

A New Space Launch Vehicle: Low Cost Access to Space Using Surplus Peacekeeper ICBM Motors

Scott Schoneman^{*}, Mark Chadwick[†], and Lou Amorosi[‡]
Orbital Sciences Corporation
Launch Systems Group
3380 South Price Road
Chandler, AZ 85248

Abstract. Since the earliest days of space exploration intercontinental ballistic missile (ICBM) technologies and designs have been applied to launching satellites. This symbiosis continues in the development of a new space launch vehicle (SLV) utilizing surplus Peacekeeper ICBM motors. This is happening under a program managed by the Air Force Rocket Systems Launch Program (RSLP), SMC Det 12/RP. In January 2003, the contract for the Orbital Suborbital Program 2 (OSP-2) was awarded to Orbital Sciences Corporation, including the development of a Peacekeeper SLV. This contract continues the capabilities of the previous OSP contract for Minuteman ICBM derived launch vehicles, including the Minotaur SLV to provide responsive spacelift support to US Government-sponsored spacecraft. The flight proven heritage of the Minotaur, along with Orbital's Pegasus and Taurus SLV's, are being applied to this new Peacekeeper vehicle, providing a reliable, low risk solution to the challenge of low cost spacelift of up to 3600 lbm to low earth orbit.

Introduction

The Peacekeeper Space Launch Vehicle (PK SLV) (Figure 1) is part of the OSP-2 contract that was awarded Orbital by the United States Air Force (USAF) in January 2003. The objective of the OSP-2 program is to provide a cost effective, reliable and flexible means of placing small satellites into orbit, using residual Minuteman and Peacekeeper ICBM booster assets, combined with modern launch vehicle avionics and other subsystem technologies.

PK SLV is designed to meet the needs of United States Government-sponsored customers at a lower cost than commercially available alternatives by the use of surplus Peacekeeper boosters. The requirements of the OSP-2 program stress system reliability, transportability, and operation from multiple launch sites. PK SLV draws on the successful heritage of four launch vehicles: Orbital's Pegasus, Taurus and Minotaur SLV, developed under the OSP-1 contract, along with the Peacekeeper ICBM systems currently being deactivated by the USAF. PK SLV's avionics are virtually identical to the Minotaur systems, which in turn have much common heritage with the Pegasus and Taurus system. This provides a combined heritage of at least 37 successful space launch missions. The integration of Orbital's state-of-the art subsystems with the long successful history of the Peacekeeper boosters

has resulted in a simple, robust, self-contained launch system to support government-sponsored small satellite launches.

Under the OSP-2 contract, the PK SLV provides a baseline, standard launch system that can then be



**Figure 1 - Peacekeeper Space Launch Vehicle
(Artist Rendering)**

^{*} Associate Fellow, OSP Mission Manager/
Lead Systems Engineer

[†] Principal Engineer, Mechanical Engineering, OSP

[‡] Vice President and Program Director, OSP

adapted to mission-specific needs by a series of discrete enhanced options. This allows customization of the launch service provided to the spacecraft in a cost-effective manner.

Building on the demonstrated capability of the Taurus and Minotaur system to operate with minimal specialized infrastructure, the PK SLV and Launch Support Equipment (LSE) is capable of operations from any of the four commercial Spaceports (Alaska, California, Florida, and Virginia), as well as from existing U.S. Government facilities at Vandenberg Air Force Base (VAFB) in California and Kennedy Space Center in Florida.

Vehicle Description

The PK-SLV vehicle, shown in expanded view in Figure 2, is a four-stage, inertially guided, all solid propellant ground launched vehicle. Conservative design margins, state-of-the-art structural systems, a modular avionics architecture, and simplified integration and test capability yield a robust, highly reliable launch vehicle design. In addition, PK-SLV payload accommodations and interfaces have been designed to satisfy a wide range of potential payload requirements.

