Minotaur V Space Launch Vehicle for Small, Cost-Effective Moon Exploration Missions

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ABSTRACT

The Minotaur family of launch vehicles has been proven to provide reliable, cost-effective, and responsive launch of U.S. Government-sponsored payloads for both space launch and suborbital applications. Since the initial mission of the Minotaur I space launch vehicle (SLV) in January 2000, thirteen Minotaur-family vehicles have successfully launched, including seven space launches and six suborbital targets. This heritage of success is now being extended to the Minotaur V SLV to facilitate high energy trajectories for small spacecraft, including supporting low-cost lunar exploration missions for a total recurring launch service cost of less than ~\$30 million.

Minotaur V is a 5-stage evolutionary version of the Minotaur IV SLV, adding the propulsive energy needed to support payloads up to 440 kg to Trans-Lunar Injection (TLI), 678 kg to Geosynchronous Transfer Orbit (GTO) and comparable performance to other high energy trajectories. The Minotaur V design leverages the flight proven heritage of the Minotaur family of launch vehicles, as well as the full spectrum of Orbital's launch vehicle experience. In particular, state-of-the-art avionics and object-oriented flight software are standardized across multiple programs, using modular designs that are readily adaptable to specific vehicle and/or mission requirements. The fourth and fifth stages are commercial solid rocket motors selected based on their extensive flight history and performance. The Minotaur V avionics, structures, and fairing are shared with the Minotaur IV SLV, requiring minimal new development - and only about \$10M in total non-recurring effort (NRE) - to create the five stage configuration.

INTRODUCTION

As the capabilities of small satellites have steadily increased in recent years, the feasibility of using these systems for missions beyond Low Earth Orbit (LEO) has similarly increased. Small spacecraft missions to Medium Earth Orbits (MEO), Geosynchronous Orbits (GEO), Trans-Lunar Injection (TLI), and beyond have all been conceived and are in various stages of planning and implementation. However, to realize the Holy Grail of small space missions – low cost – traditional large launch vehicles are not feasible. Similarly, the

currently available small launch vehicles do not have the performance to deliver significant mass to these high energy orbits. Therefore, the Minotaur V launch vehicle has been conceived to provide cost-effective, usable mass to these orbits.

The performance of the Minotaur V opens up this affordable class of high energy orbits to the small-sat community. The Minotaur V performance envelope offers significant mass to a full range of orbits, from Low Earth Orbit (LEO) to Trans Lunar Insertion (TLI)

and beyond. It does this with low risk and realistically low costs. As an evolutionary addition to the successful Minotaur family of small launch vehicles, it benefits from this solid heritage and the cost benefits of using existing, Government-owned rocket motors. As with the other Minotaur vehicles, it will be available - via the U.S. Air Force - to launch any U.S. Government-sponsored spacecraft, providing a new, valuable capability to deliver small spacecraft for technology demonstration, science, operational, and/or exploration into higher orbits than previously feasible.

MINOTAUR FAMILY AND HERITAGE

Minotaur Family

The Minotaur family includes the Minotaur I, IV, and V space launch vehicles (SLV's) and Minotaur II and III suborbital or Target Launch Vehicles (TLV's). The Minotaur "family portrait" is shown in Figure 1 along with their performance to typical orbits or trajectories. Minotaur vehicles are available via the Orbital Suborbital Program (OSP) contract, under the USAF Space and Missile Systems Center (SMC) Space Development and Test Wing (SDTW). The OSP contract was competitively awarded to Orbital originally in 1997 with a follow-on 10 year contract again competed and awarded in 2003. Via OSP, Minotaur vehicles supply a proven combination of the reliability of both decommissioned, Government-owned

boosters and Orbital's commercially-based hardware and practices. From the beginning, the requirements of the OSP program have stressed system reliability, transportability, and operation from multiple launch sites requiring minimal infrastructure. In addition to the reliability and responsiveness benefits, the use of decommissioned motors also provide a best-value to the US Government, provide realistically low-cost — and ultimately best value - launch vehicles. Moreover, this integration of existing motors with state-of-the-art commercial launch vehicle subsystems and capabilities has been a niche in which Orbital has been the leader, having a highly successful decades-long history in this area. More information on the heritage of the motors and systems is included in the Appendix.

All together, there have been thirteen launches of vehicles in the Minotaur family: seven Minotaur I SLVs and six Minotaur II suborbital TLVs (Figure 2). Because the functional architecture and systems – such as avionics, controls, software, flight termination system (FTS) analytical methodology, test/launch consoles, and integration & test practices – are shared across the Minotaur family, this combined flight experience is applicable to all Minotaur vehicles. All Minotaur vehicles benefit from the launch lessons and heritage of their Minotaur siblings, allowing low risk modifications and development of new configurations.

