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REUSABLE LAUNCH VEHICLE TECHNOLOGY PROGRAM†

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Abstract—Industry/NASA reusable launch vehicle (RLV) technology program efforts are underway to design, test, and develop technologies and concepts for viable commercial launch systems that also satisfy national needs at acceptable recurring costs. Significant progress has been made in understanding the technical challenges of fully reusable launch systems and the accompanying management and operational approaches for achieving a low-cost program.

This paper reviews the current status of the RLV technology program including the DC-XA, X-33 and X-34 flight systems and associated technology programs. It addresses the specific technologies being tested that address the technical and operability challenges of reusable launch systems including reusable cryogenic propellant tanks, composite structures, thermal protection systems, improved propulsion, and subsystem operability enhancements. The recently concluded DC-XA test program demonstrated some of these technologies in ground and flight tests. Contracts were awarded recently for both the X-33 and X-34 flight demonstrator systems. The Orbital Sciences Corporation X-34 flight test vehicle will demonstrate an air-launched reusable vehicle capable of flight to speeds of Mach 8. The Lockheed-Martin X-33 flight test vehicle will expand the test envelope for critical technologies to flight speeds of Mach 15. A propulsion program to test the X-33 linear aerospike rocket engine using a NASA SR-71 high speed aircraft as a test bed is also discussed. The paper also describes the management and operational approaches that address the challenge of new cost-effective, reusable launch vehicle systems. ©1998 Published by Elsevier Science Ltd. All rights reserved

1. INTRODUCTION||

Cost effective, reliable space transportation is a major focus of current government and commercial launch industry efforts. The paths to this goal range from incremental improvements to existing launch systems, such as the Department of Defense (DoD) evolved expendable launch vehicle (EELV) program, to new systems that hold the promise of opening the space frontier to a variety of new space industries. In the latter case, the National Aeronautics and Space Administration (NASA) reusable launch vehicle (RLV) technology program is seeking a near-term replacement for the Space Shuttle.

The RLV technology program has as a goal the development of an all rocket, fully reusable single-stage-to-orbit (SSTO) vehicle. It has several major elements: the X-33 advanced technology demonstrator, the X-34 testbed technology demonstrator, and the upgraded DC-XA flight demonstrator. The purpose of this paper is to review the current status of the RLV technology program. It examines how these elements address the technical and operability challenges of reusable launch vehicles whose solutions are necessary to reduce recurring costs. Management and operational approaches that address the challenge of new cost-effective, reusable launch vehicle systems are also discussed.

2. RLV TECHNOLOGY PROGRAM OVERVIEW

The goal of the RLV technology program is the lowering of the cost of access to space to promote the creation and delivery of new space services and other activities that will improve economic competitiveness. To this end, the program supports the development of an all rocket, fully reusable SSTO.

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||Nomenclature is given in Appendix at the end of the paper

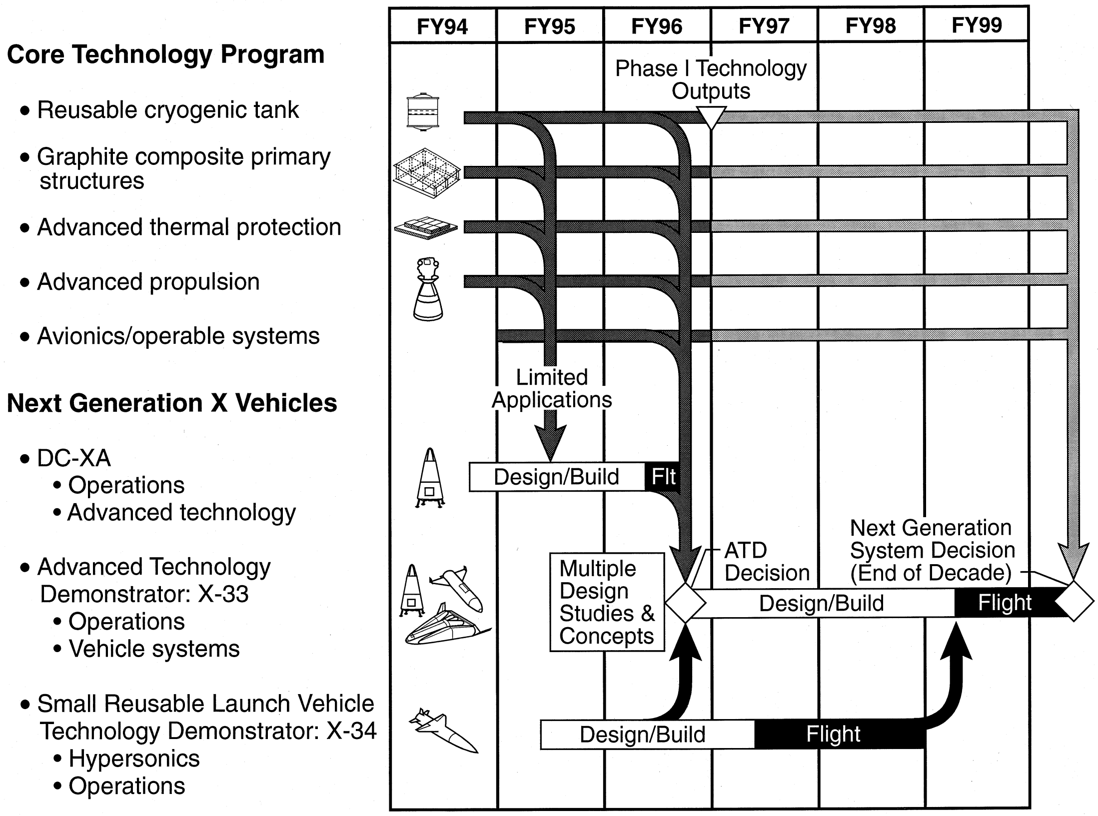

Fig. 1. Reusable launch vehicle technology program schedule.

However, the private sector is free to ultimately select the operational RLV configuration to be flown in the post-2000 time frame.

The RLV technology program has several major elements that together support its objectives. These elements are synergistic as illustrated in Fig. 1.

