

FLIGHT DEMONSTRATIONS OF ORBITAL SPACE PLANE (OSP) TECHNOLOGIES

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ABSTRACT

The Orbital Space Plane (OSP) Program embodies NASA's priority to transport Space Station crews safely, reliably, and affordably, while it empowers the Nation's greater strategies for scientific exploration and space leadership. As early in the development cycle as possible, the OSP will provide crew rescue capability, offering an emergency ride home from the Space Station, while accommodating astronauts who are deconditioned due to long-duration missions, or those that may be ill or injured. As the OSP Program develops a fully integrated system, it will use existing technologies and employ computer modeling and simulation. Select flight demonstrator projects will provide valuable data on launch, orbital, reentry, and landing conditions to validate thermal protection systems, autonomous operations, and other advancements, especially those related to crew safety and survival.

INTRODUCTION

In 2002, NASA Administrator Sean O'Keefe commissioned extensive analyses throughout the Agency by both internal teams and independent review panels to gain a clear understanding of U.S. markets and National missions as well as the Agency's fiscal responsibilities and accountability position.

The Space Launch Initiative (SLI) 2nd Generation Reusable Launch Vehicle Program, which was chartered in FY01 based on joint NASA/aerospace industry studies conducted in the late 1990s, looked at hundreds of alternative space transportation system designs and performed in-depth research on the 15 best candidates. Separating the crew transport and cargo delivery functions emerged as a logical way to improve crew safety and decrease costs. Through this process, NASA became well aware of the magnitude of investment that would be needed to replace the Shuttle.

Following the Administrator's direction, four major options were reviewed and a decision was made on which one was the best investment based on current information. Option 1 was to stay with the original plan to decide on the Shuttle's successor around 2006. Option 2 was to develop a crew transport vehicle and launch it on an evolved expendable launch vehicle by early next decade. Option 3 was to develop a new booster system with the Department of Defense (DOD) and defer crew transport until later. Option 4 was to delay the development of a new system to replace the Shuttle until high-risk, high-payoff technologies such as kerosene engines and hypersonic propulsion are ready.

With National Space Policy and U.S. mission requirements as overarching criteria, the Agency chose Option 2—to deliver a crew transport capability to service the International Space Station (ISS) as quickly as possible. Based on this decision, the revised Integrated Space Transportation Plan was unveiled in November 2002, and an amendment to the FY03 budget was submitted to identify and secure the funds necessary to accomplish this strategy.

The OSP Program is the organization chartered to design and develop an entire space transportation system, not just the vehicle itself. Ground support, launch and landing facilities, mission operation centers, crew support subsystems, and other critical systems and operations form an integrated whole. It has been three decades since NASA last built a reusable space transportation system. Before vehicle fabrication can begin, the OSP Program must first design and rebuild the facilities and machines to build and test the new system from end to end. The OSP Program is organized to take maximum advantage of lessons learned from Apollo to the Shuttle, while building innovation into the entire system design-and-development process.

Although the ISS lifetime has been estimated to end around 2016, it is possible that it could continue beyond that point. The Russian Mir space station, for

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example, was designed to be operated for about 12 years, but stayed on orbit over 15. So, with the advancements built into the ISS, it could well go beyond its projected operational lifetime. As the Shuttle system progressively ages, a replacement vehicle becomes more critical. Also, it is conceivable that in the coming decades low-Earth-orbit platforms will be used to make planetary observations, provide satellite servicing stations, or serve as launching pads for new exploratory missions. The OSP system will be able to evolve for such future missions while providing a bridge to an eventual Shuttle successor.

Before an advanced space transportation system can be built, selected hardware and software technologies must be flight-tested in a relevant ascent, orbit, and reentry environment. Flight demonstration is essential to obtain these environments and demonstrate these technologies in an integrated system. The OSP Program is supported by multiple integrated flight demonstration projects, including the X-37, Demonstration of Autonomous Rendezvous Technology (DART), and Pad Abort Demonstrator (PAD).

