NASA-TM-111868

THE REUSABLE LAUNCH VEHICLE TECHNOLOGY PROGRAM AND THE X-33 ADVANCED TECHNOLOGY DEMONSTRATOR

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BACKGROUND

The next generation of U.S. launch vehicles must dramatically lower the cost of space access. Today, many promising space missions and experiments are grounded because of overwhelming launch costs—only the Nation's highest priority payloads are being launched. The cost of space transportation consumes so many resources (budget, talent, and facilities) that too little remains to undertake the bold endeavors that push technological advancements and inspire the imagination and spirit. Reducing the cost of space access would spur the Nation's competitiveness and its industrial might.

Today's launch systems have major shortcomings that will increase in significance in the future, and thus are principal drivers for seeking major improvements in space transportation. They are too costly; insufficiently reliable, safe, and operable; and increasingly losing market share to international competition. For the United States to continue its leadership in the human exploration and wide ranging utilization of space, the first order of business must be to achieve low cost, reliable transportation to Earth orbit.

The space launch industry is at a crossroad much like the one faced by the fledgling airline industry in the early 1930's. An evolutionary technical leap, coupled with a revolutionary cultural shift, must be made—analogous to the DC–3 aircraft—for space launch to become truly routine. NASA's Access to Space Study, in 1993, recommended the development of a fully reusable single-stage-to-orbit (SSTO) rocket vehicle as an Agency goal.

An all-rocket SSTO vehicle appears to be the best blend of near-term achievable technology an affordability for low-cost routine space access after the turn-of-the-century. It is an *evolutionary, not revolutionary*, path that relies on 25 years of aerospace experience to mature and demonstrate several advanced technologies needed to make a new reusable launch vehicle a cost-effective reality.

PROGRAM GOALS AND OBJECTIVES

The goal of the Reusable Launch Vehicle (RLV) technology program is to mature the technologies essential for a next-generation reusable launch system capable of reliably serving National space transportation needs at substantially reduced costs.

The primary objectives of the RLV technology program are to (1) mature the technologies required for the next-generation system, (2) demonstrate the capability to achieve low development and operational cost, and rapid launch turnaround times and (3) reduce business and technical risks to encourage significant private investment in the commercial development and operation of the next-generation system.

Developing and demonstrating the technologies required for a Single Stage to Orbit (SSTO) rocket is a focus of the program because past studies indicate it has the best potential for achieving the lowest space access cost while acting as an RLV technology driver (since it also encompasses the technology requirements of reusable rocket vehicles in general). However, the private sector may ultimately choose the operational RLV configuration to be flown

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post-2000 that can compete in an international market.

Concept Definition

The concept definition studies develop system sensitivities for the flight vehicle and technology demonstrator systems and identify the enabling vehicle technology requirements (i.e., targets). The concept studies will focus on SSTO rocket-powered concepts. Emphasis will be placed on development, operational costs, and performance. The concept definition process will:

- Evaluate the merits of vehicle concepts for a given set of mission and system requirements —with a focus on reduced operations costs.
- Provide the operating environments and targets for the candidate technologies as a means for evaluation of the readiness of the candidates.

Propulsion Technologies

This technology area develops and demonstrates the operational and performance characteristics of engine and main propulsion systems, and defines derived requirements for an operational propulsion system. Key objectives for the RLV propulsion system must be robustness, operability, high thrust-to-weight ratio, and an affordable development program with acceptable risk. The technology component development will validate design capability, define component hardware response, and demonstrate manufacturing processes.

Vehicle Structural Technologies

This program area addresses technology maturation for reusable cryogenic tank systems, reusable composite primary structures, and thermal protection systems. The goal is to demonstrate representative systems which are manufacturable, operable, and traceable/scaleable to an SSTO system. The efforts focus on the integration and life cycle demonstrations of the load carrying structure, cryogenic insulation (as required), thermal protection material, and associated health management/monitoring. Initial activities are a balance of laboratory experiments, ground testing, and flight testing to establish the capability/limits of candidate solutions. Later efforts (post 1996) begin to develop hardware for flight testing on an advanced technology demonstrator - X-33.