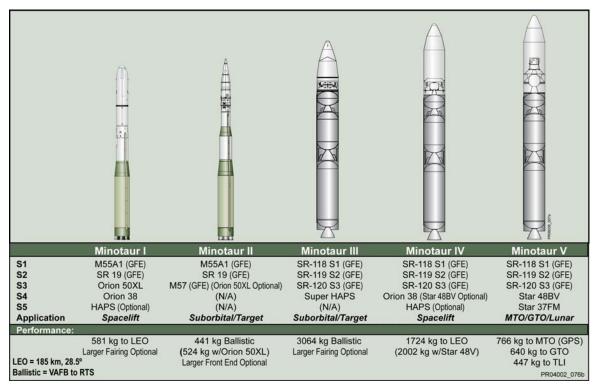


Figure 1 - Minotaur Family of Launch Vehicles

The Minotaur I space launch vehicle had its first launch in Jan 2000, successfully delivering five spacecraft to orbit. There have been seven launches to date, with the most recent being the Near Field Infrared Experiment (NFIRE) mission in April 2007. Over this septet of launches, the ability of the Minotaur I to accommodate a variety of mission requirements has been demonstrated. Nearly half of the missions have flown multiple payloads resulting in a total of 17 spacecraft being delivered to orbit by Minotaur I - the total is 25 spacecraft if eight picosats subsequently separated from carrier spacecraft are included. Six different separation system designs have been used for primary payloads plus several others for secondary spacecraft. Two different payload fairings have been demonstrated. Launches have been conducted at two different launch ranges - Vandenberg AFB on the West Coast and Wallops Flight Facility on the East Coast - which included the design, installation, and activation of basic launch access towers at both locations, which are also easily adaptable to support Minotaur IV and V launches.

Minotaur launch vehicles draw on the long, successful track record of the USAF's Rocket System Launch Program (RSLP), which is now part of the SDTW

Launch Test Squadron (LTS). For decades, they have specialized in the use of decommissioned motors for various suborbital missions. RSLP also became the focus for DoD small launch vehicle services. They entered into the small space launch area in the mid-90's when they took on the management of the USAF Small Expendable Launch Vehicle Services (SELVS) program, covering DoD use of Orbital's Pegasus space launch vehicles (SLV). In 1995, RSLP also took over the Standard Small Launch Vehicle (SSLV) project from the Defense Advanced Research Projects Agency (DARPA), adding Orbital's Taurus vehicle to their capabilities. The DARPA SSLV had set the stage for utilizing decommissioned Government-owned solid rocket motors for reducing the cost of space launch by using decommissioned Peacekeeper (PK) Stage 1 motors, starting with the first Taurus mission of the STEP 0/DARPASat spacecraft in 1994. Subsequently, RSLP initiated the OSP contract in 1997, providing RSLP with an SLV specifically designed to utilize decommissioned Minuteman **ICBM** motors state-of-the-art conjunction with commercial subsystems and practices. This vehicle was subsequently dubbed "Minotaur I."

Minotaur I and II - The Minotaur I SLV (Figure 3)

Minotaur I



Minotaur II



Figure 2 - Minotaur Family Launch History - 100% Successful

and Minotaur II TLV (Figure 4) both make use of decommissioned Minuteman II boosters. Minotaur I uses the first two Minuteman stages, whereas Minotaur II uses all three stages. For Minotaur I, the two GFE stages are combined with the upper two stages, structure, payload fairing, and several core subsystems shared with Orbital's Pegasus SLV. The heritage components have been enhanced with newer, modular avionics components and new object-oriented flight software to increase flexibility, reliability, and This OSP-standard avionics and responsiveness. software is also used on the Minotaur II - and all of the other Minotaur family of vehicles - as is the electrical ground support equipment (EGSE) consoles. allows extensive commonality between all OSP vehicles, allowing standardization of integration and test, as well as field integration and launch operations, thereby increasing overall efficiencies. Moreover, this basic OSP architecture has now been adopted on new Orbital launch vehicles, thereby allowing the improvements and lessons of multiple programs to be gleaned by the Minotaur vehicles.



Figure 3 - Minotaur I SLV for Inaugural Mission from Pad 0B at Wallops Island, VA



Figure 4 - Minotaur II TLV in LF-06, VAFB, CA

The total development time from initial to first launch of Minotaur I and II vehicles was less than 28 months and 21 months, respectively. The initial demonstration of this Minotaur-family architecture occurred on the inaugural Minotaur I launch on 26 January 2000, successfully launching the Joint Air Force Weber State Satellite (JAWSat) from Vandenberg AFB, CA. This was followed up within the next six months by the demonstration mission of the Minotaur II TLV on 28 May 2000 and the second Minotaur I SLV mission, MightySat II.1, on 20 July 2000.

Minotaur III and IV - The Minotaur III and IV utilize decommissioned Peacekeeper solid rocket motors, versus the Minuteman II motors used for Minotaur I and II. Minotaur III is a suborbital target launch configuration whereas Minotaur IV is the space launch configuration. Both vehicles share their basic structures and avionics, with the primary difference being the 4th stage propulsion systems used. Minotaur III has a monopropellant hydrazine system for applications, whereas Minotaur IV utilizes an Orion 38 solid rocket motor as an orbital insertion stage. A growth configuration, Minotaur IV+ uses the larger STAR 48BV in place of the Orion 38 to provide higher performance. The commonality between the two designs provide efficiencies in the development effort, as well as in hardware procurement and integration The development of the Minotaur IV space launch vehicle has been proceeding well, meeting all schedule commitments to date in support of the Space Based Space Surveillance (SBSS) mission. At the onset, the Air Force initiated a number of risk reduction efforts to provide early retirement of all the initial risks that were identified. Given the extensive use of flight-proven

elements in the Minotaur III and IV vehicles, there were a relatively small number of items to address.