OSP FLIGHT DEMONSTRATIONS OFFICE

The OSP Flight Demonstrations Office (FDO) encompasses flight demonstrator activities in support of several competing OSP architectures. The requirements for the demonstrators are based on mission needs, crosscutting architecture needs, and NASA Headquarters derived requirements. The FDO continually assesses and directs the flight demonstrator Projects to assure that the demonstrations will be relevant to the OSP architecture design and development timeline. This task requires the FDO to act as a continual liaison between the OSP Program elements and the Flight Demonstrations Projects.

A major objective of the FDO Projects is to reduce the risk level associated with such architecture-enabling technologies as advanced Thermal Protection Systems (TPS), advanced structures, flight operations, flight mechanics, crew escape modeling and analysis, and automated rendezvous, which will reduce the risk associated with the decisions concerning competing architectures. The FDO coordinates with other NASA programs to assure that the activities included have maximum application to, and synergy with, current NASA programs and projects, the DOD, and commercial activities.

X-37

The X-37 Project is one of the three projects managed by the FDO. The X-37 is an advanced technology demonstrator, integrating embedded technologies and serving as a platform for flight and operational experiments to validate and mature technologies that lower the cost and improve the performance of future reusable space system technologies. Improved thermal protection systems are a major focus of the X-37 Project. Since these technologies are traceable to larger reusable systems, this data will contribute to NASA's safety and reliability goals and improve access to space.

The X-37 Project builds on the X-37 cooperative agreement with the Boeing Company, which was initiated in 1999 under the Pathfinder Program Office and the SLI Program. Prior to contract award in late 2002, the X-37 Project was successful in initiating the design and development of the Approach and Landing Test Vehicle (ALTV). In conjunction with the ALTV effort, NASA, U.S. Air Force, and Boeing jointly adapted and tested the X-40A. The X-40A—though lacking the X-37's advanced thermal protection materials, rocket engine, experiment bay, and other spacecraft systems—provided a basis for aerodynamic control and stability necessary to reduce technical risk before flight-testing the X-37. The X-40A was released from a U.S. Army Chinook helicopter for seven free-flight tests in 2001, and it completed each of the seven successfully. The current X-37 Project includes the development of two vehicles: the X-37 ALTV and the X-37 Orbital Vehicle. The X-37's shape is a 120 percent scale derivative of the U.S. Air Force's X-40A, also designed and built by Boeing.

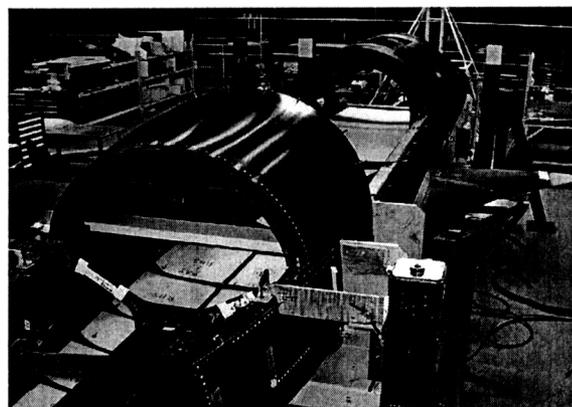


Figure 1. X-37 Assembly

The ALTV will validate system performance of the approach, landing, and turnaround operations needed for flight. It will demonstrate an integrated Flight Operations Control Center as well as range and vehicle flight test operations. In addition, the vehicle will validate aerodynamic stability and structural integrity. Finally, the ALTV will demonstrate automated, or unmanned, operations in the approach and landing range environment. For atmospheric tests, the X-37 ALTV will be released from a B-52 airplane to demonstrate descent and landing. Up to five flight tests for the ALTV are scheduled to begin in the summer of 2004.

Based on the X-37 ALTV, Boeing will also develop an X-37 Orbital System. The X-37 Orbital System will test key, embedded technologies and flight experiments in relevant environments of on-orbit, descent, and landing phases of flight. Technologies to be tested include propulsion; advanced guidance, navigation, and control; thermal protection systems; avionics; high temperature structures; conformal reusable insulation; high-temperature seals; and tile leading edges. In addition, the X-37 Orbital System will demonstrate automated orbital flight, reentry, and landing. The orbital flight test is scheduled for summer 2006.