Operations Technologies

Operations technologies include operations enhancement technologies (e.g., health maintenance systems, etc.) and advanced avionics (e.g., automated flight control). A goal of the operations enhancement area is to develop and demonstrate technologies that will permit automation and the reduce manpower requirements associted with: between flight maintenance, the launch complex, and required ground based flight operations support. A goal of the advanced avionics area is to shift the more of the responsbility for mission control from the ground to the flight vehicle.

For the first time within space launch vehicle programs, a detailed reliability, maintainability, and supportability (RM&S) approach will be established. The RM&S Program will be carried through the entire technology and X-33 / X-34 program development. These are focused on assuring that the vehicle can indeed be operated in an efficient and cost-effective manner. In addition to these specific technology tasks, the requirements to achieve low operations costs (i.e., minimal personnel and cost for refurbishment, inspection, and prelaunch processing) will be integrated into the other technology areas.

Flight Demonstrators

Flight demonstration is a key and integral part of the overall RLV technology program. It is clear that flight demonstration will force the real technology development issues to surface early in the program, thus minimizing technical issues during the more costly full scale development phase. The overall objectives which are common to all three demonstrators (DC-XA, X-34, and X-33) include:

- Provide an integrated systems testbed for advanced technologies
- Demonstration of capabilities in realistic ground and flight environments of a next generation system
- Demonstration of operability, maintainability, and reusability required for a next generation system
- Demonstration of mass fraction scalable to a full-scale SSTO (X-33 only)
- Demonstration of rapid prototyping
- Demonstration of the ability to perform "faster, better, cheaper"

RLV TECHNOLOGY PROGRAM IMPLEMENTATION

The RLV technology program is an integrated, fast-track approach for reducing the technical and business risk in developing economical, operational, reusable launch vehicles. An integrated ground and flight test program is being implemented to characterize key component technologies and to validate their systems' capabilities, both from a performance and operations viewpoint. The program will develop and validate vehicle, propulsion, and operations technologies. The integrated program is shown on Figure 1 -- RLV Technology Implementation.

To commit to specific component technologies for both the flight demonstrators and the full-scale operational vehicle, it is necessary to demonstrate that components have robust and well-understood design margins relative to the applications for which they are intended. Thus, the ground test program will entail cycling of the candidate components under realistic environmental conditions to establish the acceptable number of flight cycles before deterioration, or failure of the components will occur.

The flight test demonstration program (DC-XA, X-33, and X-34) will be implemented to identify component and system integration issues in the RLV program that are unresolved by ground test and to confirm the environments that are employed in the ground tests.

RLV Technology Program Phase I (1994 - 1996)

The primary objective of the Phase I effort is to demonstrate capability to achieve low operational cost by bringing a wide range of technology candidates to a level of maturity sufficient to permit a narrowing of component and materials choices to permit cost effective large scale (Phase II) technology demonstrations. A prime emphasis in this activity is demonstration of attributes that will enable low operational costs. Multiple technology system concepts will be evaluated in scaled relevant environments. Results will be used to validate the analytical models which will permit the construction of large scale ground and flight systems in Phase II. The technology elements in Phase I range from subscale materials and components to approximately one-third scale hardware that can permit concept selections to be made. The following technology areas are being addressed in this phase:

- Operations Technologies
- Graphite Composite Primary Structure
- Reusable Cryogenic Tanks
- Long Life/Low Maintenance TPS
- Advanced Propulsion Systems.

RLV Technology Program Phase II (1996 - End of Decade)

In Phase II, large scale hardware will be developed with a focus the X-33 Advanced Technology Demonstrator (ATD) vehicle. The X-33 is an integrated ground and flight operations demonstration of the critical technologies required for a SSTO RLV. The technology development and demonstration activities will be focused on flight demonstrations of the X-33, supported by appropriate ground test. The design of the X-33 and ground test articles will be based on the results of the Phase I technology system selections. Phase II designs will more accurately represent full-scale RLV components and will be subjected to more realistic flight environments. Ability to achieve low cost operability targets must be