The Minotaur IV vehicle design is shown in Figure 5, highlighting the minimal number of 'new' subsystems and components required. In fact two components previously identified as 'new designs' are no longer required due to changes in how the OSP architecture is interfacing with the PK boosters. Performance predictions have not changed from the original proposal values. This is due to the careful management of mass properties margins, based on Orbital's extensive history in developing new small launch vehicles. Since the Minotaur IV configuration is the basis for the Minotaur V, the maturity and depth of understanding of the vehicle characteristics extends directly into the Minotaur V configuration.

As shown in Figure 5, there is an option to use a STAR 48BV as the fourth stage in place of the baseline Orion 38. This configuration has been dubbed Minotaur IV+ and provides up to an additional 250 kg (550 lbm) to LEO. It also provides an enhancement to support Highly Elliptical Orbit (HEO) missions. In this role, it has been selected as the configuration to be used to support the TacSat-4 mission for the DoD. This Minotaur IV+ configuration also takes one major step

towards the Minotaur V since is also uses a STAR 48BV as the fourth stage motor.

The full Minotaur family of launch vehicles are 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. This is facilitated by the use of portable support equipment and minimal infrastructure requirements, as was demonstrated on the predecessor Taurus and Minotaur programs.

MINOTAUR V CONFIGURATION

As mentioned previously, the Minotaur V configuration is created by adding a fifth solid rocket motor stage to the Minotaur IV+ configuration. Following the ongoing design philosophy of the Minotaur family, the design has focused on maximizing the use of existing designs and hardware. As a result, there are no major subsystems or assemblies requiring significant development for Minotaur V. Rather, the Minotaur V development effort will focus on the configuration and integration of mature systems, greatly reducing non-recurring costs and first-mission risk.

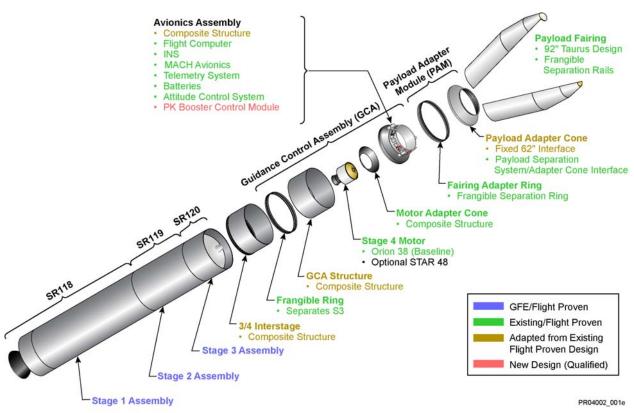


Figure 5 - Minotaur IV SLV is Composed of Mature, Flight Proven Subsystems and Designs

Propulsion

The primary area of focus to evolve the 4 stage Minotaur IV configuration into the 5 stage Minotaur V was the selection of propulsion system. Therefore, the first order of business was a trade study on upper stage propulsion. The result was the selection of a STAR 48BV as the 4th stage motor and two variations of ATK's STAR 37FM as 5th stage options. STAR 37FM options are either a spin-stabilized 5th stage (using the STAR 37FM) or a 3-axis stabilized 5th stage employing a STAR 37FMV. These are all flight proven motors with extensive history as upper stage motors dating back decades. The primary change required was the inclusion of a vectorable nozzle to the STAR 48BV and the STAR 37FMV configurations. However, the flex seal nozzle design is also an existing, qualified design, as are the Thrust Vector Controller (TVC) options being considered to control the nozzle.

Avionics

The avionics used for Minotaur V are the same common avionics used on all Minotaur family vehicles and other Orbital launch vehicles. For Minotaur V, the modular nature of the avionics design allows it to be readily reconfigured to address the added 5th stage configuration. For the spin-stabilized, STAR 37FM-based configuration, the avionics layout is virtually identical to Minotaur IV. Since the 5th stage is not

actively controlled during its burn, the control avionics can remain behind on the 4th stage in the same locations as Minotaur IV. Only components necessary to command the 5th stage events remains with the stage, including those needed to initiate spin motors, operate nutation control systems (if required), command despin, and payload separation.

For the 3-axis stabilized configuration utilizing the STAR 37 FMV 5th stage motor, a subset of the Minotaur avionics is moved to the 5th stage to control the vehicle during the burn of all five stages and postboost events. The avionics, including the INS, flight computer, Orbital's Modular Avionics Component Hardware (MACH) avionics, and batteries are mounted on the same composite cylindrical structure design that serves as the Minotaur I and Pegasus avionics assembly. This layout is shown in Figure 6.

