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OPERATIONALLY RESPONSIVE SPACELIFT FOR THE U.S. AIR FORCE

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Abstract

This paper will focus on the capabilities that the Air Force needs in order to meet emerging warfighter requirements for 2010-2020. The Operationally Responsive Spacelift Mission Need Statement will be discussed along with the Air Force's plan to integrate various technologies to develop a responsive spacelift architecture. Recent responsive spacelift activities will also be discussed.

Introduction

The 1991 Persian Gulf War or Operation Desert Storm as it is referred to, is said to be the first "space war" because of the coalition's reliance on satellites and space technology. Indeed, use of satellites for intelligence preparation of the battlefield, for navigation through featureless desert, for precision targeting, and for detecting and tracking Scud missiles made a sizable impact on the duration and outcome of the war. Many analysts believe that all major wars of the future will increase their reliance on satellites and space technology. This poses a challenge when conflicts suddenly arise. For example, how does one rapidly replenish and augment existing satellite constellations? How does one quickly launch additional space assets to concentrate coverage over a particular area of interest? Current military launch vehicles take many months of planning, budgeting, and preparation before they can execute a successful launch. They are not suited for the rapid, responsive payload integration and launch that will be required in the future.

When the idea of force application through space enters the equation, the requirement for responsive launch becomes even more demanding. For example, a transformational concept of non-nuclear deterrence would capitalize on the ability of CONUS-based responsive launch to hold critical targets at risk around the globe.

Military Mission Need

The Air Force captured this required capability for the warfighter in a document known as the Operationally Responsive Spacelift (ORS) Mission Need Statement (MNS).[1] The Air Force Requirements Oversight Council approved this document in late 2001. The Joint Requirements Oversight Council validated it in April 2002. ORS ensures the Air Force has the capability to rapidly put payloads into orbit and maneuver spacecraft to any point in earth-centered space, and to logistically support them on orbit or return them to earth. Once this capability is part of its space force mix, the Air Force will be postured to conduct the full spectrum of military activities required to ensure U.S freedom of action, or defeat an enemy, in space. Basically this Mission Need Statement calls for routine access to space as early as 2010-2020. Routine access includes affordable, launch-on-demand capability and "aircraft-like" sortie rates.

Another document used to describe the need for ORS is the Air Force's *The Aerospace Force: Defending America in the 21st Century*.[2] This document states: "The country's growing investment in and reliance on, space-based capabilities that support the national information and commercial infrastructure are creating an economic and military center of gravity—a vulnerability that, if exploited, could adversely affect the nation." A solution to the ORS mission need statement could provide the ability to enhance and reconstitute our current and future space-based capabilities such as: intelligence, surveillance, and reconnaissance (ISR); navigation and timing; communications; weather data; future Force Application and Space Control Missions that are critical to joint operations.

Other references citing the need for responsive launch include the Air Force Space Command (AFSPC) Strategic Master Plan (SMP)[3] and the Military Spaceplane Concept of Operations [4]. The former document establishes a strategic vision of where AFSPC is heading in the decade or so to come. The SMP also guides the Command's modernization investment decisions. The latter document presents a top-level notional idea of how a responsive launch capability will be utilized.

Need for Operability

The need for launch-on-demand and "aircraft-like" (quick turn around) sortie rates drives the overarching characteristic of operability. Operability implies, but is not restricted to, reusable space vehicles. It's crucial that advanced spacelift reusability characteristics be responsive to the warfighter, not only in relation to meeting anticipated sortie generation rates, but also in meeting sustained and emergency surge turn times. Reusable spacelift operability characteristics will have a major impact on mission characteristics such as system availability, mission capable rates, alert holds, etc.

Operability also impacts the ground launch infrastructure. Launch pads will have to accommodate rapid and possibly frequent payload integration, stacking, test, checkout, as well as launch vehicle fueling, mission planning, etc. Launch ranges will have to upgrade to accommodate responsive launches. Since current launch-on-schedule operations have many months to plan and prepare for each launch, new paradigms, launch concepts of operations, and technologies will be required to transition to this launch-on-demand capability.

Architectural Concepts

The Air Force's notional concept of a reusable spacelift system includes a generic "system of systems" known as the military spaceplane (MSP). This concept ideally features a reusable launch vehicle known as the Space Operations Vehicle (SOV), an on-orbit maneuvering vehicle called the Space Maneuver Vehicle (SMV), a Modular Insertion upper Stage (MIS) a munitions platform known as the Common Aero Vehicle (CAV), and an On-Orbit Servicing element (OOS).

The SOV is envisioned to be an unmanned, reusable launch vehicle to low earth orbit. Current concepts call for a two-stage to orbit design. As an evolutionary weapon system, it offers revolutionary capabilities such as launch-on-demand, rapid turn around, and high sortie rates that enable a cost effective national and space missions to support the Combatant Commanders.

The SMV is a flexible, reusable orbital vehicle, which would normally be deployed on the SOV. Once it completes its on-orbit mission, it re-enters and lands for refurbishment.

The Modular Insertion Stage (MIS) is designed to complement the SOV. It is envisioned to be a reliable, inexpensive, expendable upper stage. The MIS would boost payloads into Medium Earth Orbit (MEO) and Geosynchronous Earth Orbit (GEO).

