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The Road from the NASA Access to Space Study to a Reusable Launch Vehicle

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NASA is cooperating with the aerospace industry to develop a space transportation system that provides reliable access-to-space at a much lower cost than is possible with today's launch vehicles. While this quest has been on-going for many years it received a major impetus when the U.S. Congress mandated as part of the 1993 NASA appropriations bill that: "In view of budget difficulties, present and future..., the National Aeronautics and Space Administration shall ... recommend improvements in space transportation." NASA, working with other organizations, including the Department of Transportation, and the Department of Defense identified three major transportation architecture options that were to be evaluated in the areas of reliability, operability and cost. These architectural options were: (1) retain and upgrade the Space Shuttle and the current expendable launch vehicles; (2) develop new expendable launch vehicles using conventional technologies and transition to these new vehicles beginning in 2005; and (3) develop new reusable vehicles using advanced technology, and transition to these vehicles beginning in 2008. The launch needs mission model was based on 1993 projections of civil, defense, and commercial payload requirements. This "Access to Space" study concluded that the option that provided the greatest potential for meeting the cost, operability, and reliability goals was a rocket-powered single-stage-to-orbit fully reusable launch vehicle (RLV) fleet designed with advanced technologies.

The Access to Space study demonstrated that this RLV vehicle needed many advanced technologies to be viable. Those technologies identified that are not currently available are:

1)Graphite-composite reusable primary structure
2)Aluminum-lithium and graphite-composite reusable cryogenic propellant tanks
3)Advanced main propulsion systems designed for robustness and operability
4)Low-maintenance thermal protection systems
5)Advanced avionics that include vehicle health monitoring and autonomous flight control.

The effect of these technologies on the vehicle weight can be seen in figure 1. The mission for the baseline vehicle was to deliver 25,000 lb to the International Space Station (ISS) in 220 n.mi. circular orbit inclined at 51.6°. (ISS orbit has been changed to 248 n.mi. circular orbit at 51.6°.) Figure 1a is for each technology added individually to the baseline vehicle which was designed using Space Shuttle technology. The dark bar at the top of each bar represents the weight reduction that occurs by simply replacing the equivalent Space Shuttle technology with the advanced technology. However, because this vehicle can now be redesigned using this technology, there is a multiplicative effect of weight reduction. For instance all systems can now be resized to account for this reduced weight requirement, thus the landing gear is lighter, the wing smaller and lighter, the tanks smaller (less propellant required to reach orbit), etc. This multiplicitive effect is shown by the lighter bar. Note that there are relatively small weight benefits due to advanced avionics and thermal protection systems. The advancements in these areas was primarily for operability and reliability, not weight reduction. An additional note, for this study the advancements in main propulsion systems was assumed to provide no weight reduction, but only improved operability and reliability. This chart shows that the advanced cryogenic tanks, and the use of composite structure instead of aluminum offer the largest weight reductions. Figure 1b shows the impact if the cumulative effect of these technologies is calculated. It shows that if all these technologies mature as projected, it would be possible to build a RLV vehicle to do the design mission with a dry weight near 200,000 lb. This dramatic effect of technology was the primary reason behind the Access-to-Space study conclusion.

NASA elected to proceed with the development and demonstration of the technologies which would enable a rocket-powered single-stage-to-orbit reusable launch vehicle through a cooperative agreement with industry, which marks a significant departure from the way NASA implements programs. The cornerstone of this activity is the X-33 advanced technology flight demonstrator - currently under construction. NASA is assisting industry with the development of the "high-risk technologies that industry cannot afford." said Goldin, "But NASA won't build the vehicle, industry will. NASA will be a user, not an operator." The RLV is to lead to a commercialization of space access with more airplane-like operations, such that the cost of delivering payload to orbit is significantly reduced. The goal is to decrease the cost to deliver payload to low earth orbit from the current estimated $10,0000 per pound to $1,000 dollars per pound.