Structures

The other composite structures necessary for the Minotaur V configuration are derived from similar structures created for Minotaur IV. The Spacecraft Adapter Cylinder, as shown in Figure 6, is only a slight modification of the avionic structure used on Pegasus and Minotaur I. The adapter from the full 92 inch diameter to the 48 inch 5th stage separation interface is modified from the cone used to support the 4th stage motor and also used as the standard payload adapter

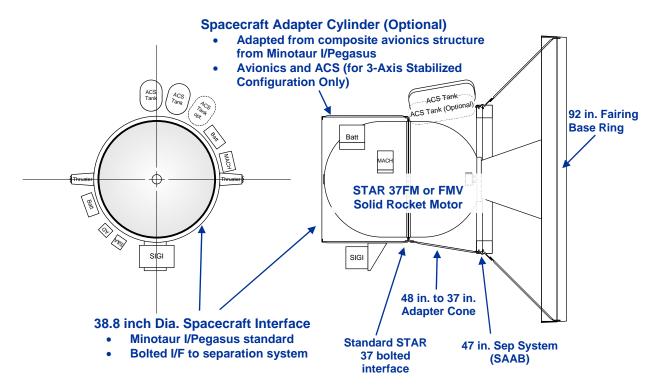


Figure 6 - Minotaur V Upper Stage Configuration

cone. The adapter attaching the STAR 37 motor to the 48 inch interface is a new design since is requires a difference cone angle. However, it is based on the same composite design experience used on all other Minotaur, Pegasus, and Taurus composite structures design. The 5th stage assembly will be separated using a flight-proven 47 inch separation system available from SAAB Aerospace.

PERFORMANCE AND MISSION DESIGN

The Minotaur V performance envelope offers significant performance in a full range of orbits, from Low Earth Orbit (LEO) to Trans Lunar Insertion (TLI) and beyond. For the purposes of this paper, we have defined a set characteristic orbits, shown in Table 1, to define the associated performance figures of merit. The launch sites included in the performance analysis cover the comprehensive range of potential sites from which any of the Minotaur family of vehicles can be launched. These sites were chosen based on favorable launch boundaries and inertial energy for each specific orbit.

Orbit Type	Launch Site	Perigee (km)	Apogee (km)	Inclination (deg)	Arg. of Peri- gee (deg)	$\frac{\text{C3}}{(\text{km}^2/\text{s}^2)}$
LEO	KSC	200	200	28.55	NA	-60.59
МТО	WFF	185	20367	37.83	NA	-23.93
GTO	KSC	185	37800	28.55	180	-15.71
Molniya	VAFB	500	39965	63.40	90	-14.98
TY 1	WFF	200	408,556	37.83	180	-1.89
TLI	KSC	200	408,556	28.55	180	-1.89

Table 1 - Benchmark High Energy Orbits for Minotaur V Evaluation

There the potential to launch Minotaur vehicles from the Reagan Test Site (RTS) on the Kwajalein atoll. However, despite its seemingly unencumbered position in the open ocean, there are in fact quite a number of inhabited islands that must be considered for launch safety considerations. A thorough evaluation of these launch boundaries was beyond the scope of this study and, therefore, has not been included. However, for consideration of the use of Minotaur V for RTS launches, a simple conservative assumption can be made for LEO, MTO, and GTO orbits: utilize the performance values for the respective KSC or WFF

launches, but allow that the spacecraft would only need to change it orbital plane from the 9 deg inclination feasible from RTS, versus the higher inclinations from the more northerly sites.

The Minotaur V design is a logical evolution of the Minotaur family. The addition of STAR 37 insertion motor to the Minotaur IV+ configuration result in a vehicle capable of providing high launch energies with flexible trajectory options for small-sat payloads. With the option of either a spin stabilized or thrust vector controlled insertion stage, the satellite customer has an additional degree of freedom on insertion Table 2 below provides vehicle environments. performance to the benchmark orbits provided above.

		Stab (STAR	axis ilized 37FMV tage)	Spin Stabilized (STAR 37 FM 5 th Stage)		
Orbit	Launch Site	Kg	Lbm	Kg	lbm	
LEO	KSC	2165	4774	2213	4879	
МТО	WFF	721	1590	766	1690	
GTO	KSC	594	1311	640	1411	
Molniya	VAFB	450	993	496	1094	
TLI	WFF	386	852	432	952	
	KSC	402	886	447	986	

Table 2 - Minotaur V Performance to Benchmark High Energy Orbits

The targeting methodology for the Minotaur V provides the flexibility to control the insertion argument of perigee while still taking advantage of the excess booster capability. Minotaur V argument of perigee targeting uses an elliptical intermediate orbit to maximize the energy at target orbit insertion. In the targeting process, perigee and argument of perigee ω of the intermediate orbit are constrained to be coincident with the target orbit. The apogee of the intermediate elliptical orbit is then maximized. This results in maximum delivery of energy to the perigee of the target Figure 7 illustrates a typical Minotaur V trajectory with argument of perigee control. Minotaur V is also capable of insertion to a specific argument of perigee from a circular parking orbit. Excess booster energy can also be used for plane change to support

