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Paper Session II-C - Titan IV Heavy-Lift Space Launch System Evolution

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Titan IV, the nation's most capable launch system, was initiated in 1984 as the Complementary Expendable Launch Vehicle (CELV). The mission of the CELV was to back-up the space shuttles for specific, large Department of Defense (DOD) payloads. National space policy changes, following the loss of the Space Shuttle Challenger in 1986, fundamentally altered the CELV program and initiated an evolution that has established Titan IV as the primary launch capability for many of the nation's most critically-important space systems. Major developmental initiatives are now near completion, and the program is moving to its mature operational phase.

This paper examines the Air Force/contractor team response as program requirements expanded and the nation's priorities shifted. The resulting heavy-lift capability of the Titan IV system will be described. Technological improvements and system modernization initiatives will be reviewed. Projected applications of the Titan IV to meet future national space launch requirements will be evaluated.

Introduction

Titan launch vehicles have contributed to the national space objectives for more than thirty years. Titan configurations have supported commercial, National Aeronautics Space Agency (NASA), and DOD missions. These mission requirements have resulted in the development of fourteen distinct configurations. Impressive performance improvements have allowed the launch capability of less than 2000 lb geotransfer orbit in 1959 to increase to today's equivalent of over 20,000 lb. With over 330 launches, achieving a mission success rate of 95%, the Titan has become the workhorse of the nation's heavy-lift space launch missions.

Developing new launch systems is prohibitively expensive. With the present investment in Titan system development and infrastructure (design, manufacture, test, and launch) in place, our nation can leverage this investment to cost effectively provide the nation's near-term, heavy-lift capability. The Titan system is well-understood with all five configurations now flight proven. Minimal investment can ensure that the program is reliable, robust and operable.
Mission Requirement

The Titan IV was developed to launch the nation’s largest, high-priority, high-value payloads (see Figure 1). The system was originally envisioned for assured access to space as a back-up to the space shuttle to launch 10,000 lb geostationary (GSO) payloads only. Following the space shuttle failure, the Titan IV requirement was increased to include high-inclination missions, Inertial Upper Stage (IUS) missions, and 25% greater GSO capability.

Titan IV is the only space launch system that can meet these critical mission requirements. Although the projected launch rate declines in the future, the need for this class capability is long term. Mission requirements exist beyond 2010. The nation’s highest priority space systems are launched on Titan IV.

Titan IV Capability

Multiple Titan IV configurations have been developed to meet the nation’s mission requirements. With the 7 February 1994 launch of the Titan IV Centaur, all five configurations have been flight proven with the United Technologies, Chemical Systems Division, Solid Rocket Motors (SRMs) (see Figure 2). The Hercules Solid Rocket Motor Upgrade (SRMU) is fully qualified and flights are scheduled beginning in 1996.

Titan IV is capable of placing 10,000–12,700 lb payloads into GSO, more than twice the capability of any other launch vehicle; 38,000 lb payloads into high-inclination polar orbit, more than three times the capability of any other launch vehicle; and nearly 48,000 lb payloads into low-earth orbit (LEO) from Cape Canaveral Air Force Station (CCAFS), more than any other launch vehicle. In addition, the Titan IV can support high-energy planetary missions requiring the Centaur upper stage, which provides nearly three times more energy than any existing launch vehicle.

The Titan IV can accommodate payloads 15 feet in diameter with length in excess of 60 feet. This provides a payload volume equal to the space shuttle.

Mature launch infrastructure is operational at CCAFS for low-inclination missions and at Vandenberg Air Force Base (VAFB) for high-inclination missions. All three of the launch facilities (Launch
Complex 40 & 41 at CCAFS and Space Launch Complex 4E at VAFB) have supported the first eight launches.

With the qualification of the SRMU complete, and the successful launch of the first Centaur in February, all Titan IV team major element contractors are in production.

The manufacturing and launch infrastructure is fully qualified, in place and operational to support a launch manifest of up to 3 high-inclination (VAFB) and 6 low-inclination (CCAFS) missions per year. Figure 3 depicts the current planned launch rate to support the nation’s requirements.