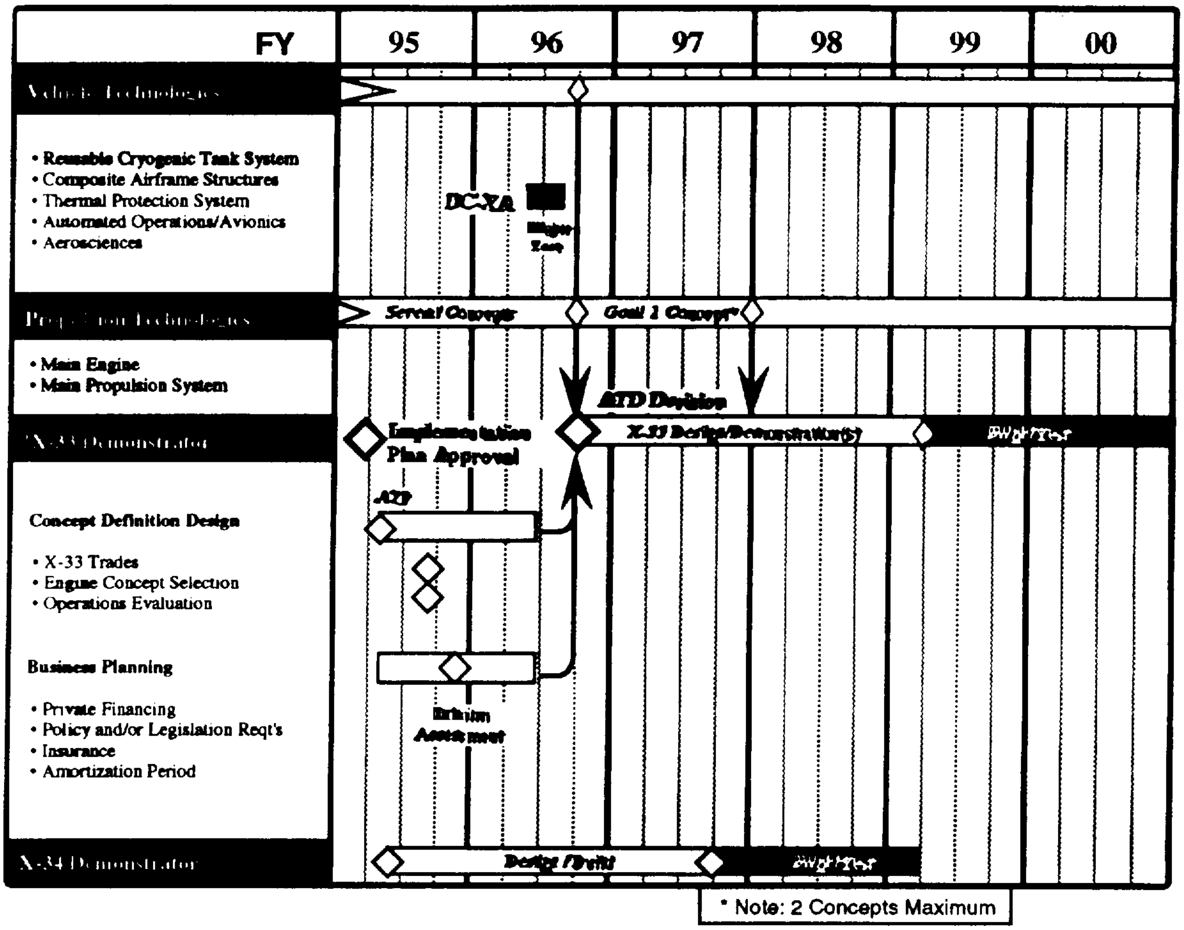

Figure 1.-- RLV Technology Implementation

demonstrated by the X-33. In addition to the issues addressed in Phase I, SSTO mass fraction will be demonstrated.

Business and technical information developed at the end of this phase will permit Government / private sector decisions on development and operation of a next generation launch system.

Propulsion Technologies

Propulsion technology efforts will demonstrate the operational and performance characteristics of candidate engine and main propulsion systems and define and establish a set of derived requirements for an operable propulsion system. Key targets for the next-generation propulsion system are robustness, operability, high thrust-to-weight ratio, and an affordable development program with acceptable risk. Both U.S. and foreign technologies that offer the potential for expediting the development of technology for future next-generation engines will be investigated. Ground-based subscale engine and main propulsion systems demonstrations will provide a testbed for demonstration of operability and performance targets and will permit extrapolation of targets from demonstrated conditions to full scale. A technology component development activity will validate design concepts, define component hardware response, and demonstrate cost-effective manufacturing processes.