Propulsion

The first three stages of the PK-SLV consist of the refurbished Government Furnished Equipment (GFE) Peacekeeper Stages 1, 2 and 3. These booster assemblies are used as provided by the Government, requiring no modification or additional components. A PK Booster Control Module (PBCM), based on Orbital's Module Avionics Component Hardware (MACH) technology, allows the OSP-based avionics to control the GFE PK booster control systems.

standardized across most of Orbital's launch vehicles, including the flight computer and Honeywell-built Space Integrated GPS Inertial Navigation System. The PK SLV Stage 4 motor is the ATK-built Orion 38 used on Orbital's Pegasus, Taurus, and Minotaur SLV's. The Orion 38 motor provides the velocity needed for orbit insertion, in the same functional manner as it is used on the predecessor vehicles. The Orion 38 features state-of-the-art design and materials with a successful flight heritage and is currently in production, actively flying payloads into space, with 37 flawless flights to date and one static test.

Avionics

The avionics system design incorporates Orbital's "common hardware" critical components that are

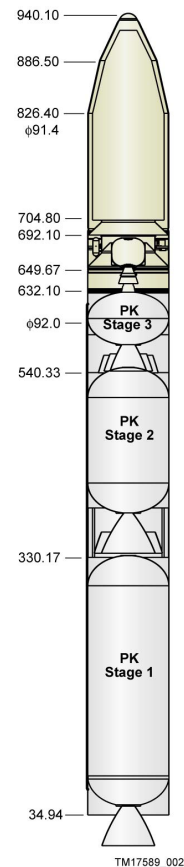


Figure 3 PK SLV Configuration

(SIGI). The PK SLV also makes extensive use of the innovative, flight-proven Modular Avionics Control Hardware (MACH). Modular, function-specific modules are combined in stacks to meet vehicle-specific requirements. The functional modules from which the MACH stacks are created include power transfer, ordnance initiation, booster interface, communication, and telemetry processing. Orbital has designed, tested, and flown a variety of MACH modules, which provide an array of functional capability and flexibility. MACH has exhibited 100% reliability on all flights to date.

Attitude Control System

The PK-SLV Attitude Control System (ACS) provides three-axis attitude control throughout boosted flight and coast phases. Stages 1, 2 and 3 utilize the PK Thrust Vector Control (TVC) systems, using the PBCM to transfer the flight computer actuator commands to the individual Thrust Vector Actuators (TVAs). Stage 4 utilizes the same TVC system used by the Pegasus, Taurus and Minotaur vehicles which combines single-nozzle electromechanical TVC for

pitch and yaw control with a three-axis, cold-gas attitude control system integrated in the avionics section providing roll control.

Modular Structure

The structures that house the avionics and stage 4 motors, as well as providing the structural support for the payload, are made of graphite epoxy with aluminum honeycomb core construction. They are based on similar structures flown on the Taurus launch vehicle. They are also mostly shared with the Target Vehicle (TV) configuration of the OSP-2 PK launch vehicles. The structure has been designed to house the avionics on a toroidal bulkhead around the central core motor adapter cone (Figure 3). This allows flexibility in the use of the central volume to house the baseline Orion 38, as well as growth options employing other boosters such as a Star 48 or liquid booster systems for specialized applications, as illustrated in Figure 4.