**Continuous Process/Product Improvement**

The nation’s multibillion-dollar investment in the Titan IV heavy-lift capability, coupled with the future low launch rate projections, suggest that, in the near term, it makes better sense to invest moderate amounts on improvements to the current launch systems, rather than to invest in the creation of a new system. To achieve incremental and dramatic improvements, the Titan program is implementing its ten-year improvement plan. The Air Force, contractors, and system users have contributed to the development and refinement of this plan (see Figure 4). Key tenants of the approach address: Robust System/Reliability Improvement, Cost Reduction, Increased Operability, Improved Responsiveness, Safety, and Environmental Friendliness.
Implementation of the Titan ten-year improvement plan to date has developed Lightning Mitigation at CCAFS, Ring Laser Gyro Advanced Avionics, Common Core Vehicle, Payload Integration Process Streamlining, Programmable Aerospace Ground Equipment (PAGE), Safety compliant Flight Termination System, Solid Rocket Motor Upgrade, and Liquid Engine nozzle expansion ratio increase.

Lightning Mitigation System at the launch pad allows 5–10% greater vehicle processing availability by eliminating required work stoppage and pad clearing due to potential lightning in the area, while significantly increasing crew safety.

Ring Laser Gyro Advanced Avionics reduces the guidance price while improving injection accuracy and payload capability.

Common Core Vehicle incorporates Stage One and Stage Two common hardware, interfaces and systems for all vehicles after the 23rd vehicle. This commonality reduces production cost while improving operability and responsiveness. Cost is reduced by manufacturing identical components in larger lot sizes. Operability and responsiveness are improved since any core vehicle can be used to fly any mission. Payload unique interface requirements are met with mission unique hardware kits.

Payload Integration process streamlining has reduced cost and improved responsiveness by reducing number of tasks, task scopes due to inefficiencies, and timelines required to perform the mission unique analyses. An example of this was demonstrated recently on the Titan II program when the
Ballistic Missile Defense Organization (BMDO) Deep Space Science Experiment, a lunar mission, was successfully integrated in less than 16 months.

Programmable Aerospace Ground Equipment (PAGE) in place at all launch sites will improve the operability and responsiveness while reducing cost by replacing the aging Programmable Aerospace Checkout Equipment (PACE) system. The PACE system is becoming increasingly difficult and costly to maintain and operate reliably. The PAGE system will reduce this cost while being significantly more operable.

The Flight Termination System (FTS) will be fully range safety approved beginning with the 24th vehicle. The improvement will include new redundancy features, higher reliability components, and ordnance safety.

The Titan system robustness will be improved with the development of the SRMU, and the Stage One Liquid Rocket Engine (LRE) nozzle expansion ratio increase. These improvements increase the performance of the system so that it will not be required to operate at full capability for all missions. The increased performance can also be used for unique missions that may need this additional capability.

Future elements of the Titan ten-year plan have been developed and are continuously being refined by the Titan Leadership Team. This team is made up of the system users, Air Force, and contractors. To address the most important issues first and to maximize the productivity and efficiency of any improvement, the team first prioritized the system requirements. The requirements contained in the Titan IV Operations Requirements Document (ORD) were used as the foundation of this prioritization. Figure 5 presents the results of the assessment.

Specific improvement initiatives address this prioritization in the launch vehicle hardware, manufacturing and launch operations process areas. Resulting high return system improvements are grouped in three categories: those supporting the contracted 41-vehicle production program, those that enhance the launch infrastructure, and those appropriately fitting for a block update at vehicle 42.

![Figure 5 Operational Requirements Prioritization for Effective Improvement](image)
Table 1 shows these three groups. The first group of initiatives are mostly component and subsystem development and modification while the infrastructure initiatives and third group are more system oriented.