The RLV program is structured in three phases. In Phase I, which began in March 1994, contractors developed conceptual-level vehicles - both operational vehicles and a corresponding technology demonstration vehicle; technology requirements; demonstration and operational vehicle development plans; and business plans detailing how the contractor would commercialize the RLV. This activity also included the demonstration of many key subscale technologies, including the first successfully tested large scale graphite composite liquid hydrogen tank, automated checkout main propulsion system, and advanced, durable ceramic and metallic thermal protection systems. The Phase I effort was preparation for contractor proposals to NASA for Phase II NASA funding. Three contractors, Rockwell International, McDonnell Douglas and Lockheed Martin worked in cooperation with NASA on the Phase I effort. Lockheed Martin Skunk Works (LMSW) was awarded the Phase II contract on July 2, 1996. The RLV industry team includes, LMSW as prime, Rocketdyne as engine subcontractor, Rohr as thermal protection system contractor, and Allied Signal as subsystems contractor.

Phase II, funded by NASA with signifcant cost-sharing by industry, includes the development, fabrication and flight demonstration of the X-33 technology demonstrator; technology development and ground testing of technologies required for the RLV not included on the X-33 flight vehicle; and preliminary design of the actual operational RLV. RLV development encompasses vehicle, ground systems, and operations development, as well as maturation of the business and financial plan for commercializing the RLV. The culmination of Phase II will be a decision by NASA and industry around the end of the decade on whether or not to proceed with final development and construction of the operational RLV.

Support from the government in phase III is currently being evaluated but will likely include participation from NASA centers in areas of unique capability or expertise and a package of financial committments and incentives . The array of RLV missions, however, is planned to be significantly broader than delivery of NASA personnel and cargo to and from the International Space Station, encompassing a range of commercial and military applications and customers. The first flight of the Lockheed Martin RLV, known as VentureStar, is projected to be in the 2004-5 timeframe.

One of the primary milestones of the Phase II program is the development, design, fabrication and flight testing of the X-33. Technologies to be demonstrated by the X-33 were defined directly by the technology requirements of the VentureStar. Thus X-33 is defined by the traceability requirements to VentureStar. The X-33 is an approximately half scale vehicle as compared to VentureStar. Technologies that will be demonstrated by X-33 flight vehicle include:

- Low cost operations withrapid, safe turnaround of the vehicle
- Autonomous ascent, reentry and landing
- Graphite composite multilobe liquid hydrogen tanks
- Graphite composite primary airframe system
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- Metallic thermal protection systems
- Lifting body flight from subsonic to hypersonic speeds
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- Aerospike engine performance when integrated with a lifting body

- Modular rocket engine thruster concept
- Thrust vectoring by thrust modulation
- Avionics systems based on micro-electromechanical technology

X-33 flights are planned to start in July 1999. 15 flights are planned for completion by December 1999. The X-33 will be launched vertically from Edwards Air Force Base, California. The first flights will land horizontally at Dugway Proving Ground, UT with later higher Mach number flights planned for Malmstrom Air Force Base, MT. The X-33 Critical Design Review was completed at the end of October 1997, which signaled the go-ahead for completing component fabrication and assembly of the X-33.

Though the X-33 flight demonstrator will go a long way toward demonstrating the flightworthiness of technologies critical to the reusable launch vehicle, there are a number of ground tests required to develop and demonstrate technology not tractable for inclusion in the X-33. Phase II, as mentioned above, also includes many of these technology development and ground test demonstration efforts. A crucial element to a succesful RLV decision which will not be demonstrated on the X-33 will be demonstrating those technologies required for an operational aerospike rocket engine. A significant element of ground activities will be to develop and demontrate critical engine elements including a full scale, flight weight powerpack (gas generator and turbopump assembly) and composite nozzle. In addition, ground durability tests will be completed on critical airframe components to certify their life cycle for 100 flights. The LOX tank on X-33 is Aluminum but planned to be composite for the RLV. Therefore, significant ground testing of the composite LOX tank will be completed, both to demonstrate durability, and to demonstrate load carrying capability. Non-autoclave large scale, conformal structures and trades on metallic TPS integration will also be addressed. Finally, a significant amount of wind tunnel testing will be required, beyond that for the X-33, to build the aerodynamic and aerothermodynamic database for the RLV.