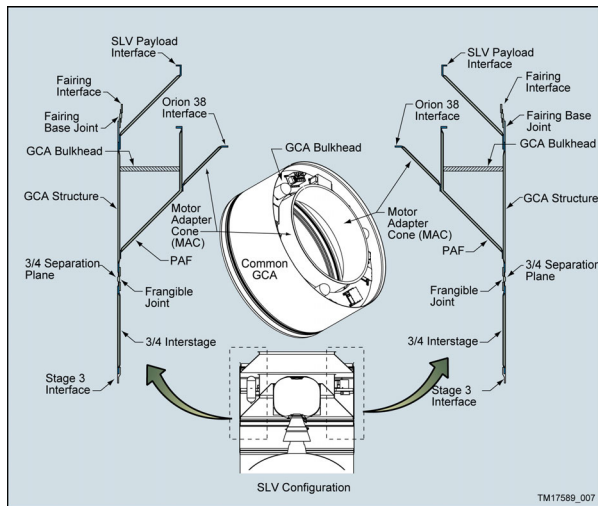


Figure 3 – PK SLV’s Modular Composite Structure

Payload Fairing and Attach Cone

The payload fairing utilized for the PK SLV is the same 92” fairing developed and demonstrated on the Taurus launch vehicle (Figure 5). Because the PK LSV maintains a constant 92” diameter the full length of the booster and GCA stack, the fairing integrates directly to the GCA via a short adapter structure without any steps or boat tails (See Figure 3). The adapter structure also incorporates a payload attach cone to which the spacecraft is integrated. This will allow the spacecraft, fairing, and adapter ring to be vertical integrated, independent of the GCA and other booster components. This integrated assembly will come together with the rest of the launch vehicle at the launch facility as part of the final stacking operation, as discussed later in this paper.

Performance

The combination of the high-performance PK solid rocket motors, the Orion 38 insertion stage, and lightweight composite structures allows the PK SLV to provide performance that fills the gap between small launch vehicles such as Pegasus and Minotaur and larger, more expensive traditional launch vehicles.

West Coast Launches

For missions requiring high inclination orbits (greater than 60°), launches can be conducted from facilities at VAFB or Kodiak Island, AK. Both facilities can accommodate inclinations from 60° to 120°, although inclinations below 72° from VAFB would require an out-of-plane dogleg, thereby reducing payload capability. As with the initial OSP Minotaur missions, PK-SLV can be launched from the California Spaceport facility operated by Spaceport Systems International (SSI), on South VAFB.

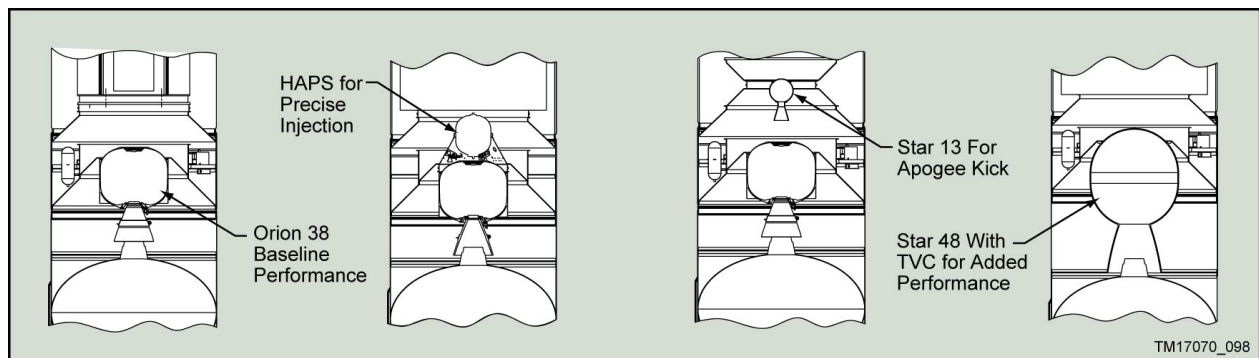


Figure 4 Modular Structure Accommodates Growth and Mission-Specific Booster Options



Figure 5 - 92 Inch Payload Fairing

The launch facility at Kodiak Island, operated by the Alaska Aerospace Development Corporation (AADC) has been used for both orbital and suborbital launches.

For a typical 99 deg inclination orbit, launched from VAFB, the PK SLV performance is shown in Figure 6. For a typical, 400 nm, sun synchronous orbit the performance is greater than 2200 lbm (1000 kg). Performance from Kodiak Island will be similar.