Candidate engine systems currently identified for reusable vehicles include both bipropellant (e.g., LO_2/LH_2) and tripropellant (e.g., LO_2/LH_2/RP-1) engines. Initial studies indicate that tripropellant or advanced bipropellant (high thrust-to-weight configurations) propulsion systems are required to achieve sufficient design margins. Engine concepts being evaluated include a Space Shuttle Main Engine (SSME)-derived dual bell, an advanced aerospike, an advanced full-flow-staged combustion cycle single bell for bipropellant, an SSME-derived bell-annular concept, an RD-704-derived concept, and an RD-0120-derived concept for tripropellant. Key technologies for all of these concepts include LO_2 rich compatible materials, modular combustion chamber development, and the use of advanced Ceramic Matrix Composite (CMC) materials in component designs. Table 1 provides an overview of major products in 1995 and 1996.

Vehicle Structural Technologies

Vehicle structural technologies encompass reusable cryogenic tank systems, graphite-composite structures, and Thermal Protection Systems (TPS). The efforts focus on the operability and integration of the load-carrying airframe structure, cryogenic insulation (as required), thermal protection material, and associated health management for the next-generation system. Early (1994-96) activities will be a balance of laboratory experiments, ground testing, and flight testing to establish the operability, performance, and limits of candidate solutions. Foreign technologies that offer the potential for expediting the development of advanced technology for future structural systems will be investigated. Later efforts (1996-99) will focus on the development of large-scale hardware for flight testing on the X-33.

The reusable rocket must return from orbit with its cryogenic propellant tanks, presenting complex thermal-structural challenges. Issues associated with life-cycle effects on the integrated tank system—tank wall, cryogenic insulation, and TPS—must be addressed. Aluminum-lithium (alloys) and graphite-composite tank materials are being considered. To significantly reduce structural mass and alleviate fatigue and corrosion concerns, nonpressurized airframe structures will be constructed of graphite composite, drawing on current aircraft and rocket designs. These include both low- and high-temperature composites. TPS candidates for acreage areas include both ceramic and metallic concepts. Leading edge, nose cone, and control-surface material candidates include advanced carbon/carbon and CMC.
Table 1 provides an overview of major products in 1995 and 1996.

Operations Technologies

To meet the fundamental goal of affordable access to space, a major emphasis will be placed on realizing significant savings in operations cost through advancement in operations and maintenance technologies and processes. Fast turnaround times, small ground crews, and airline-type maintenance will permit operations costs to drop dramatically.

Automated operations technologies will be applied to the streamlining and simplifying of the ground and flight operations of the next-generation system to achieve cost and performance goals. Technologies include automated checkout, vehicle health management/monitoring systems, autonomous flight controls and "smart" avionics/guidance navigation. Incorporation of process enhancements such as one-time flight certification, hazardous materials elimination, ground-scheduling systems, and a philosophy of reliability-centered maintenance and minimum operations between flights will contribute to an aircraft-like operations process. A detailed reliability, maintainability, and supportability approach will be established and executed throughout the program to ensure that the vehicle can indeed be operated in an efficient and cost-effective manner.