The core technology program, initiated in early 1994, supports design and manufacture of key technology elements necessary for an operational RLV. Testing of initial demonstration articles took place using the DC-XA flight test vehicle during the summer of 1996. The core technology program implements the National Space Transportation Policy that specifies, "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."

In January 1995, two Cooperative Agreement Notices (CAN 8-1 and 8-2) [1,2] were issued by the NASA calling for design and development of a: (1) RLV advanced technology demonstrator designated the X-33; and a (2) RLV small reusable booster designated the X-34.

NASA's intent with the X-33 solicitation is to demonstrate critical elements of a future SSTO rocket powered RLV by stimulating the joint industry/government funded concept definition/design of a technology demonstrator, the X-33, followed by design and flight demonstrations of one or more competitive concepts. The X-33 must adequately demonstrate key design and operational aspects of a future commercially viable RLV.

The intent of the X-34 solicitation was originally to stimulate the joint industry/government funded development of a small reusable, or partially reusable, booster that had potential application to commercial launch vehicle capabilities to provide significantly reduced mission costs for placing small payloads (1000–2000 lb) into a low Earth orbit starting in 1998. Importantly, from the NASA perspective, the CAN stated that "the booster must demonstrate technologies applicable to future reusable launch vehicles."

3. DC-X, DC-XA

In 1990, The Ballistic Missile Defense Organization (BMDO) initiated the single-stage rocket technology (SSRT) program to demonstrate the practicality, reliability, operability and cost efficiency of a full reusable, rapid turnaround single-stage rocket. Following an initial design competition phase, BMDO awarded McDonnell-Douglas a $59 M contract in August 1991, with the primary emphasis on the design and manufacture of a low-speed rocket demonstrator vehicle named the DC-X (Delta Clipper Experimental), Fig. 2, a subscale ver-

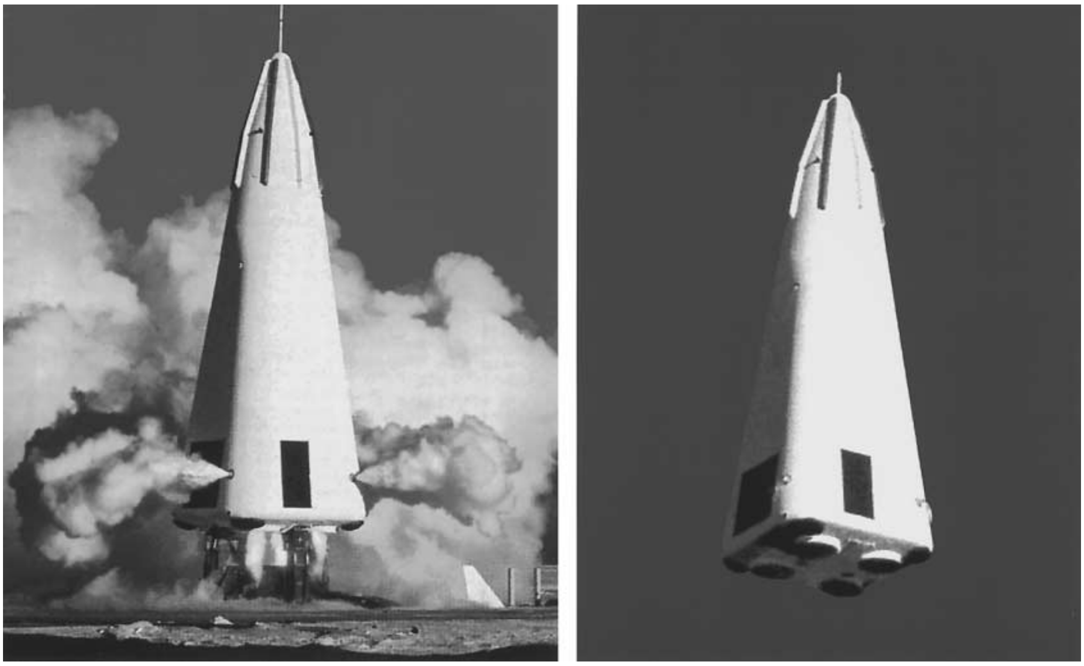

Fig. 2. DC-X at take-off and in flight.

sion of the Delta Clipper vertical takeoff, vertical landing SSTO under study by McDonnell-Douglas. The goals of the DC-X program [3] were a demonstration of rapid prototyping of hardware and software, demonstration of vertical takeoff and landing, aircraft-like operations, and rapid system turnaround.

The DC-X achieved a rapid prototyping development and flew for the first time two years after the award of the contract. From August 18, 1993 through July 7, 1995, the vehicle flew eight test flights with the test envelope expanded with each succeeding flight. The last three flights in particular demonstrated engine differential throttling for flight control, the use of a gaseous oxygen/hydrogen reaction control thruster module, and engine performance under wide pitch-over excursions that help demonstrate maneuvers such a vehicle would have to make following re-entry. Ground operations data were collected and flight operations with a small number of personnel demonstrated although one of the goals, a rapid system turnaround was not achieved. The test flights were not without incident. Although a ground explosion on flight No. 5 severely damaged the vehicle's composite aeroshell, the vehicle continued its flight, owing to its rugged boilerplate construction, and demonstrated its emergency autoland system. A faster-than-nominal vertical descent to landing on the flight No. 8 damaged the landing gear and buckled the aeroshell.

In July 1995, the DC-X was transferred from the U.S. Air Force to NASA for use in the RLV program. Renamed DC-XA (A for advanced), the vehicle was modified by McDonnell-Douglas to test several key technologies of the RLV program. Changes, depicted in Fig. 3, included: (1) a switch from an aluminum oxygen tank to a Russian-built aluminum–lithium alloy cryogenic oxygen tank with external insulation; (2) a switch from an aluminum cryogenic hydrogen tank to a graphite–epoxy (Gr–Ep) composite liquid hydrogen tank with low-density reinforced foam internal insulation, (3) a Gr–Ep composite intertank structure; (4) a Gr–Ep composite feedline/valve assembly; (5) a gaseous hydrogen/oxygen auxiliary power unit (APU) to drive the hydraulic systems, and (6) an auxiliary propulsion system (APS) for liquid-to-gaseous hydrogen conversion for use by the vehicle's reaction control system. Manufacture, integration and ground tests were completed by May, 1996.