East Coast Launches

For Easterly launch azimuths to achieve orbital inclinations between 28.5° and 60°, PK-SLV can be

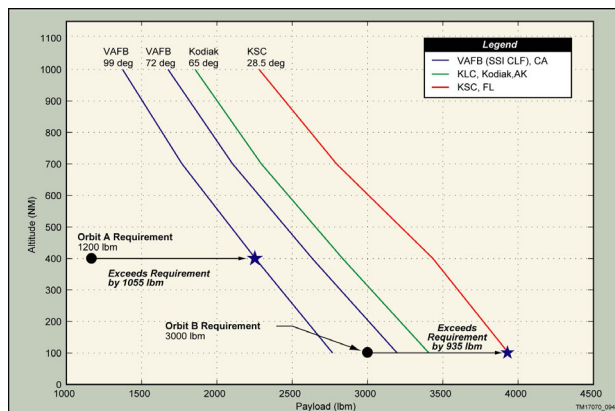


Figure 6 – Preliminary PK Performance Predictions

launched from facilities at Cape Canaveral, FL or Wallops Island, VA. Launches from Florida will nominally use the Florida Spaceport Authority (FLSA) launch facilities at LC-46. These will be typically for inclinations from 28.5° to 40°, although inclinations above 35° may have reduced performance due to the need for a trajectory dogleg. For the baseline Low Earth Orbit (LEO) of 100 nm altitude and 28.5 deg inclination, the PK SLV has performance over 3600 lbm (1633 kg). The Virginia Spaceflight Center facilities at the Wallops Flight Facility (WFF) may be used for inclinations from 30° to 60°. Southeasterly launches from WFF offer fewer overflight concerns than Florida. Inclinations below 35° and above 55° are feasible, albeit with doglegs and altitude constraints due to stage impact considerations.

Geosynchronous Transfer Orbits

The PK SLV also has the potential to provide a unique small satellite capability to Geosynchronous Transfer Orbits (GTO). Performance curves for this application are still in development and will be presented in the presentation accompanying this paper.

Payload Accommodations

The PK SLV is designed to flexibly accommodate a variety of spacecraft mission requirements. The payload fairing and attach structure are designed to allow modular integration separate from the rest of the launch vehicle. Providing a number of optional enhancements enhances the baseline capabilities, as well as maintaining the willingness to coordinate additional mission-specific options with individual spacecraft organizations.

Standard Payload Accommodations

The baseline payload accommodations have been designed to support the greatest number of spacecraft designs and missions. Standardized designs for the mechanical and electrical interfaces have been defined to aid spacecraft designers in initial mission planning.

Mechanical Interface

The standard mechanical interface between the spacecraft and launch vehicle used the Evolved Expendable Launch Vehicle (EELV)-standard 62-inch bolt pattern, contained within the Taurus-derived 92 inch fairing. This results in the spacecraft dynamic envelope shown in Figure 7.

Electrical Interface

The payload electrical interface supports battery charging, external power, discrete commands, discrete

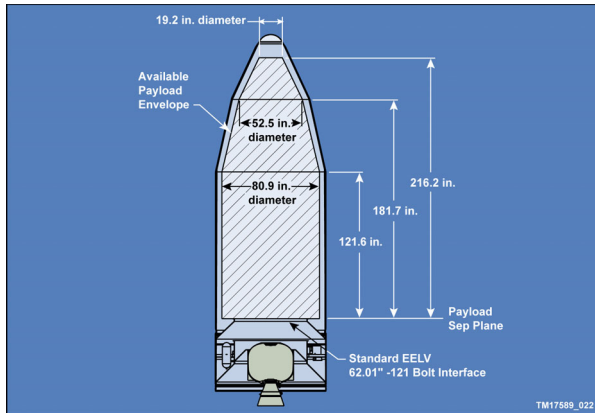


Figure 7 - PK SLV Payload Dynamic Envelope

telemetry, analog telemetry, serial communication, payload separation indications, and up to 16 separate ordnance discretes.

A dedicated payload ground umbilical is provided as a direct payload interface for use in ground testing and pre-launch operations. The Payload umbilical interface consists of at least 24 circuits (48 copper lines) will be provided via a dedicated payload umbilical within the vehicle. This umbilical is a dedicated pass through harness, which allows the payload command, control, monitor, and power to be easily configured for user requirements. The cable interface between the Payload Front Section umbilical and Payload bulkhead interface can be tailored to different connectors to match payload cabling requirements. The payload electrical interface and associated GSE interface requirements are documented in a mission specific ICD. A typical LV-to-Payload interface is shown in Figure 8.