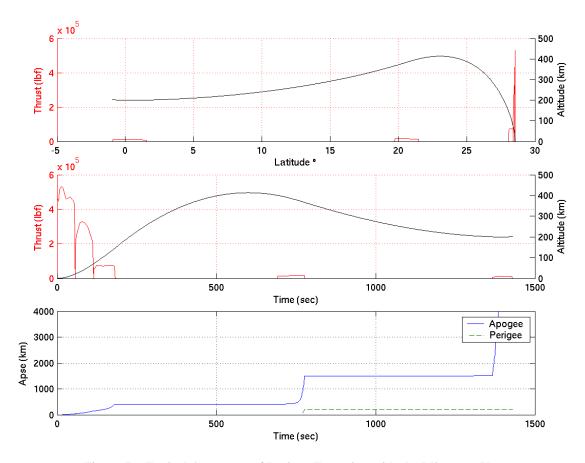


Figure 7 - Typical Argument of Perigee Targeting with the Minotaur V

mission-specific requirements. The synoptic capabilities for these cases are shown in Table 3.

It can be seen that the use of the intermediate elliptical orbit — versus circular parking orbit — provides a significant increase in performance for the high energy trajectories. Figure 8 illustrates the Minotaur V Trans Lunar Insertion capability from both Cape Canaveral Air Force Station (CCAFS), FL, and Wallops Island, VA, with respect to variations in argument of perigee. The relative difference in payload weight between WFF and CCAFS is about 30 pounds.

Figure 9 and Figure 10 provide the performance to a continuum of C3 energy levels for the 3-axis and spin-stabilized 5th stage configurations, respectively. Within the plots, curves are provided both for the direct insertion case and with an intermediate parking orbit. The space between the curves is, therefore, effectively becomes the trade space available for mission planning for variations in argument of perigee or other final insertion timing considerations.

			3-A Stabi (ST 37FI	lized AR	Spin Sta (STAR	
Orbit	Launch Site	Inclin. (deg)	kg	lbm	kg	lbm
GTO	KSC	28.55	514	1133	560	1234
TLI	WFF	37.835	293	648	338	746
	KSC	28.55	293	648	338	746

Performance from Parking Orbit

Orbit	Launch Site	3-Axis or Spin Stabilized
GTO	KSC	26.3
TLI	WFF	34.6
	KSC	25.2

Minimum Inclination Achievable

Table 3- Minotaur V Performance From Circular Parking Orbit

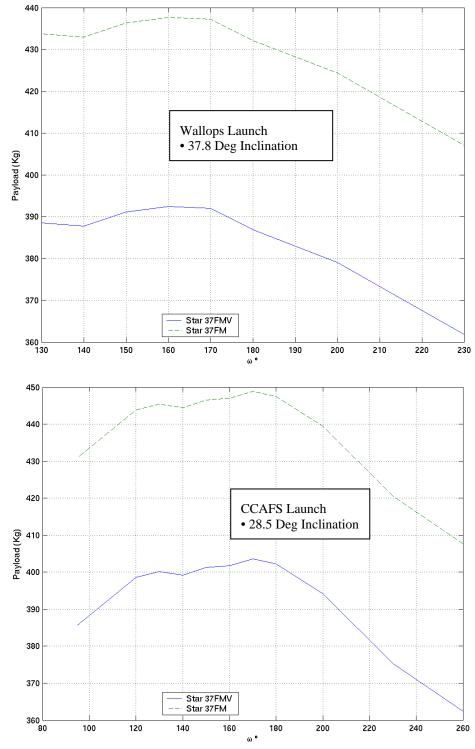


Figure 8 - Trans Lunar Insertion Performance versus Argument of Perigee from WFF

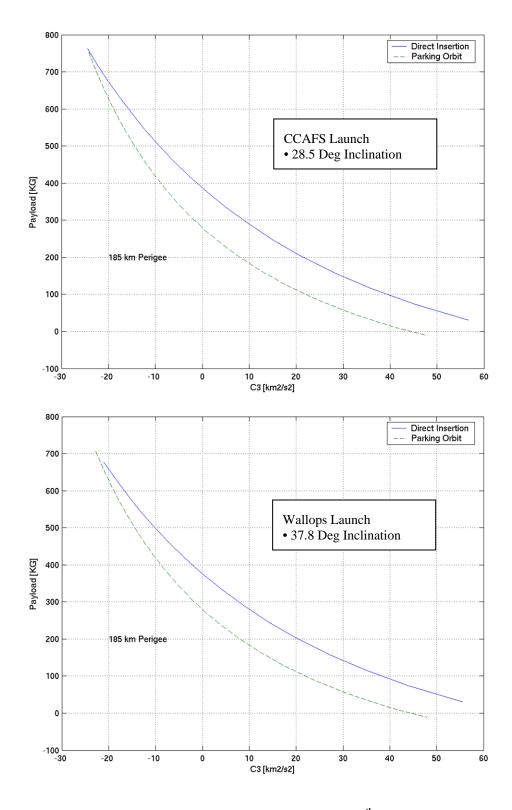


Figure 9 - Minotaur V C3 Performance – 3-Axis Stabilized 5th Stage (STAR 37FMV)