The DC-XA team, consisting of NASA, McDonnell-Douglas, U.S. Air Force's Phillips Laboratory, and the Army's White Sands Missile Range, planned a series of five test flights to focus on the basic functionality of the DC-XA system and its readiness to conduct regular flight operations. This was to include: (1) verifying functional integrity and operational suitability of the newly installed technologies; (2) verifying the hardware and software functions of the integrated DC-XA vehicle, the three-person Flight Operations Control Center, and the Ground Support System (15-person touch labor) under launch and flight conditions, and (3) determining the operational characteristics and flight readiness of the vehicle for any subsequent flight tests. Reflight of the vehicle within 72 h, a goal that was not achieved during the DC-XA flight series, was also another objective.

The first flight of the DC-XA took place on May 20, 1996 at White Sands, New Mexico. The flight

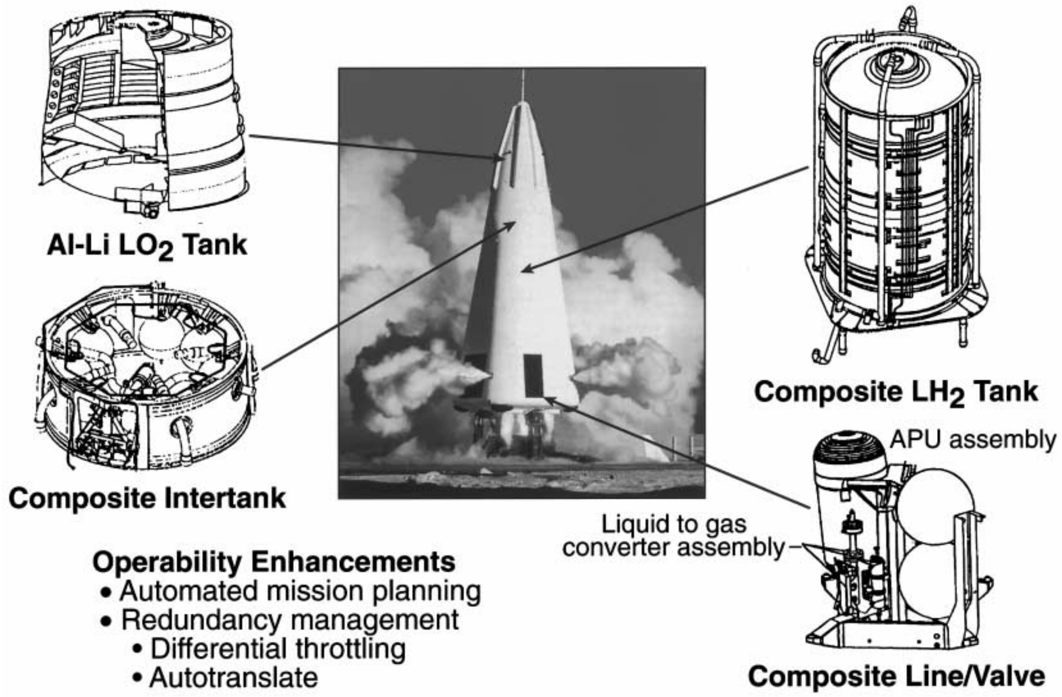

Fig. 3. DC-XA technology components.

lasted one minute with a climb to 800 ft, a translation of 350 ft and a descent to a prepared landing pad. This marked the first flight test of a composite liquid hydrogen tank on a rocket. On June 7, the DC-XA was renamed the "Clipper Graham" in honor of the late Lt. Gen. Daniel Graham who championed the promise of fully reusable SSTO launch vehicles. On the same day, the Clipper Graham flew a successful 63 s test flight. Just 26 h later, on June 8, the rocket successfully flew a 142 s flight reaching an altitude of 10,300 ft and landing on a concrete pad 350 ft from its launch pad. This rapid reflight fulfilled one of the original objectives of the DC-XA program.

On July 29, 1996 the Clipper Graham rocket flew a 140 s fourth test flight reaching an altitude of 4,100 ft. Traveling laterally, the rocket pitched its nose up to 60° back and forth along the flight path to demonstrate maneuvers such a vehicle would need to make upon re-entry. During the vertical landing phase, however, one of the four landing gears failed to deploy. Without support of the fourth gear, the vehicle tipped over after landing, as shown in Fig. 4, and both of the propellant tanks ruptured with fire destroying most of the vehicle. An incident investigation board was convened in early August, 1996, to determine the cause of the accident with a final report due in within two months.

Although the DC-XA program ended prematurely, a number of key technologies for RLVs were successfully flight tested and rapid vehicle turnaround was demonstrated. While these flights highlight the value of X-vehicles in a development program, they also suggest the reliability challenge that exists for future demonstrators and full-scale operational vehicles.

4. X-33

The objective of the X-33 NASA Cooperative Agreement Notice issued in January 1995 was "to stimulate the joint industry/government funded concept definition/design of a technology demonstrator vehicle, the X-33, followed by the design/demonstration of competitively selected concept(s)." The three phases of the program leading to an operational RLV are shown in Fig. 5.

Phase I was a concept definition and design phase, initiated in early 1995, which ended in May 1996. The three industry design teams selected for this phase included Lockheed/Martin; McDonnell-Douglas teamed with Boeing; and Rockwell International. Government labs were teamed with and assisted all the three teams during this phase. Phase II includes the design, manufacture and flight test of an X-33 concept. It was initiated in July 1996 and is to continue through to the end of the decade with X-33 flight testing beginning in early 1999. Phase III will be the implementation, based on private sector and Government decisions at the end of the decade, of the development of an operational, next-generation reusable launch system.