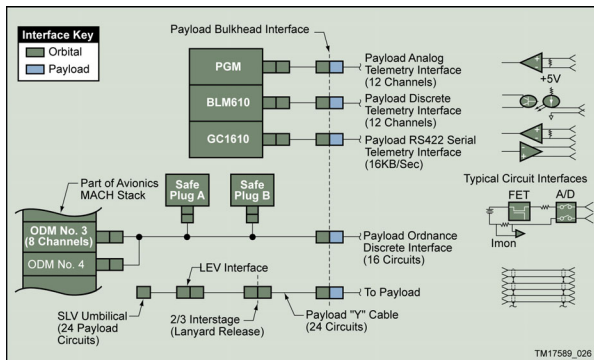


Figure 8 - Typical Payload Interface Circuits

Discrete sequencing commands generated by the launch vehicle's flight computer are available to the payload as closed circuit opt-isolator pulses in lengths of 40 ms multiples. The current at the payload interface must be less than 10 mA, with the payload supplying the voltage source and current limiting resistance to complete this circuit.

The PK SLV also provides the capability to directly initiate 16 separate pyrotechnic conductors through two dedicated MACH Ordnance Driver Modules (ODM). Each ODM provides for up to eight drivers capable of a 5 A, 100 ms, current limited pulse into a 1.5 Ohm resistive load. All eight channels can be fired simultaneously with an accuracy of 1 ms between channels. In addition, the ODM channels can be utilized to trigger high impedance discrete events if required. Safing for all payload ordnance events will be accomplished through an Arm/Disarm (A/D) Switch.

The baseline PK SLV telemetry subsystem provides a number of dedicated payload discrete (bi-level) and analog telemetry monitors through dedicated channels in the vehicle telemetry encoder. Up to 24 channels will be provided with type and data rate being defined in the mission requirements document. The payload serial and analog data will be embedded in the baseline vehicle telemetry format. The number of analog channels available for payload telemetry monitoring is dependent on the frequency of the data. Payload telemetry requirements and signal characteristics will be specified in the Spacecraft-to-Launch Vehicle ICD.

Environments

Preliminary payload environments have been developed for the PK SLV. Environments are defined from ground operations through all phases of launch. The scope of the present document does not allow presentation of great detail regarding the environment, but the levels predicted are within those typically seen for existing launch vehicles. Preliminary characteristic values are shown in Figure 9.

Environment	Characteristic Level (Preliminary)
Random Vibration	12.9 g-RMS (Upper Bound)
Sine Vibration	1.6 g (variable between 45 and 75 Hz)
Shock	
Sep System	3,500 g
Non-Separating	3,000 g
Acoustic	138 dB-OASPL
Acceleration (Steady-State)	9 g's (2,000 lbm payload)

Figure 9 PK SLV Characteristic Payload Environments (Preliminary)

The environmental design and test criteria presented have been derived using measured data obtained from previous Pegasus, Taurus and Minotaur missions,

motor static fire tests, other system development tests and analyses. The predicted levels presented are intended to be representative of mission specific levels. Mission specific analyses that are performed as a standard service are documented or referenced in the mission ICD.

Non-Standard Options

The OSP launch service is structured to provide a baseline vehicle configuration that is then augmented with optional enhancements to meet the unique needs of individual payloads. The baseline vehicle capabilities are defined in the previous sections and the optional enhanced capabilities are defined below. The enhanced options allow customization of launch support and accommodations the PK vehicle designs on an efficient, “as needed” basis. Some of most relevant of these options are discussed below.

Separation Systems

Various separation systems can be provided or accommodated to meet mission-unique requirements. As a baseline option, OSP offers a payload separation system that is flight proven on Taurus. SAAB Ericson Space (SES) manufactures the separation system for Orbital. This system is based on a design that has flown over 30 times with 100% success.