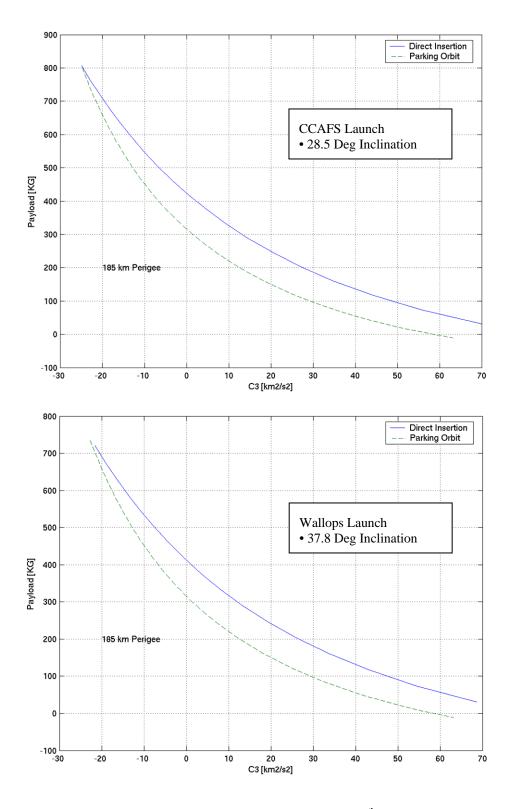


Figure 10 - Minotaur V C3 Performance – Spin-Stabilized 5th Stage (STAR 37FM)

MINOTAUR V SPACECRAFT INTEGRATION

The objective of using low risk, existing hardware and designs on Minotaur V is carried over into the area of spacecraft interfaces and integration, utilizing the same mature processes and methodology as for the Minotaur I and IV SLV's. In general, accommodations and mission-specific options will be the same 'ala carte' selection that is available on these vehicles. Similarly, the electrical and mechanical interfaces are identical to those used on Minotaur I and/or IV to the greatest extent possible. Although a Minotaur V-specific User's Guide as not been developed to date, the existing Minotaur IV User's Guide* provides a good reference and guidelines on Minotaur V spacecraft integration and interfaces.

Optional Enhancements

Through out the history of the Minotaur vehicles, the flexibility to adapt to new and varied mission requirements has been demonstrated. Under the OSP contract - through which Minotaur vehicles are provided - mission-unique enhancement are available as a menu of options. A list of typical enhancements that can be provided is shown in Figure 11. More detailed descriptions of these enhancements, as implemented for Minotaur IV, can be found in the Minotaur IV User's Guide*. The options have been defined to encompass the majority of requirements that might be needed to support typical space launch However, there are always additional requirements that may be identified to support unique needs. These can also be readily accommodated through early coordination with Orbital and the OSP Air Force program office at Kirtland AFB, NM.

- Payload Accommodations
 - Separation Systems
 - Additional Fairing Access Doors
 - Conditioned Air
 - Nitrogen Purge
 - > Enhanced Contamination Control
 - ➤ Navigation Data Pass-Through
- Performance Enhancements
 - ➤ HAPS for Insertion Accuracy
- Launch Support Enhancements
 - Enhanced Telemetry (High Data Rate)
 - > TDRSS TM Relay
 - > GPS Metric Tracking
 - ➤ Alternate Launch Sites
 - > Temporary Access Structure
 - Booster Temperature Control
- Secondary Payload Missions

Figure 11 - Minotaur V Enhanced Options (Typical)

Mechanical Interface

The standard mechanical interface for the Minotaur V vehicle is the same 38.81 inch diameter bolt pattern used on Orbital's Pegasus, Taurus, and Minotaur I vehicles, as shown in Figure 12. This interface was originally defined for the Pegasus SLV but has since been adopted as a de facto standard for small launch vehicles. As such, several flight proven separation systems are available. Similarly, a number of standardized spacecraft busses - available from various suppliers – are compatible with this interface design. The Minotaur V uses the same 92 inch fairing as Minotaur IV and Taurus, so the fairing dynamic envelope is well understood. However, the fifth stage is within the fairing envelope, as shown in Figure 13.

Electrical Interface

There two general categories of electrical interfaces are provided on all Minotaur launch vehicles: 1) Groundto-Spacecraft and 2) Launch Vehicle-to-Spacecraft. For the first, pass-thru cabling is provided via a dedicated umbilical within the launch vehicle umbilical allowing the spacecraft direct connection to its own Ground Support Equipment (GSE) at the launch site. The standard service for this interface is 60 wires, accommodating such functions as spacecraft battery charging, spacecraft ground communications, and hard line telemetry. For the Launch Vehicle-to-Spacecraft interface, the modular nature of the standard Minotaur avionics allows electrical interfaces to be readily adapted to mission-specific requirements. Support can be provided for discrete electrical commands, pyrotechnic initiation signals, spacecraft telemetry, and digital interfaces such as RS-422/RS-485. More details on the electrical interface support can be found