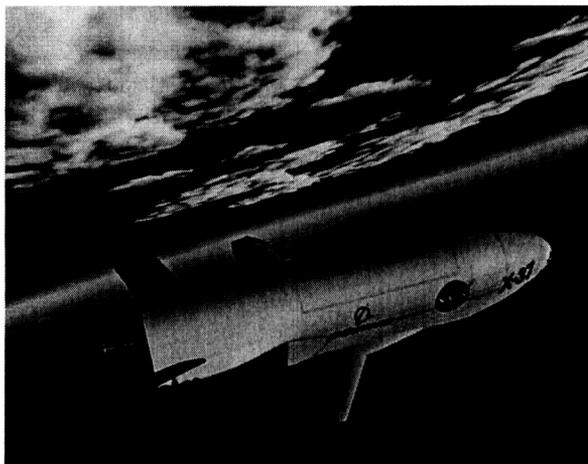


Figure 2. X-37 Artist Conception

DART

The DART Project is the second of three projects managed by the FDO. The DART Project will develop the systems necessary to perform a flight demonstration of autonomous rendezvous technology

in conjunction with an Advanced Video Guidance Sensor (AVGS) and Autonomous Rendezvous and Proximity Operations (ARPO) software. The DART System is comprised of a DART Chase Vehicle, a Target Vehicle, and Mission Operations.

The DART Chase Vehicle consists of a modified Pegasus 4th Stage and an AVGS bus. The Pegasus 4th Stage is comprised of a Hydrazine Auxiliary Propulsion System and a Pegasus Avionics System. The AVGS bus will house the AVGS instrument, avionics, propulsion, and power systems required for proximity operations. The Pegasus 4th Stage systems will be integrated with the DART unique systems to form an integrated DART Chase Vehicle capable of performing the designated mission.

The Target Vehicle—owned by Orbital Sciences Corporation (OSC)—is baselined as the Multiple Paths, Beyond-Line-of-Sight Communications (MUBLCOM) satellite, currently in orbit. The MUBLCOM satellite has been chosen as the baseline target since it is fully operational and has reflectors installed that were expressly designed for use with the AVGS. The target satellite will require software modification to enable broadcast of its Global Positioning System (GPS) state vector. The target satellite GPS state vector will be monitored for a pre-determined time to establish the stability and accuracy of the data.



Figure 3. DART Chase Vehicle

DART Mission Operations will be conducted in four distinct phases. Phase 1 consists of the launch of the DART Chase Vehicle by Pegasus, ascent, and insertion into a parking orbit. Phase 2 involves the autonomous transfer from parking orbit to MUBLCOM orbit using state vector differencing.

Phase 3 comprises the ARPO, with an autonomous approach to within 50 feet of MUBLCOM, and station keeping at a distance of 50 feet. In Phase 4, the autonomous departure and deorbit of the DART Chase Vehicle is accomplished.

The DART mission seeks to integrate the AVGS and ARPO algorithms with a modified Pegasus upper stage and AVGS bus to provide a DART Chase Vehicle capable of performing a flight demonstration of automated, closed loop, proximity and rendezvous operations with a non-maneuvering, on-orbit target. The AVGS is one of the three key elements of the DART Project effort. The AVGS can accurately track an object outfitted with the appropriate passive optical targets within a range of approximately 100+ meters. Tracking data can be used as a navigational input to the rendezvous algorithms. The algorithms will provide guidance commands to the DART Chase Vehicle to facilitate an autonomous rendezvous with the Target Vehicle.

The other two equally important elements involve the modification of a Pegasus Launch Vehicle upper stage to incorporate ARPO hardware and software upgrades and to implement ARPO algorithms as part of the Pegasus flight code. Current Pegasus software will act as a translator between the Pegasus subsystems and the ARPO algorithms for data being sent as input to the algorithms and commands being generated by the algorithms. When integrated, these elements will then become the DART Chase Vehicle.