Payload Isolation System

OSP offers a flight-proven payload isolation system as a non-standard service. The Air Force Research Laboratory (AFRL) and CSA Engineering developed the Softride for Small Satellites (SRSS). It was successfully demonstrated on the two initial OSP Minotaur missions and five Taurus missions. This passive, mechanical isolation system has demonstrated the capability to significantly alleviate the transient dynamic loads that occur during flight - typically transient loads are reduced to approximately 50% of the level they would be without the system. However, the exact results can be expected to vary for each particular spacecraft and with location on the spacecraft. The isolation system does impact overall vehicle performance (by approximately 20 to 40 lb [9 to 18 kg]) and the available payload dynamic envelope by up to 4 inches (10.16 cm) axially and up to 1.0 inch (2.54 cm) laterally.

Enhanced Insertion Accuracy

Insertion accuracy greater than standard or support for multiple payload insertion can be provided as an enhanced option utilizing the Hydrazine Auxiliary

Propulsion Stage (HAPS) developed and flown on Orbital’s Pegasus. HAPS is integrated inside the avionics structure and consists of a monopropellant hydrazine propulsion subsystem and a separation subsystem. After burn-out and separation from the Stage 4 motor, the HAPS hydrazine thrusters provide additional velocity for both improved performance and precise orbit insertion. Six-DOF analyses show that the HAPS system provides a controlled impulse to achieve insertion accuracies of less than 10 nm ($3\text{-}\sigma$) and inclinations of less than 0.05 deg ($3\text{-}\sigma$).

Alternate Stage 4 Motors

The modular design of Orbital’s GCA and integrating structures provides great flexibility in accommodating alternative Stage 4 propulsion systems. As one low risk example, an optional configuration using an ATK Thiokol Star-48 motor has been conceived, as shown previously in Figure 3. This option provides approximately 500 lbm greater throw-weight-to-orbit capability to 100 nm, 28.5 degree circular orbit relative to the baseline Orion 38 design. The only modifications required to accommodate this change are a modified Motor Adapter Cone (MAC) with the Star 48 forward interface and a longer 3/4 interstage to allow room for the increased motor length. Other alternative motors can also be similarly adopted, also as shown in Figure 3..

Environmental Control Options

Several options to provide enhanced environmental control to the payload are available with the PK SLV. These include the ability to deliver conditioned air, clean nitrogen purge, and enhanced encapsulation cleanliness. The enhanced cleanliness is available with Class 100,000 or Class 10,000 air quality and fairing interior surface cleanliness at “Visibly Clean”, Levels 1 or 2.

Shared Launch Accommodations

Because of the modular nature of the structures, dual payload configurations can be easily accommodated by the PK-SLV structural design. The standardized 62.01-inch PAF and 38.81-inch Motor Adapter Cone (MAC) can be combined in various combinations, as shown notionally in Figure 10. The GCA PAF can be used as the base of the PAM, using the cylinder as the base section of a flight-proven Taurus Dual Payload Attach Fitting (DPAF). A MAC mounted inside provides a 38.81-inch interface for the secondary payload internal to the DPAF. The primary (top) payload would mount to an extended 62.01-inch cylinder and if necessary it would cone down to the 38.81-inch diameter. The notional configuration is shown in Figure 10.