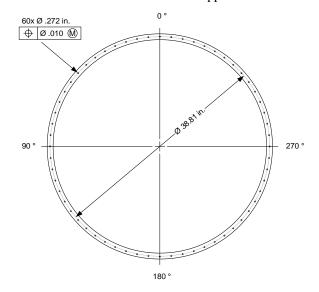


Figure 12 - Minotaur V Standard Mechanical Interface

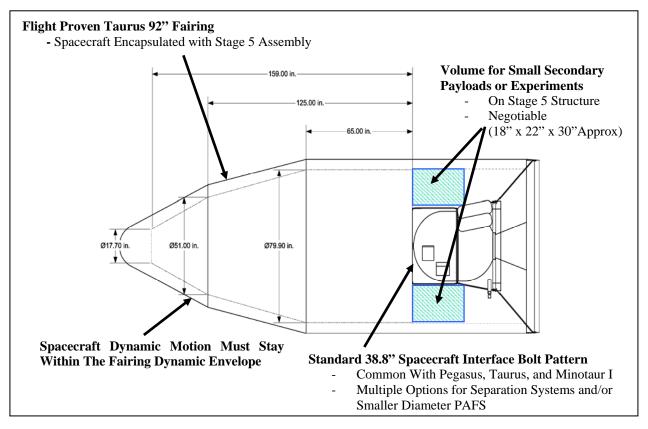


Figure 13 - Minotaur V Spacecraft Dynamic Envelope

in the Minotaur IV User's Guide*

Environments

Qualitatively, the Minotaur V environments will typically be less severe than those predicted for Minotaur IV due to the added mass and structure on top of the baseline Minotaur IV configuration. These are available in the Minotaur IV User's Guide*. Moreover. Minotaur IV environmental levels are comparable with other available launch vehicles, so no uniquely severe environments are anticipated for Minotaur V. Definition of detailed Minotaur V environments will be undertaken as the first priority in the development effort. In the interim, commonality with the Minotaur IV configuration allows the environments of that vehicle to be used as guidelines. This increased mass results in lower peak accelerations in the axial direction. Similarly, it causes a slower ascent through the atmosphere, thereby reducing the generation of aero acoustic vibrations. The mass and extra joints also mitigate vibration and shock environments propagated up from the lower stages. Thermal environments are managed and controlled in the same manner as Minotaur IV, so no significant changes are anticipated.

CONCLUSIONS

Minotaur V opens up this affordable class of high energy orbits to the small-sat community. It's performance to LEO through TLI – and beyond-

provides the capability to deliver useful spacecraft into orbits heretofore inaccessible within the context of small, low-cost space missions. This capability will support a new generation of small-sats going where no small-sat has gone before!

References:

^{*} Minotaur IV User's Guide, Release 1.1, Jan 06, Orbital Sciences Corporation, http://www.orbital.com/NewsInfo/Publications/Minotaur_IV_Guide.pdf

Appendix

A-1. MINUTEMAN AND PEACEKEEPER HERITAGE SYSTEMS

The foundation of the Minotaur-family vehicles is the use of boosters from decommissioned Minuteman II and Peacekeeper (PK) ICBMs. Because these vehicles were designed to be at the vanguard of the U.S. strategic forces, they are inherently designed for reliability and longevity. Moreover, they are specifically designed to be storable and responsive – characteristics that were vital in the ICBM role, needing to launch in a matter of minutes when called upon.

The Minuteman II system has its origins in late 1950's when Air Force research indicated that a solid-fuel system was technologically feasible[†]. The burgeoning solid fuel technology gave it significant advantages over the original liquid-fuel launch vehicles of the time. A solid fuel system was desired because it provided a much higher reliability, lower maintenance and the ability to be stored for longer periods of time. Unlike a liquid fuel system, which required fueling and/or other preparations before launch, the Minuteman system was capable of being launched within second of activating the launch sequence. Similar logic makes solid fuel rockets preferable for the responsive launch solution. Moreover, solid propellant systems are generally considered to be safer than liquid systems when properly handled, particularly for long term storage and rapid launch. They do not require the storage, handling, and fueling of volatile, combustible liquids nor hazardous cryogenic fluids. This safety advantage of solid propellant systems has been confirmed by their use on all modern major missile systems, small to large, and by all military services.

The first test flight of a Minuteman I system occurred in Feb 1961 from Cape Canaveral, Florida and was successful. The first Minuteman I vehicles were on operational alert by Oct 1962. The Minuteman II, with a new, higher performance 2nd stage motor was first launched in Sep 1964 and the Minuteman III, with an new Stage 3 motor, was first launch in August 1968. All told, there have been 838 Minuteman-based launches of which 816 have been successful for an overall success rate of greater than 97%[‡]. This value includes early developmental failures in the 1960's. The unmodified Minuteman II boosters that are used for the Minotaur vehicles have an unprecedented success rate of 100%: 198 of 198 launches³. These numbers include the twelve Minuteman II-based RSLP launches under the OSP program, as well as the eight launches under the predecessor Multi Service Launch System (MSLS) program.

The PK system has a similar highly successful history, starting with the first test launch in June 1983 (Figure A-1). Although the total numbers are not as large, PK boosters have a 98% success rate of 50 successful

launches out of a total of 51[§]. (53 of 54 counting the three Taurus launches which used the PK Stage 1 This launch motor). history is supplemented multiple static firings of each stage: 20 for Stage 1, 18 for Stage 2, and 18 for Stage 3. Moreover, the one failure of a PK booster was not caused by an element that is being used for the Minotaur III or IV.