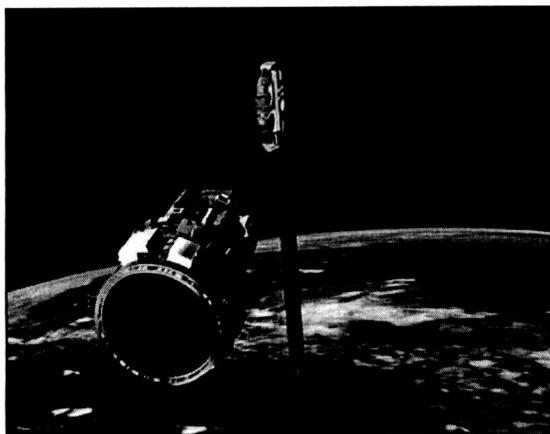


Figure 4. DART Chase Vehicle Approaching the MUBLCOM Satellite

Technology Readiness Levels for AVGS and ARPO

In the mid-1990s, NASA's Marshall Space Flight Center (MSFC) Automated Rendezvous and Capture (AR&C) Program used ground simulators to demonstrate automated capabilities essential for the progression of unmanned and manned space operations. These objectives were met by the development of hardware and software to achieve a safe, assured rendezvous, close approach, and dock between a chaser and target vehicle. The AR&C hardware, which included the Video Guidance Sensor (VGS) and its software; the Three-Point Docking Mechanism (TPDM); the On-Board Computer (OBC); and GPS filter have all been tested in multiple digital and closed loop ground simulations. The VGS and its software are the only components of the AR&C Program that have been tested in a flight environment, culminating in two highly successful AR&C flights aboard the Space Shuttle (STS-87 and STS-95). This success paved the way for MSFC to team with OSC to design, build, and fly the next generation, advanced VGS—AVGS.

The primary goals of the DART Project are to increase the Technology Readiness Level (TRL) for AVGS and ARPO from the current level of three to a level of seven. The technologies are a proximity sensor in the form of the AVGS and an expert software system containing advanced ARPO algorithms.

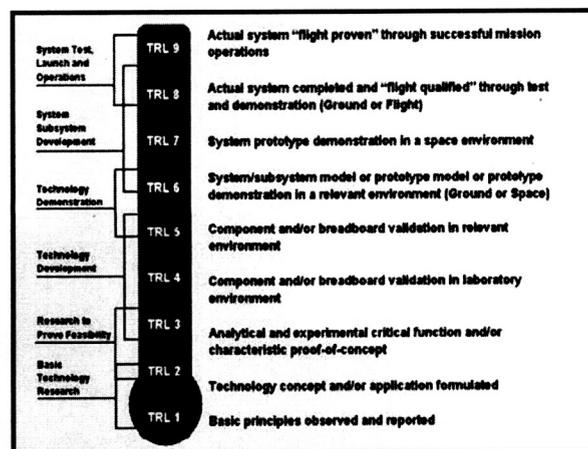


Figure 5. Technology Readiness Levels

PAD

The PAD Project is the third of the three projects managed by the FDO. The PAD Project supports the risk reduction activities of the OSP Program by focusing on requirements for system safety, loss of crew, crew escape, and launch pad abort. Crew

escape capability will be a critical element for improved safety of the new OSP vehicle. Studies have shown that one of the most dangerous crew escape scenarios involves the “on-pad” or “zero-zero” condition where the crew needs to get safely away from the launch pad in case of a catastrophic failure.

In November 2002, a contract was awarded to the Lockheed Martin Corporation to develop a reusable launch pad abort demonstration vehicle that provides the capability to test technologies in a launch pad abort situation. The PAD is a full-scale reusable system that will test and evaluate crew escape technologies should a need arise to escape from an emergency situation while the vehicle is still on the launch pad. The flight demonstrator will include crew escape and survival systems, subsystems, and components using current technologies—all designed to protect and safeguard crewmembers. Fully instrumented mannequins will be used to generate data on crew environments during demonstration of propulsion systems, parachute systems, orientation and landing techniques, and external aeroshell configurations. As new crew escape technologies mature, the PAD testbed will be adaptable to help meet testing needs.