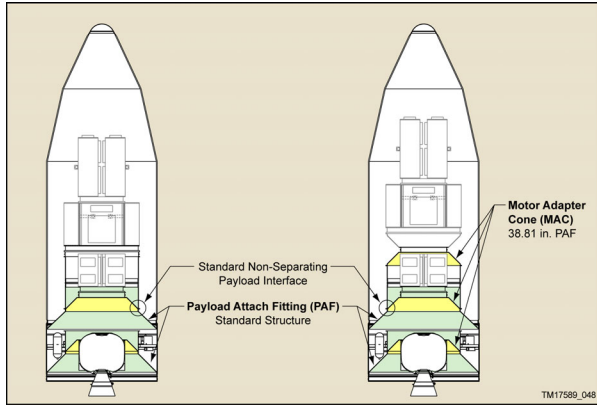


Figure 10 - Shared Launch Conceptual Designs

Launch Operations concept

Much of the Taurus and Minotaur ground processing and launch operations are also employed, providing many proven processes and unique knowledge base. The system uses the same flat pad, stool launch approach as Taurus and the same portable electrical ground support equipment (GSE) used on Minotaur – and all other OSP vehicles – to be readily adaptable to multiple potential launch sites. The payload is modularly encapsulated in a manner similar to Taurus, allowing vertical integration and parallel processing of the spacecraft and launch vehicle in separate facilities. The top-level integration flow is shown in Figure 11.

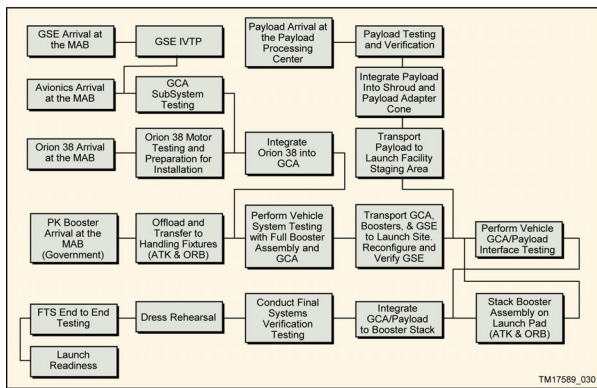


Figure 11 - PK SLV Processing Flow

The PK-SLV system utilizes transportable Launch Support Equipment (LSE) (Figure 12) designed to allow operation as a self-contained satellite delivery system. To accomplish this goal, the Electrical Ground Support Equipment (EGSE) is standardized for all OSP launch vehicles, having been developed to be portable and adaptable to varying levels of infrastructure. While the PK-SLV system is capable of self-contained operation using portable vans to house the EGSE, it is typically launched from an established range where

the EGSE can be housed in available, permanent structures or facilities.



Figure 12 - OSP -Standard Portable Launch Control Consoles

Mission Initiation Process

The OSP program has been structured as a requirement based contract, providing a baseline capability plus options to tailor the launch service to the specific needs of the payload. The PK-SLV program is managed through SMC Det 12/RP. SMC Det 12/RP serves as the primary point of contact for the payload customers for the PK-SLV launch service. A typical integrated OSP organizational structure is shown in Figure 13. Open communication between SMC Det 12/RP, Orbital, and the customer, emphasizing timely transfer of data and prudent decision-making, ensures efficient launch vehicle/payload integration operations.

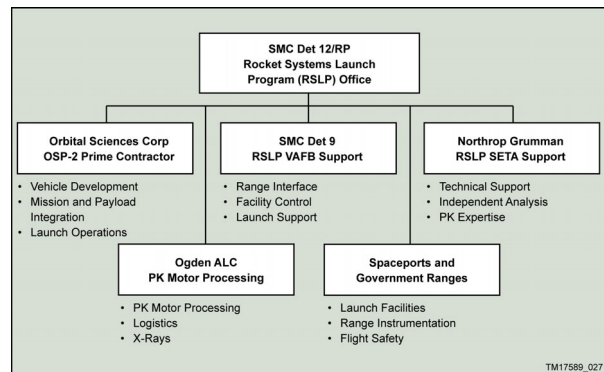


Figure 13 - OSP-2 Program Organization

The first mission for the PK SLV will be 24 months from the time Orbital is authorized to proceed until the initial launch capability. Follow-on missions will have an 18 month response time. More details on the launch initiation process, as well as overall OSP-2 information can be obtained by contacting the Air Force Det 12 RSLP program office.

Summary

The PK SLV will provide a new, cost effective, and responsive spacelift service the Government and University-sponsored space missions. It follows in the footsteps of the first OSP contract, which saw the successful development and demonstration of the Minotaur space launch vehicle. The PK SLV will leverage the proven OSP technology, efficient processes, and expertise – combined with the greater performance of the PK boosters – to provide reliable space launches for the next ten years and beyond.