, scenario analysis, war games, design reference mission selection, the minimization of ideal mission velocity requirements, and safety.

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A least-cost operationally responsive transatmospheric suborbital vehicle demonstrator could be built today using legacy technology. The demonstrator could represent the first stage of a reusable two-stage-to-orbit vehicle. By selecting a staging velocity of 7,200 m/sec and adjusting gross takeoff weight, the demonstrator could have a residual global range capability. Both engines and a validated structure-TPS concept are available.

It is unclear how large the demonstrator has to be to achieve the approximately 0.85 usable propellant fraction required to achieve global range, which depends on both engine performance and vehicle gross weight. The structure-TPS concept was validated at a propellant utilization fraction of 0.88 and a vehicle gross weight of 550,000 kg. It is not clear at this time how the propellant utilization fraction scales with vehicle gross weight. There are three different rocket engines available, which correspond to three different levels of vehicle gross weight. For cost reasons it is desirable that the gross weight be as low as possible.

While the design concept and legacy technology selections used in the formulation of the proposal may not represent the final parameters of a least-cost operationally responsive reusable space launch vehicle demonstrator, it is a representative "straw-man" design that has the desired attributes of low cost and an operational responsiveness.

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