• **Structures and TPS**	**CY 1995**	**CY 1996**
- Reusable Cryo Tank System	DC-XA Gr-Comp. LH2 Tank Sys. (MDA) DC-XA Russian Al-Li LO2 Tank Sys.-2 (MDA) Gr-Comp. LO2 Bottles (MDA) Reusable Cryo Insulation (MDA and RI) Cyro Tank Panels (RI)	Sub-Scale Gr-Comp. LH2 Tank Sys. (RI) Sub-Scale Gr-Comp. LO2 Tank Sys. (MDA)
- Graphite Composture Primary Structure	DC-XA Intertank (MDA) Intertank, Wing, and Thust Structure Components and Elements (RI)	Sub-Scale Intertank Sys. (MDA) Sub-Scale Isogrid Intertank (MDA-Russian) HITemp Composite Structures (MDA) Full Scale Intertank Sys. Segment (RI) Full Scale Thrust Structure Sys. Segment (RI) Full Scale Wing Sys. Section (RI)
- TPS	Internal Multiscreen Insulation (MDA) Metallic Panels (MDA) C/SIC Panels (MDA) TABI Blankets (RI) TABI Blankets w/ MLI (RI) Waterproofing Demo (RI) Attachment Test Articles (AETB, CMC - RI)	Metallic Panel Arrays (MDA) C/SIC Panel Arrays (MDA) TABI Panel Arrays (RI) TABI w/ MLI Panel Arrays (RI)
• **Propulsion** - Main Propulsion System	Catalytic Igniter (Allied Signal) Passive LO2 Conditioning (MMC) LO2 Cavitation Prevention (MMC) 19 Element Tri-Prop Injector (P&W) Unielement Tri-Prop Injector (Penn State) Unielement Ox Rich Injector (Penn State) Modular Combustion Chambers (R'dyne) Ox Rich Turbline Drive (R'dyne)	Tri-Prop Preburner (Aerojet) 40 K Nozzle Extension (Fiber Mat'ls&RCI) Unielement Tri-Prop Injector (Penn State) Unielement Ox Rich Injector (Penn State) Modular Combustion Chambers (R'dyne) Ox Rich Turbline Drive (R'dyne) Integrated Bi-Prop Prop. System Testbed (RI)
- Auxiliary Propulsion System	Liq-Gas Conversion System (MDA) O2/H2 APU (MDA) Composite Valve Body (MDA) Integrated DC-XA Pallet (MDA)	RCS Chamber Mat'l Prop' (Fiber Mat'ls&RCI)

Note: System Includes Structure, Insulation, TPS, and VHM (each where appropriate)

Table 1 -- Key 1995 and 1996 Technology Products

Flight Demonstrations

Because they are an integrated system, flight demonstrations force the key technology development and operations issues to surface, thus minimizing technical and operational risk during the more costly next-generation-system development phase. These are also the key testbeds for proof-of-system operability and rapid turnaround times. The following paragraphs describe the planned demonstrators and their respective roles in the development and demonstration of RLV technologies.

<u>DC-XA - Experimental Advanced</u>

The McDonnell Douglas Delta Clipper-Experimental (DC-X) vehicle, developed and initially demonstrated by the Ballistic Missile Defense Organization, will be transferred to NASA, and advanced technology upgrades will be installed, reconfiguring it as the DC-XA. The following technology components are currently planned to be incorporated into the vehicle: (1) aluminum-lithium liquid oxygen tank, (2) composite liquid hydrogen tank, (3) composite intertank structure, (4) integrated auxiliary propulsion system consisting of a liquid-to-gas conversion system, (5) modified auxiliary power unit, and (6) hydrogen leak-detection sensors. Each of these components will be built to technical specifications traceable and scalable to a next-generation system and will undergo ground-checkout testing prior to installation in the DC-XA vehicle for mid-1996 flight testing. Testing of the upgraded technology components in flight and natural environments will be used to demonstrate system operability.

<u>X-34 Small Booster Technology Demonstrator</u>

The X-34 will be used to investigate technologies that may be incorporated into future reusable launch vehicles. This program, which will be jointly funded with the commercial launch industry, minimizes development uncertainties and accelerates timetables for validating less costly, more operable and reliable small booster vehicle components and flight test articles. Orbital Sciences Corporation (OSC) was selected on March 6, 1995 as the developer of the X-34.

The X-34 will benefit the overall RLV program since it offers the prospect of an early testbed, including a realistic flight environment, for some of the advanced components that could be used for the next-generation system. These components and systems potentially include the following:

- Advanced thermal protection systems (high-temperature nose cap and leading edges),
- Advanced avionics and flight-control systems, including autonomous reentry and landing,
- Vehicle health monitoring systems, and
- Ground operations/rapid turnaround.

Just as important as the technology that it will demonstrate, the X-34 provides an early opportunity to demonstrate streamlined management and procurement, industry cost sharing and lead management, and the economics of reusability. The X-34 is a logical precursor to a full-scale next-generation reusable launch system.