Figure A-1 - PK Test Launch, VAFB, CA

The overall combined success rate of the PK and MM II boosters used for the Minotaur vehicles is greater than 99%. This contrasts quite dramatically with the success rate of the liquid fuel ICBMs of similar origins: 74% (168 of 228) for Atlas (A thru F)**, 71% (53 of 74) for Thor^{††}, and 70% (47 of 67) for Titan I^{‡‡}. Titan II has the best record with an 81% success rate (66 of 81)§§. but it still falls substantially short of the solid-motor MM and PK vehicles. Note that these values reflect only the ICBM application of these boosters to give a representative comparison of the fundamental booster reliability in a responsive roll. For the space launch derivatives, particularly in the case of the Gemini launches on Titan II, significant extra scrutiny and effort was applied to assure success, but also with correspondingly reduced responsiveness.

Although some have characterized this use of decommissioned motors as the Government taking away business from the commercial launch vehicle industry, this is not the case. In reality, it allows the Government to make use of its valuable existing assets – reliable, decommissioned motors – rather than paying to have them destroyed. Overall, more than 90% of the funding for OSP launches goes to commercial contractors via competitively awarded contracts. Additionally, the OSP launches are contracted on a fixed-price incentive firm (FPIF) basis, thereby limiting the Government's liability to unexpected cost overruns.

A-2. MINOTAUR AS TEST-PLATFORM

In addition to providing cost-effective launches, the Minotaur family of vehicles has also served successfully as a platform for testing out new launch vehicle technology in a expedient manner. Experiments, technology demonstrations, and other "firsts" have been a part of most Minotaur missions. Among these are a GPS Postion Beacon (GPB) providing autonomous metric tracking for Range safety, a Low Cost TDRSS Transmitter (LCT2), and an advanced grid-stiffened composite fairing. The first two, in particular are pertinent to ORS applications. By providing autonomous tracking and a satellite-based telemetry link, the need for Range support infrastructure, such as downrange telemetry antennas and tracking radars is greatly diminished. Also, this simplifies operations by reducing the number of sites and systems involved, similarly improving the ability to react and launch in a responsive manger. These are each discussed briefly below and shown in Figure A-2.

- 1. GPS Metric Tracking. A GPS Position Beacon (GPB) system has been demonstrated on two Minotaur I missions. The inaugural JAWSat mission successfully flew a second generation of Orbital's GPB. More recently, the third mission, XSS-11 in April 2005, flew the latest technology fourth generation GPB-IV system. The data from this flight has been certified by Range Safety engineers at the Western Range, as one of three flights necessary to validate the GPB-IV for Range Safety use. GPB-IV systems are also planned to fly on future Minotaur and other Orbital-built launch vehicles.
- 2. Low Cost TDRSS Transmitter. On the fifth Minotaur I launch, a NASA-developed Low Cost TDRSS Transmitter (LCT2) was flown. It worked flawlessly, delivering real-time telemetry throughout the mission via the TDRSS link. This system is much less costly that previous TDRSS transmitter solutions and avoided the need for the expense and complications of downrange telemetry

- receiving sites. As with the GPB-IV, there are plans to fly LCT2 systems on future Minotaur vehicles.
- 3. Grid-stiffened Composite Fairing. The TacSat-2 launch was the first mission to fly a larger, 61 inch diameter fairing that was jointly developed by AFRL and Orbital. It used an innovated fiber-layup manufacture to create a grid-stiffened design from composite fiber construction

† Web Page: http://www.geocities.com/minuteman_missile/ launches.htm

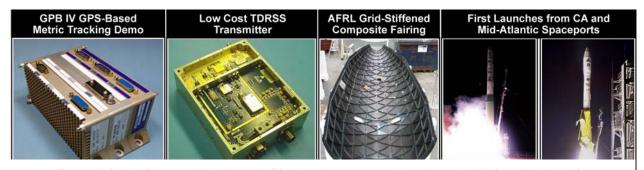


Figure A-2 - - Minotaur I Has Been Utilized to Demonstrate New Launch Vehicle Technologies

[†] Neufeld, J., "The Development of Ballistic Missiles in the United States Air Force 1945-1960", Office of Air Force History, United States Air Force, Washington, DC, 1989.

[§] Web Page: http://www.geocities.com/
peacekeeper_icbm/launches.htm

^{**} Web Page : Gunter's Space Page – Atlas ICBM: http://www.skyrocket.de/space/doc_lau/atlas_icbm.htm

^{††} Web Page : Gunter's Space Page – Thor IRBM: http://www.skyrocket.de/space/doc_lau/thor_irbm.htm

^{‡‡} Web Page : Gunter's Space Page – Titan I ICBM: http://www.skyrocket.de/space/doc_lau/titan-1.htm

^{§§} Web Page: Gunter's Space Page – Titan II ICBM: http://www.skyrocket.de/space/doc_lau/titan-2 icbm.htm