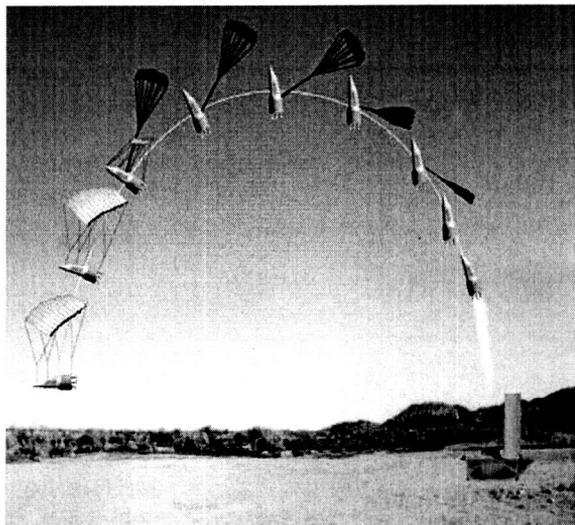


Figure 6. PAD Mission Profile

CONCLUSION

The OSP Program is challenged to simultaneously build an agile Government enterprise responsible for designing model acquisition systems for the National Space Transportation Infrastructure and to meet

unprecedented deadlines within the National roadmap for assured access to space. The OSP vehicle—or vehicles—and total transportation system will support the U.S. requirements for ISS crew rescue and crew/cargo transport, and will serve as the foundation for evolving National space transportation needs, including National Security Space. The optimum OSP design, to be chosen in FY04, will allow NASA to make a full-scale development decision.

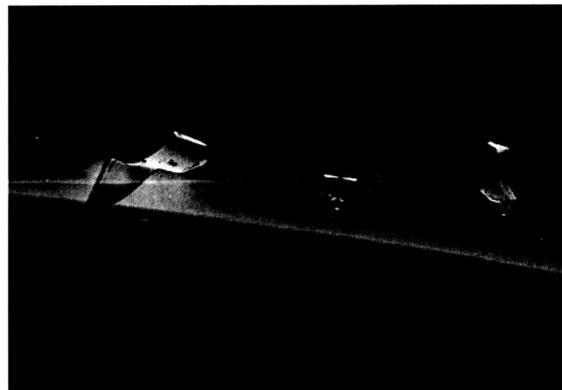


Figure 7. OSP – Expanding U.S. Capabilities in Space

The X-37 Project is part of NASA’s new innovative business strategy to dramatically reduce the cost of space transportation. For the first time, NASA will be able to readily test and validate new, state-of-the-art space transportation technologies on-orbit during the orbital and reentry phases of flight. Results from the X-37 will aid in the design and development of NASA’s OSP vehicle—designed to provide a crew rescue and crew transport capability to and from the ISS. Five flight tests for the Approach and Landing Test Vehicle are scheduled to begin in the summer of 2004. The Orbital Vehicle flight test is scheduled for the summer of 2006.

The DART Project will demonstrate the technologies required for spacecraft to locate, rendezvous, and perform closed loop, proximity operations with another spacecraft without direct human guidance. These technologies represent a critical step for establishing an automated rendezvous capability for the U.S. and will lay the groundwork for future reusable manned and unmanned launch vehicle operations. A successful automated rendezvous of the modified Pegasus/DART Chase Vehicle with an existing on-orbit target is currently scheduled for a mid-2004 launch.

Crew escape capability is a critical element for improved safety of the OSP system. As technologies mature, the PAD testbed will be adaptable to evolving test requirements. Three demonstration tests are planned in 2005 with four additional tests slated for 2006.

Flight demonstrators provide the opportunity to test key technologies in their actual working environment. The X-37, DART, and PAD flight demonstrator projects will provide crucial data toward the development of an innovative system that satisfies NASA's mission requirements. But beyond satisfying requirements, success in developing a safe, more reliable space vehicle will foster renewed excitement in the general public and in our Nation's youth—excitement that will in turn feed the desire for knowledge that can only be gained beyond the bounds of Earth. Technology demonstrators, therefore, will help secure our Nation's role in scientific exploration and space leadership.

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