In Phase I the teams were to look at business investment strategies and planning for X-33 and the operational RLV, provide for operations planning

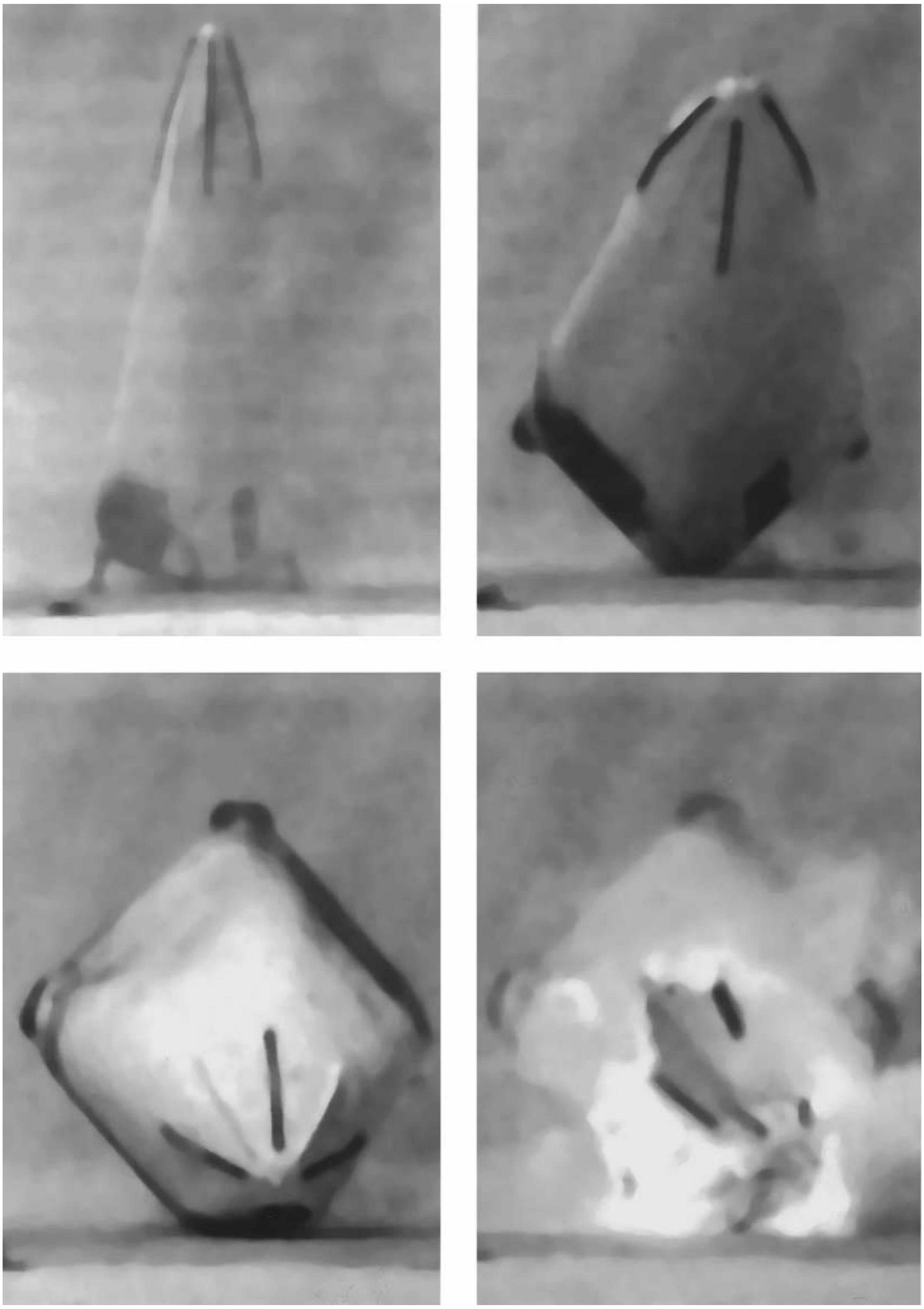

Fig. 4. Clipper Graham landing incident following fourth flight.

of the X-33 and RLV, and perform vehicle design and analysis of the X-33 designs with detail sufficient to permit a downselect to a single concept at the end of Phase I. The teams were encouraged to propose supporting technology demonstration efforts. X-33 demonstrator vehicles were subscale versions of these concepts. Included in the Phase I proposals were a vertical takeoff-horizontal landing lifting body from Lockheed-Martin, a vertical takeoff-vertical landing system from the McDonnell-Douglas and Boeing team, and a vertical takeoff-horizontal landing winged vehicle from Rockwell.

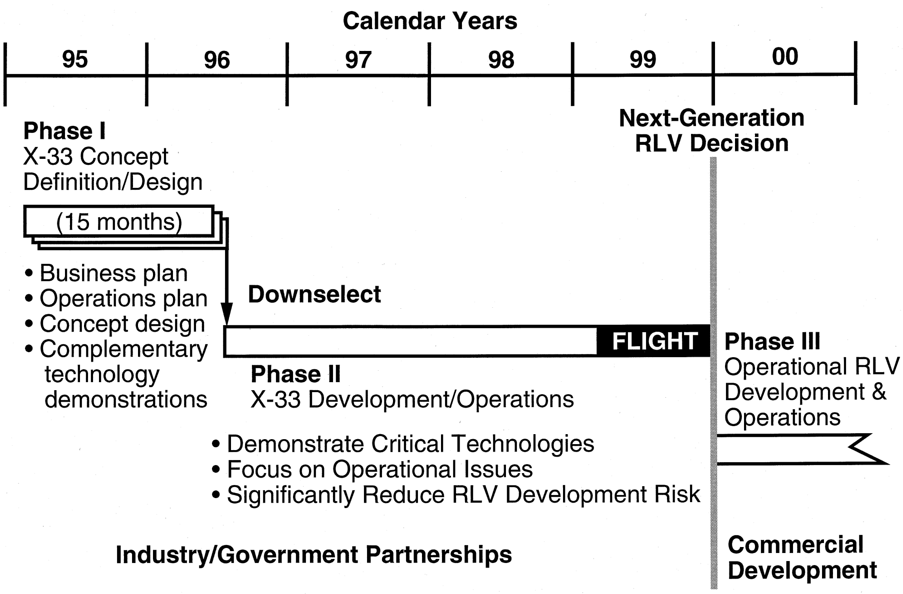

Fig. 5. Reusable launch vehicle technology program.