X-33 Advanced Technology Demonstrator

The X-33 is an experimental SSTO rocket proof-of-concept demonstrator. The X-33 system must prove the concept of a next-generation system by demonstrating key technology, operations, and reliability requirements in an integrated flight vehicle. This program will implement the recently released National Space Transportation Policy, specifically Section III, paragraph 2(b): "Research shall be focused on technologies to support a decision no later than December 1996 to proceed with a sub-scale flight demonstration which would prove the concept of single-stage to orbit."

Critical characteristics of SSTO systems, such as the structural/thermal concept, aircraft-like operations and maintenance concepts, flight dynamics, flight loads, ascent and entry environments, mass fraction, fabrication methods, etc., will be incorporated into the X-33 system. As a minimum, the X-33 will be an autonomous, suborbital, experimental, single-stage rocket flight vehicle. As shown in Figure 2, three basic classes of X-33/SSTO are being investigated: vertical takeoff, horizontal landing (VTHL) wing-body, vertical takeoff, horizontal landing (VTHL) lifting-body, and vertical takeoff, vertical landing (VTVL) concepts.

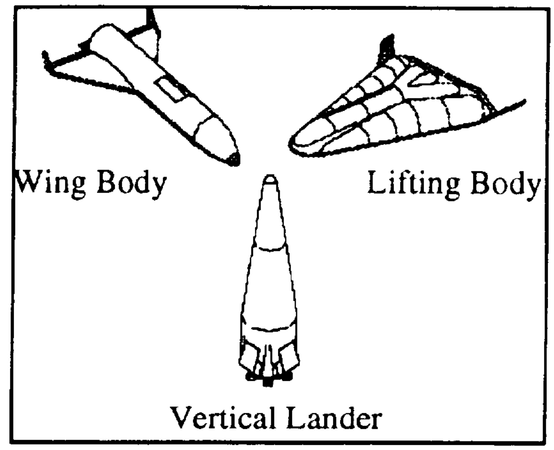

Figure 2.-- Basic Classes of X-33/SSTO Concepts

During Phase I, a competitive X-33 concept definition/design activity combined with ongoing technology developments and demonstration, will culminate in the downselection of the X-33 concept in FY 1996. A wide range of technology candidates will be demonstrated to a level of maturity sufficient to reduce the number of alternatives, enabling the design and development of a cost-effective, large-scale technology demonstrator. Sufficient data must be available by the summer of 1996 to support the decision to proceed into the final design/development and flight test of the X-33 (Phase II). Business and operations planning results from this activity, when combined with the design maturity and technology status, will serve as major elements in the selection process. Three industry teams were selected on March 6, 1995 to compete during this phase to develop the X-33: Lockheed/Martin, McDonnell Douglas / Boeing, and Rockwell.

In Phase II, and based on a Presidential decision to proceed, the X-33 will serve as the flight testbed for large-scale elements of critical RLV technologies and is the focus of the program leading to the next-generation-system decision by the end of this decade. This phase will consist of the final design, fabrication, assembly and test of the X-33 system. The X-33 vehicle will be flight tested, using a flight envelope expansion process and will demonstrate "aircraft like" operations (minimal ground crew size, short turnaround times, etc.). Flight testing will be accomplished at an appropriate test range. Complementary ground based demonstrations will round out the technology development efforts required for the next generation system.

The end of the decade decision could result in an operational vehicle in the 2005 timeframe. However, depending on the success of the technology development program, the initial next-generation- system operations date could be sooner.

Table 2 describes the minimum set of technical requirements for the X-33. A set of initial requirements for its corresponding operational SSTO rocket are shown and are subject to later trades to be performed during Phase I.

An overarching requirement is that the X-33 system, subsystems, and major components will be designed and tested so as to ensure their traceability (technology and general design similarity) and scaleability (directly scaleable weights, margins, loads, design, fabrication methods, and testing approaches) to a full scale SSTO rocket system.

PROGRAM MANAGEMENT

The NASA RLV technology program is being executed in cooperation with the Department of Defense (DoD) and by involving the private sector as partners in planning and evaluating the activities. The management approach provides a full understanding of the cost, schedule, and development risks before decisions to proceed are made.