Concurrent engineering is another technology being utilized and demonstrated for the first time with this class of vehicle. The objective of concurrent engineering is to reduce vehicle development and fabrication cost by significantly reducing the time between initiation of the program and first flight. From contract award, the program had 36 months to design and build an X-33 - unheard of for a vehicle of this complexity and a program of this magnitude, i.e. 29 organizations in 16 states. In the concurrent engineering environment, operations and manufacturing is involved in the design at the initiation of the program; design information is transmitted between design and manufacturing electronically; and manufacturing is able to identify and initiate fabrication, for example tooling, before the final vehicle design is complete. Lessons learned from the concurrent engineering process in X-33 will be applied to the reusable launch vehicle. The extent of concurrent engineering for RLV will be a balance between technical feasibility and cost.

For the X-33, weight control is critical to achieving the flight environments necessary to obtain the range of data required for application to the RLV. However, as critical as weight management is for the X-33, it is much more critical for the VentureStar. If the X-33 does not achieve its weight goals, the primary objective of technology demonstration may still be achieved, but if the VentureStar does not achieve its weight goals, its viability as a cost-effective launch vehicle is reduced. VentureStar must deliver the payload to the delivery orbit. For example, one of the primary mission requirements is the delivery of a 25,000 lb payload to the International Space Station. For a fixed size vehicle, every pound of extra weight added to the VentureStar structure, or engine, or subsystems, is one less pound of payload that can be delivered to orbit. It doesn't take much weight growth before the payload weight allowance is consumed. During the design process, the vehicle can be scaled up to gain back the payload capacity only to a point. The vehicle must remain within the size limitations projected by the business sector to ensure the required level of profitability. Even without the business limit, however, at some point the payload capacity does not increase with increasing vehicle size, and at some size the vehicle becomes technically infeasible.

To make the decision onthe development of an RLV around the end of the decade, the X-33 flight and ground test results, technical feasibility, commercial viability,. andplans for transitioning from the current Space Shuttle to the RLV will be considered. RLV development will take full advantage of the technology and lessons learned through the X-33. It will also require system and component level trades, and compromises as necessary, to enable technical feasibility and maximize commercial profitability.

Weight and cost minimization, is one of the primary systems-level issues for the RLV, and the objective of many of the on-going trades. For example trades are aimed at improved structural integration from an overall systems standpoint, improved integrated engine/vehicle efficiency and performance, etc. Vehicle trim, while minimizing weight, is a significant RLV systems trade. In this case, lessons learned in X-33 combined with RLV trades led to a modification of the control surface architecture for the RLV. The X-33 configuration carries ballast in the vehicle nose to tailor the vehicle cg to the aerodynamics for across-the-Mach-trim capability. For the RLV, trades have been conducted to minimize vehicle weight while enabling across-the-Mach trim. These trades have resulted in a modification to the RLV control architecture as compared to the X-33. The X-33 and the current RLV baseline are shown in Figures 2 and 3, respectively. (Note that the RLV configuration is still under development. The outer mold line is not targeted to be frozen until December 1998.) The lifting body-type configuration and packaging layout between X-33 and RLV are maintained, however, still enabling technology traceability from the X-33 to the RLV. Thus the gains required to achieve the end objective- to produce a commercially viable reusable launch vehicle, significantly reducing the costs for access to space- are maximized.

This paper will discuss the significant RLV trade studies that have led to the current configuration, with the objective that the lessons learned from the X-33 and the ground test program provide the necessary information required for the end-of-the decade RLV decision