Figure 6 shows the three X-33 concepts examined by the design teams.

On April 1, 1996 a Cooperative Agreement Notice [4] was issued calling for proposals for Phase II of the RLV technology program, specifically, the design and demonstration of the X-33. On July 2, 1996 the Vice President of the United States announced that the Lockheed-Martin Skunk Works had been selected to build and fly the X-33 Advanced Technology Demonstrator. The selected team consists of Lockheed-Martin led by the Skunk Works in Palmdale, California, Rocketdyne (Engines), Rohr (Thermal Protection Systems), Allied Signal (Sub-systems), and Sverdrup (Ground Support Equipment) and various NASA and DoD laboratories. NASA issued a Cooperative Agreement to Lockheed-Martin worth approximately $1 billion over 42 months to build and then

Fig. 6. X-33 concepts developed during Phase I.

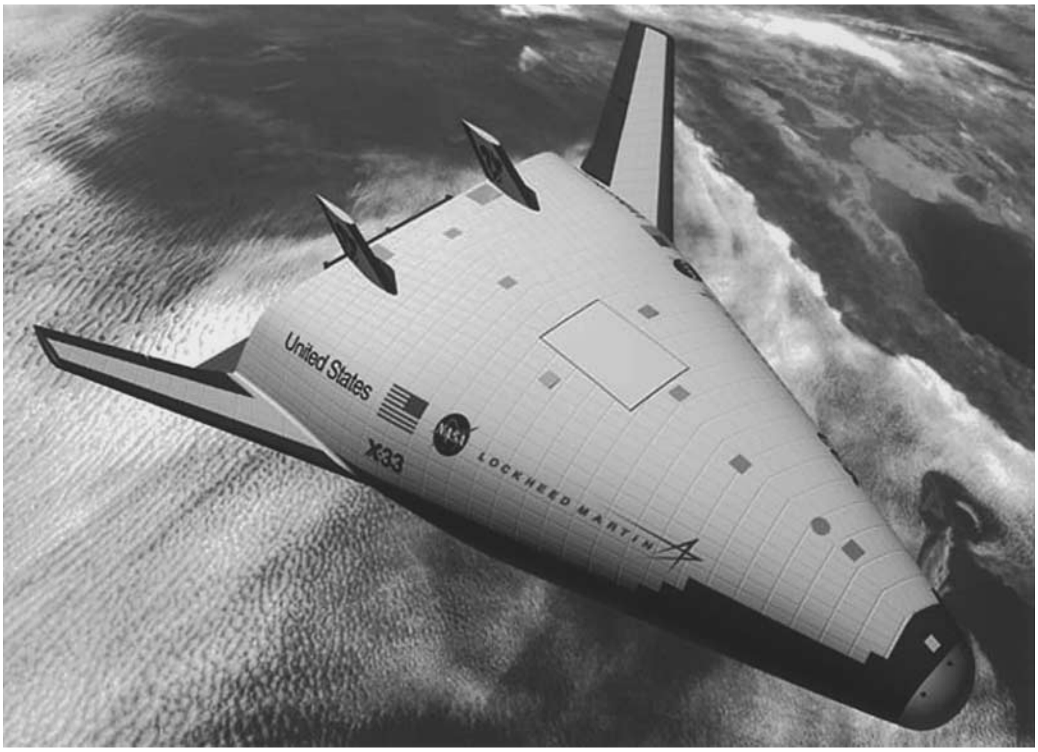

Fig. 7. Lockheed-Martin Skunk Works X-33 concept.

conduct 15 unmanned, suborbital test flights between March and December 1999. This cooperative agreement is a partnership between the Government and industry which allows both parties to contribute resources towards a common goal—low cost space access in this case. No profit is made by industry. Lockheed-Martin is cost sharing over $200 million on the X-33 program.

The Lockheed-Martin Skunk Works X-33 will be a half-scale prototype of an operational rocket-based RLV SSTO. It uses a lifting body shape coupled with an aerospike rocket engine concept to propel the vehicle to Mach 15. The overall configuration is depicted in Fig. 7.

The X-33 will consist of an integrated ground and flight test program that characterizes key component technologies and validates system capabilities both from a performance and operations viewpoint. The X-33 must demonstrate the RLV operations concept, flight stability and control, airframe, tanks and TPS technologies, loads, weights ascent/re-entry environments, fabrication methods and testing approaches. The X-33 is scheduled to complete its first flight by March of 1999. The X-33 will launch from Edwards Air Force Base in California and land at one of three test sites. The vehicle is processed horizontally within a translating shelter, rotated to the vertical position, and then launched. Upon landing the X-33 is returned to the launch site via the NASA-747 Shuttle Carrier Aircraft.

Based on the experiences of X-33 manufacture, ground and flight testing, decisions will be made by the private sector and Government as to the development of an operational, next-generation reusable launch system at the start of Phase III. The selection of the current X-33 design does not imply what such a future RLV system will look like or preclude any other industry company from pursuing such a system. The Lockheed-Martin Skunk Works proposal for an RLV dubbed "VentureStar" is depicted on the launch pad in Fig. 8. This particular design features a 45 ft long payload bay that would house removable cargo canisters designed to speed launch processing.

5. X-34

The X-34 effort was initiated as part of the overall RLV technology program in early 1995. The NASA objectives were to provide a flight demonstration vehicle between DC-XA and X-33, provide early technology demonstration of advanced operations technologies, provide a pathfinder for the more advanced X-33 program and to demonstrate cost reduction benefits of "new ways of doing business". The initial X-34 effort combined these government objectives with industry's need for a commercially viable small launcher capable of placing small payloads (1000–2000 pound class) into low Earth orbit with a factor of three reduction in launch costs.

Fig. 8. Lockheed-Martin RLV "VentureStar".