NASA's approach of forging partnerships with industry will be reflected in the use of contractual vehicles, such as cooperative agreements for this joint Government/industry ventures approach. Both industy and government partners contribute cash (or IR&D), in-kind, and manpower resources to the effort.

Marshall Space Flight Center (MSFC) will serve as the host Center for the program, which will draw upon the resources of other NASA Centers and the U.S. Air Force (USAF) to support the effort. The RLV program will be managed by a small program office. Government and contractor personnel will be minimized in order to demonstrate the effective streamlined management approach necessary to reduce development and operations costs. This approach will incorporate the experience gained from the DC-X program.

The USAF has been designated as the DoD organization which will coordinate and manage related DoD investments, including RLV technologies. The cooperative NASA/USAF technology program will provide the technology base for future related applications of both agencies. The USAF, with its expertise in aircraft operations, maintenance, and flight testing, will bring these complementary disciplines to the cooperative RLV activities. With these capabilities, the USAF will provide leadership in the RLV flight demonstration program for operations concepts, performing flight-test range facilitation, flight-test planning, and flight-test operations.

The DC-X program, which preceded this effort, was executed by DoD by the aggressive application of similar management concepts and principles. NASA intends to adapt its internal procedures and its relationship with industry and DoD and apply these concepts and principles to the RLV program.

The new model for the relationship among NASA, industry, and DoD is a partnership. The concept of a partnership embodies mutual responsibility for the effort, mutual benefit from the research and design efforts, and mutual contribution of assets to the execution of the effort.

Table 2: Minimum X-33 and Corresponding SSTO Requirements

	X-33	Corresponding SSTO
CAPABLE		
Performance		
• Suborbital, reusable rocket-based flight system	REQ	N/A
• Mission Applications: -- Payload Delivery: Government (Civil/Military) and Commercial Missions. -- Capable of delivering/returning cargo and crew complement to/from the International Space Station (ISS) in accordance with ISS requirements (e.g., minimum sizes, loads, schedule) • • ISS located at 220 nmi (244 nmi max) Altitude and 51.6° Inclination. • • Current estimated payload delivery requirement: 20–25,000 lbm	N/A	REQ
Launch and Flight Operations		
• Automated pre-flight and flight operations (launch, ascent, on-orbit, reentry, landing)	REQ	REQ
• The flight vehicle shall be capable of safely aborting to the launch site during the ascent phase if required	GOAL	REQ
• 7 day maximum mission duration	N/A	REQ
• 7 day ground processing time from landing to launch.	GOAL	GOAL
• 3.5 day ground processing time from landing to launch for reflight under emergency conditions.	GOAL	GOAL
On-Orbit Operations		
• The system shall be able to autonomously rendezvous and station keep with the International Space Station and other orbital spacecraft.	N/A	As REQ
• The system shall be able to autonomously dock payloads with the International Space Station.	N/A	REQ
Accommodate Payloads		
• The flight vehicle shall provide standardized structural, mechanical, electrical, communications, and other interfaces to payload.	N/A	REQ
• 15 ft diameter x 30 ft long cargo bay	N/A	REQ
OPERABLE		
Schedule Dependability		
• The probability of launching within TBD days of scheduled is 0.95	GOAL	REQ
Responsive		
• Maximize robustness to adverse weather conditions.	REQ	REQ
Supportable		
• Launch and landing at same location (nominal condition).	REQ	REQ
• The flight vehicle shall be capable of unplanned landing at alternate landing sites with minimal support equipment/facilities, e.g. -- No existing cryogenic facilities, launch stands/equipment, etc. -- Self-ferry of flight vehicle between landing and launch sites (add-on engines, landing/nav lights, etc. equipment allowed).	GOAL	REQ
Maintainable		
• To the extent practical, on-board subsystems required for the flight vehicle shall be field repairable/replaceable.	GOAL	REQ
• Equipment required to repair, process and return vehicle to launch site shall be transportable.	GOAL	REQ
RELIABLE		
• 0.995 Probability of safe recovery of the flight vehicle per mission.	N/A	REQ
• 0.999 Probability of safe recovery of the human passengers per mission.	N/A	REQ

REQ: Requirement / GOAL: Desirable Attribute
N/A: Not Applicable