**Table 1 Recommended Titan IV System Improvements**

<table>
<thead>
<tr>
<th>41-Vehicle Program</th>
<th>Infrastructure</th>
<th>Beyond the 41-Vehicle Program</th>
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<tr>
<td>System Margin Definition &amp; Improvement (2)</td>
<td>Centaur Processing Facility-Operational (1)</td>
<td>Integrated Fault Tolerant Avionics (4)</td>
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<td>LRE Turbo Pump Rotor Upgrade</td>
<td>Off-Pad Payload Encapsulation, Cape Canaveral</td>
<td>Stage I Boattail Redesign</td>
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<tr>
<td>Standard Payload Interfaces</td>
<td>Off-Pad Payload Encapsulation, VAFB (3)</td>
<td>Composite Payload Fairing</td>
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<tr>
<td>Centaur Lip Seals &amp; Welded Tubing</td>
<td>Critical Facility Repairs, Vandenberg</td>
<td>LRE Stage I 18.75:1 Nozzle Expansion</td>
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<tr>
<td>Lightweight Casting Upgrades (Core &amp; LREs)</td>
<td>Improved Data &amp; Trend Analysis System</td>
<td>LRE Manufacturing Expertise Retention</td>
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<tr>
<td>Improved Analytical Tool Set</td>
<td>Propellant Loading System Replacement</td>
<td>LRE Stage II 55:1 Nozzle Expansion</td>
</tr>
<tr>
<td>LRE Injector Upgrade</td>
<td>Off-Pad Boost Vehicle Processing (3)</td>
<td>Centaur Single Engine (5)</td>
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<tr>
<td>SRMU Periodic Case Burst Test</td>
<td>Centaur Auto Data Monitor/GSE</td>
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<tr>
<td>Solid Motor Flight Hardware Retrieval</td>
<td>Integrated Launch Site Management System</td>
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<tr>
<td>Centaur Redundant Vent Valves</td>
<td>Automated Hydrazine Tanking, Launch Complex 41</td>
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<tr>
<td>SRMU Corrosion Control</td>
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Noteworthy continuous improvement initiatives referenced in Table 1 are:

1. Outfitting the Centaur Processing Facility with operational equipment will eliminate processing bottlenecks caused by the conversion of a booster erection cell in the VIB and support a safer off-pad cryogenic loading test. This facility can support the Atlas Centaur needs through more efficient consolidated operations.

2. System Margin Definition and Improvement to recover margin lost by payload performance demands and increase the system robustness to match today’s standards.

3. Off-Pad Payload Encapsulation and Booster Processing to raise the system availability and responsiveness by reducing the critical path operations in the launch processing. The time associated with in-line critical processes drives system cost.

4. Integrated Fault Tolerant Avionics for the launch vehicle guidance and flight control eliminates mission losses due to single-point failures.

5. Single Engine Centaur simplifies the upper stage design by removing one of the two engines and provides increased performance at a lower cost.
Future National Space Launch Applications

Titan program direction, and much of its funding, has been used to maintain the national mission support features such as access to space and launch call-up. Future mission applications can be met by the inherent flexibility of the system.

DOD potential use includes communications and surveillance systems. As programs are combined and system hardware size reduced, some missions will continue to require the size of Titan IV capability for mission performance or economy of scale. The Titan IV payload size and weight capability provides users the flexibility to develop cost-effective systems. The launch cost is typically a small percentage of the life cycle cost of these national priority systems. Experience has shown that downsizing is effective for many of the spacecraft components, but the physics required to achieve resolution, power, and precision will always drive the need for heavy-lift capability.

NASA use of the Titan IV as a complementary launch system may provide greater mission science data while relieving pressure on the space shuttle launch rate. The use of unmanned vehicles avoids needlessly endangering shuttle crews.

The Titan IV Centaur can launch greater payloads (more science instruments) with a significantly shorter transfer time for the Pluto Fast Fly-By mission since this vehicle has greater energy for planetary missions than any other space launch system (see Figure 6).

The Advanced X-Ray Astronomical Facility (AXAF) mission benefits include lower mission cost, lower risk and continuous data coverage. Mission cost is reduced by placing AXAF in an optimized orbit while avoiding the cost of a new unique upper stage. This orbit allows science data to be collected at all times, thus lowering the mission cost. Risk is reduced by avoiding the development of a new unique upper stage to meet this mission orbital requirement. Elimination of the human rating requirements allows greater spacecraft design flexibility, which may also reduce mission risk. For example, explosive-separation systems are more reliable than the motor-driven systems required for human-rated system safety.

Figure 6 shows that the Space Station assembly and resupply missions could benefit by the greater payload capability of Titan IV to the Space Station orbit. Additionally, reduction of the routine space shuttle flights, when humans are not required, provides the shuttle launch manifest schedule flexibility and margin. Back-up capability for other foreign launches removes program risk for long-term stability.
Space Station Delivery

Figure 6  Titan IV Provides Largest performance Capability for Planetary or Space Station Delivery

Summary

The nation’s requirement for large, heavy, polar and GSO spacecraft exists well into the next decade. The investment made in the Titan IV launch system meets these critical mission requirements. Long-term reliance on this system establishes the need to continuously improve systems and operations with a moderate investment (7–8% of the program annual cost). Additional use of this versatile infrastructure by NASA and DOD will lower future unit costs and maintain a robust national production capacity.