The original X-34 contract was awarded in April 1995 to an Orbital Sciences Corporation-Rockwell team. The $70 M cooperative agreement called for an equivalent amount of cost sharing by the industry team. Based on OSC's experience with the Pegasus air-launch small payload launcher, the OSC-Rockwell team proposed an air-launched X-34 booster configuration. However, the program was terminated in March 1996 when the industry partners determined that the economic viability of an operational X-34 payload launcher could not justify their investment.

A number of lessons were learned in the initial X-34 effort. First, combining a technology demonstrator program with a commercial development program results in mixed objectives which can be mutually exclusive at times. The primary example from the X-34 program was the need to fly by 1998 in order to support overall RLV needs. This requirement severely limited schedule margin and the program could not accommodate major configuration changes associated with commercial interests. Also, all teaming agreements among industry need to be in place before NASA signs cooperative agreements. The agreements should include details regarding authorities, responsibilities and decision processes. In the X-34 case, significant schedule time was lost due to negotiations between industry partners while the program was in process. Disagreements between partners led to configuration changes and missed milestones. A number of technical issues arose during the process including reaching viable vehicle mass fractions, delayed engine selection, and thermal protection system (TPS), cost and schedule issues.

Although the initial X-34 effort was unsuccessful in leading to a flight test vehicle, NASA's objectives remained and the program was redefined as a pure booster technology demonstrator without the commercial goals of the earlier program. On March 27, 1996 a NASA Research Announcement [5] (NRA) was released soliciting proposals for a restructured X-34 effort to meet NASA objectives of demonstrating technologies applicable to future RLV systems. On June 10, NASA selected Orbital Sciences Corp., Dulles, Virginia, for final negotiations leading to the award of a contract to build the X-34 demonstrator. The contract negotiations were finalized on August 30. The 30 month contract includes the first two X-34 flight tests and covers a program valued at approximately $50 million with an additional $10 million to be spent by NASA in direct support of the X-34 by NASA Centers and other government agencies.

The fast-track X-34 program calls for demonstrating a vehicle that will be capable of flying up to 25 times a year at a cost of 500,000 dollars or less per flight, attaining altitudes of at least 250,000 ft, and flying at speeds of up to eight times the speed of sound. Flight testing is to begin in the fall of 1998. Other specifications for the vehicle include use of advanced TPS and demonstration of the ability to fly subsonically through rain and fog. Flights of the X-34 will involve testing of new technologies such as composite material structures, composite tanks and new, integrated avionics, as well as demonstrations of safe abort and autonomous landing techniques, in cross winds up to 20 knots, using advanced landing systems.

Currently under study is a design shown in Fig. 9. The X-34 is a single-engine rocket with short wings and a small tail surface. The vehicle is 58.3 ft long, 27.7 ft wide at the wing tip and 11.5 ft tall from the bottom of the fuselage to the top of the tail. The X-34 will be carried aloft and launched from an Orbital Sciences L-1011 aircraft at the White Sands Missile Range in New Mexico. It will complete the initial flights within the White Sands range air space and land at the facility's runway.

6. TECHNOLOGY PROGRAM

For an SSTO to be feasible and practical (cost effective, reliable, safe) is a major challenge. While there is considerable discussion of the merits of one configuration over another, the fact is that any SSTO must incorporate a number of newer technologies with many of them common to any configuration. Some technologies are necessary to enable the concept of SSTO (to meet the feasibility challenge), while others are required to make the system cost-effective, reliable, and safe (to meet the practicality challenge). Some technologies span the feasibility and practicality challenges in SSTO design.

The specific technologies for the DC-XA test vehicle have been described in a previous section. The core technology program, however, includes additional technology developments aimed at the X-33, X-34, and operational RLV vehicles and is enhanced by contractor technology demonstrations relative to their specific vehicle configuration.

6.1. *Reusable cryogenic tanks*

The design and manufacture of large-scale, flight-weight reusable cryogenic tanks using suitable tank and insulation materials has been considered the most challenging aspect of reusable vehicle design. Multi-use cycling and application of flight loads on the aluminum–lithium liquid oxygen and graphite composite liquid hydrogen tanks in the Clipper Graham DC-XA were a step towards meeting this challenge. In particular, the composite liquid hydrogen tank, shown in Fig. 10 as it arrived at NASA Marshall Space Flight Center for testing, was the first reusable such structure to fly on a rocket and weighed 2020 pounds—1200 pounds lighter than the tank used on the DC-X. Yet, the composite tank provided the same strength of an aluminum tank. The DC-XA aluminum–lithium oxygen tank weighed nearly 600 pounds less than its DC-X aluminum counterpart. Material and structure options development will continue as the RLV program matures. Another key area of research and testing by the contractors includes material charac-

Fig. 9. Orbital Sciences Corporation X-34.

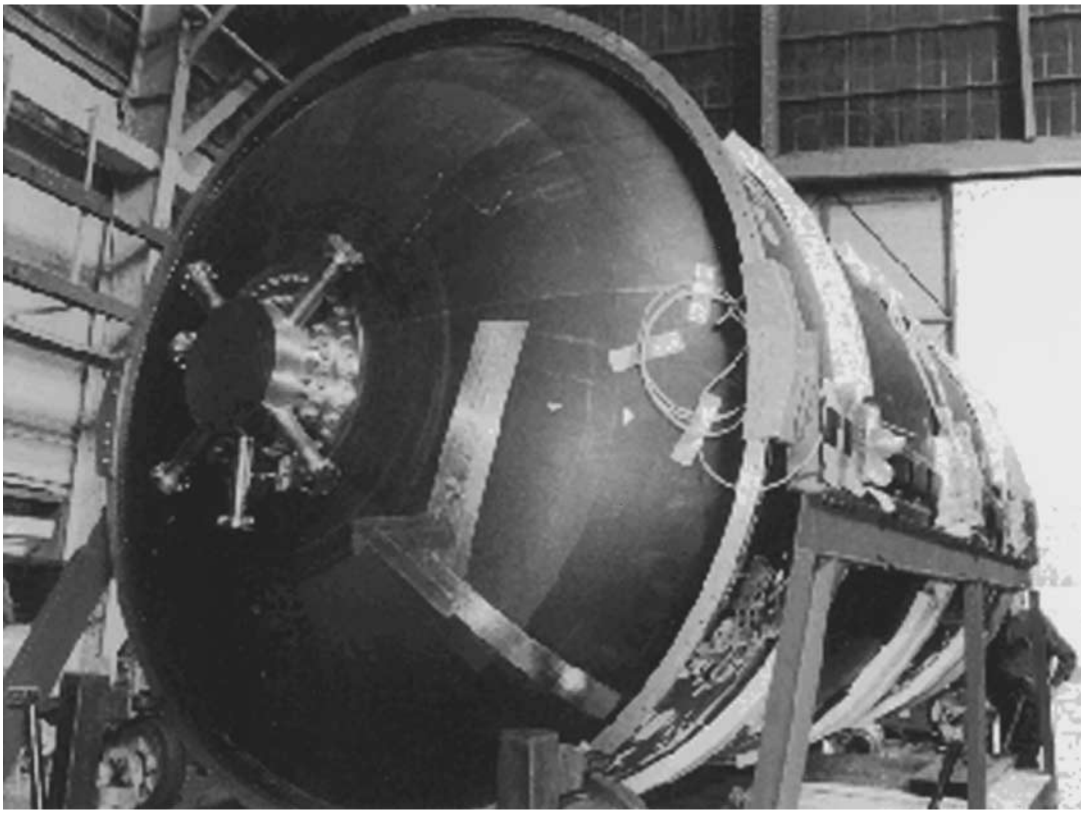

Fig. 10. DC-XA Composite Liquid Hydrogen Tank.

terization, process development, integration and test of both internal and external types of cryogenic tank insulation. Reusability and inspectability are important aspects of insulation design to be evaluated. Non-destructive evaluation and health management of reusable cryogenic tanks will also be studied. Aluminum–lithium and graphite composite tanks will be constructed and integrated with the required TPS, insulation, health monitoring, and attachment subsystems for test.

A documented analysis will be performed to demonstrate that selected materials and tank subsystems are scalable to a full-scale RLV and can be adequately demonstrated by an X-33 vehicle. Correlations between analytical predictions and experimental test results must be at a high level of confidence to ensure analytical tools are valid for purposes of full-scale vehicle design.

6.2. Composite primary structures

Composite structures offer the potential of large weight savings for RLVs. The DC-XA composite intertank, for example, provided a 300 pound weight savings over the original structure.

For the X-33 and follow-on RLV configurations, technology development efforts will demonstrate relative merits of state-of-the-art composite materials for application in wing and/or aerosurfaces, intertanks, and thrust structures. Figure 11 shows a composite RLV wing box structure under test at NASA Langley Research Center. Issues to be addressed include estimating the material property, life cycle, manufacturing, inspectability and repairability of composite materials. The objective is to meet weight, reuse, cost and operations requirements for X-33 and RLV configurations. Intertank, thrust structure, wing panel or aerosurface test articles will be constructed and integrated with TPS (if required), health monitoring, and attachment subsystems and tested. Additional coupon and subscale testing will be used to quantify weight, strength, producibility, inspectability, and operability characteristics. The documented results are necessary to validate analytical tools applicable to both X-33 and full-scale RLV configurations.

6.3. Thermal protection systems

The primary issue being addressed in this technology area is the lack of data available to estimate the durability and reuse of TPS materials in launch and entry environments. Both ceramic and metallic TPD test articles will be constructed and tested prior to use on X-33 and RLV configurations. The panels will undergo both thermal and environmental (acoustic, wind/rain, frost/ice, impact) tests. Figure 12 shows a number of TPS panels on a test fixture that was flown through rain on an F-15 fighter to examine TPS durability. Also, fail-safe attachment options for metallic and ceramic TPS panels will be examined. New thermal seal design

Fig. 11. Composite RLV Wing Box in Test Stand.

based on lessons learned from the STS and NASP programs will be tested.

Test objectives are to develop thermal protection systems capable of a 100-mission minimum lifetime and an order-of-magnitude reduction in maintenance and inspection requirements as compared to existing Shuttle TPS.

6.4. Propulsion systems

The objective of the propulsion system technology program is to develop and demonstrate main engine performance and operational characteristics. Included are investigations of thrust-to-weight, robustness, operability, inspectability, and affordability characteristics. With the selection of the Lockheed-Martin X-33 lifting body configuration which uses an aerospike engine, emphasis in propulsion will be placed on understanding the performance and operations of aerospike engines such as the J-2-based aerospike for the X-33, and a new RS-2200 aerospike engine by Rocketdyne for the RLV configuration using liquid oxygen/liquid hydrogen propellants.

A comprehensive effort has been underway for the past year and a half to characterize the aerodynamics of the integrated lifting body/aerospike. NASA and Lockheed have tested a 5% scale model of the lifting body configuration in the supersonic wind tunnel at the Arnold Engineering Development Center to characterize the engine exhaust/vehicle aerodynamic interaction. In the spring of 1996, an individual thrust chamber (one of 14) for the Lockheed-Martin X-33 engine was tested at NASA's Marshall Space Flight Center.

It is planned to have the aerospike engine undergo early flight testing to determine vehicle aerodynamic/aerospike engine interactions during flight. These relate directly to the basic understanding of overall engine performance. As shown in Fig. 13, a 10% scale, half-span model of the Lockheed-Martin lifting body configuration and aerospike is being mounted on the back of an SR-71 reconnaissance jet aircraft for flight tests planned for late 1996 depending on the outcome of engine ground tests. Thirteen test flights will duplicate the trajectory of an RLV between flight Mach numbers of 0.6 through 3.2. The tests will be used to measure installed thrust, demonstrate engine operation, and validate analysis methods, including computational fluid dynamics (CFD), for use on full scale system design.

7. MANAGEMENT & OPERATIONAL APPROACHES

The RLV Technology program, looking to SSTO as the goal for low-cost access to space, has been

Fig. 12. TPS Rain Test Fixture.

redefining the working relationship between Government and industry as well as commercial users and foreign involvement. Significant reductions in development and operations costs require the streamlining of management methods that oversee technology development and demonstrations, i.e. "new ways of doing business". The National Research Agreements (NRAs), and Cooperative Agreement Notices (CANs) have been successfully used to quickly set up work relationships between the Government and industry.

The use of small, efficient project offices is critical to demonstrating low-cost developments, streamlining acquisition procedures, minimizing Government oversight and providing for the "cultural changes" needed to meet cost reduction goals. The RLV program management office, for example, is staffed with no more than 20 people. The DC-XA program demonstrated that a small Government/industry project team could design, develop, and integrate advanced technology components into an experimental flight system within budget and schedule constraints. The total touch labor and flight operations personnel remained at the level used in the DC-X program. The X-34 experience demonstrated the ability to stop and restructure a program quickly when program objectives were not met.

In concert with the fast-track management approach is the use of X-vehicle demonstrators to reduce technical risk and demonstrate technologies and operational approaches. Flight demonstrators add confidence to ground test and analytical results that address the technical feasibility and cost advantages to operational RLVs. The DC-X and DC-XA programs represented initial steps towards these goals, but had limited capabilities in investigating the harsh flight environments, mass fraction requirements, and more complex operations of op-

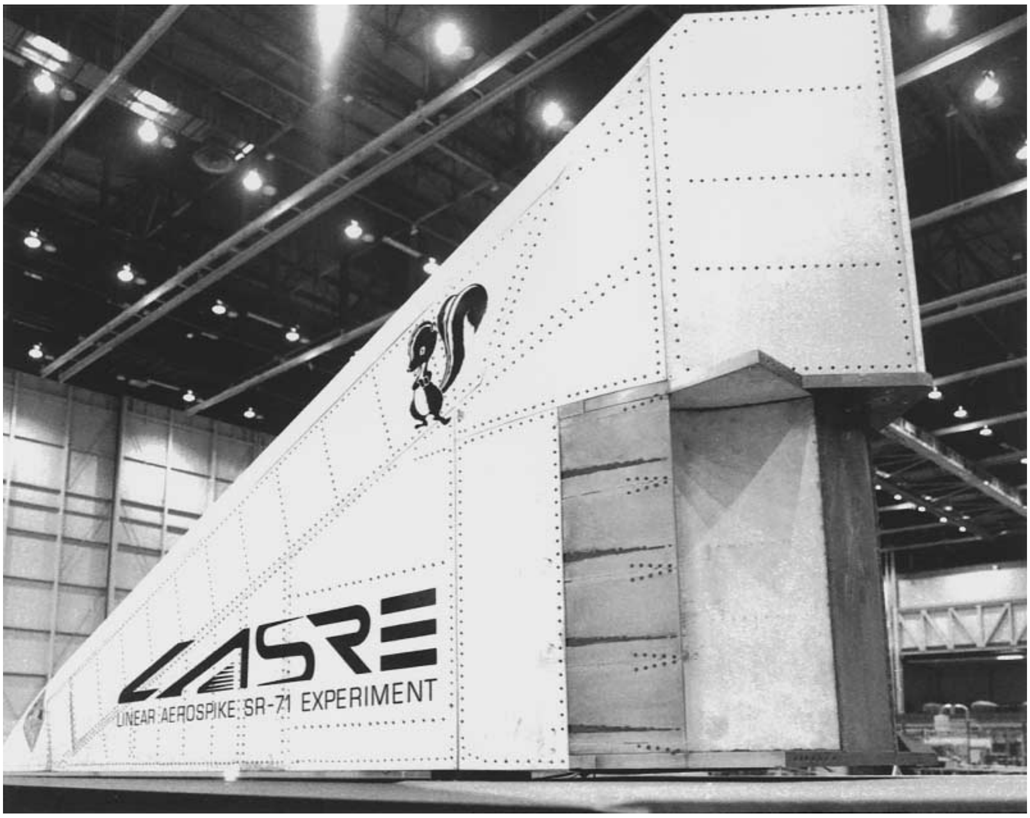

Fig. 13. Lockheed Aerospike Engine Flight Test Vehicle.

erational systems. Issues of reliability and risks of flight test provide insight into implementing future program structure. The X-33 advanced technology demonstrator and X-34 testbed technology demonstration vehicle will engage the primary issues of mass fraction, propulsion performance, flyability, structures, TPS, and operations (both ground and flight).

8. SUMMARY

A fully-reusable, rocket-powered SSTO launch vehicle is, at present, considered to be the likely means of achieving affordable access to space. The NASA RLV technology program is working the challenges of SSTO by addressing both the technical and programmatic aspects of new vehicle development. Industry/Government partnerships have been established with the Clipper Graham DC-XA, X-33, and X-34 elements of the RLV program. Technologies required for SSTO including reusable cryogenic tanks, composite primary structures, durable thermal protection, and operable main propulsion systems are under development. The DC-XA, X-33 and X-34 flight vehicles have and are demonstrating these technologies to a degree so as to lend confidence to the decision to proceed with full-scale RLV development. Understanding of risks involved in program execution and flight tests are being factored into the ongoing program elements.

The technology and flight demonstration programs underway will support Government and industry decisions at the end of the decade relating to an RLV operational vehicle. This decision will take into account the DoD progress in the EELV program, the evolution and outlook for commercial markets, budget limitations, and national needs. Together, these factors will determine what form a feasible, practical future launch system will take.

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APPENDIX

Nomenclature

APS	auxiliary propulsion system
APU	auxiliary power unit
BMDO	Ballistic Missile Defense Organization
CAN	Cooperative Agreement Notice
DoD	Department of Defense
DC-X	Delta Clipper experimental
DC-XA	Delta Clipper experimental advanced
EELV	evolved expendable launch vehicle
Gr-Ep	graphite epoxy
LH2	liquid hydrogen
LO2	liquid oxygen
MSFC	Marshall Space Flight Center
NASP	National Aero-Space plane
NRA	NASA research announcement
RLV	reusable launch vehicle
SSRT	single-stage rocket technology
SSTO	single stage to orbit
STS	space transportation system
TPS	thermal protection system