The Common Aero Vehicle is an unpowered weapon delivery system. It is envisioned as the primary weapons delivery system for the MSP concept. It is flexible, highly maneuverable, reentry vehicle that could be capable of carrying a broad array of submunitions such as unitary pentrators, small diameter bombs, and wide area standoff munitions.

The On-Orbit Servicing (OOS) concept is the least mature of the MSP concepts. Currently this capability is broad enough to potentially encompass several different servicing vehicles. These vehicles may include a refueler satellite, a component servicer, and a space "tug".

The refueler would be analogous to the air "tanker" concept whereby satellites could be refueled while on-orbit. The capability of having refuelable satellites on-orbit not only extends their mission duration and Delta-V capability, but also enables them to be launched with little or no fuel on board, thus decreasing launch weights.

The component servicer would be used to replace or upgrade various avionic components analogous to the "line replaceable units (LRUs)" that the Air Force uses today in its aircraft. Again the benefits include extended mission duration and avoidance of parts obsolescence. Processor upgrades could become routine on operational satellites.

The space tug could be used to maneuver satellites into different orbits thus conserving the satellite's on-board fuel. In addition, a space tug would provide a central vehicle for orbit analysts to plan their orbit change maneuvers, rather than having to perform that planning for individual satellites.

The MSP concept is just one of many potential concepts that could satisfy the ORS MNS. Other potential concepts include expendable rockets, hybrids of reusable and expendables, air launched concepts, or even modifications to existing systems. The ORS analysis of alternatives will identify the most effective solution(s) to satisfying the need.

Technology Needs

Since ORS represents a revolutionary change in the way the Air Force performs its launch and on-orbit missions, new enabling technologies will be required not only for the launch vehicle components themselves, but also for the responsive infrastructure that will have to be developed, as well as for revolutionary new responsive payloads.

For instance, a broad array of specialized submuntions, payloads and sensors must be developed in parallel with any ORS concept to ensure we fully realize its space warfighting potential. These systems must provide specific ISR and counterspace capabilities required by the Combatant Commanders. They should be relatively small and be able to provide operational functionality as soon as possible after deployment-i.e. a first pass capability. Current concepts range from free flying tactical satellites (TACSATs) inserted into optimized operational orbits and able to operate anywhere from days to months. Some systems could be sensors designed for operation with an SMV-like orbital vehicle and robust enough to withstand re-entry and recovery within the SMV. Others could be developed to provide off-board sensing needed to enhance the effectiveness of air-breathing platforms. These concepts will drive enabling technologies for rapid payload initialization, checkout, and calibration. New technologies will also be needed to avoid relatively long periods of out gassing and platform stabilization.

As previously described, notional SOV concept for the sake of this paper is an unmanned, operationally responsive, fully reusable launch vehicle system with the following potential characteristics:

- All azimuth / weather launch capability
- Low cost operations
- Growth toward aircraft-like turn times
- Minimal logistics footprint
- High reliability
- Safe overflight of populated areas
- Delivery of 15,000 lb payload to LEO East at 28.5 deg inclination

As a weapon system, the vehicle may be required to conduct sustained, daily operations in support of the Joint Force Commander (JFC) and Joint Force Air Component Commander (JFACC), in the Air Tasking Order (ATO) system. As a result, the vehicle must not only be highly robust and reliable, but problems with the vehicle systems must be able to be identified, isolated and repaired on the flightline, to include removal and replacement of a main propulsion system

Design for advanced spacelift operability, in this context, must then address several factors including not only operability, but also maintainability, and supportability. Operability includes routine ground turnaround, while maintainability, and reliability (robustness and fault tolerant design) includes actions to address non-routine problems with the system. Supportability factors (logistics, spares, etc.) are also important to the overall ownership costs of the system.

The Air Force Research Laboratory (AFRL) and the National Aeronautics and Space Administration (NASA) are currently investigating a vast array of technology development needs for advanced reusable spacelift, with a focus on operability, in the areas of integrated airframe, propulsion, avionics, and ground systems.

Airframe

A unique aspect of launch vehicle airframes in relation to meeting "aircraft-like" operations is the extreme reentry heating rates and dynamic environments encountered. These conditions require an airframe with either hot-structure surfaces (composites), and/or cold-structures covered by thermal protection systems (TPS).

Maintenance and repair on current TPS is excessively high and must be reduced significantly. This includes technology advances for minimal times required for inspection, repair, remove/replacement, sealing, waterproofing, etc. It is likely that an automated TPS inspection system (e.g. High-resolution digital cameras) will be required to meet overall turn time requirements.

Booster airframes may likely require structural health monitoring and instrumentation (leak detection). Technology development will be needed to develop and improve sensing techniques & analysis tools for structural usage and damage monitoring, including inspection of composite and multi-layer structures.

Advances in hot/cold structures, integrated structures, advanced composites, and hot seals for moveable surfaces, will be required. Operability should be considered when selecting these airframe materials as well. Materials that are durable and damage tolerant should be selected. Materials selected, especially for critical structures, should have simple, non-destructive inspection characteristics and demonstrated flight line repair methods

Propulsion

The vehicle main engines will be a major driver in costs and operations, and is a primary technology development item. The need for operability, reliability, and maintainability are prime considerations.

Propulsion systems (engines, turbo pumps, propellant feed components and pressurized tanks) by their nature are complex and extensive; therefore, potentially time consuming and costly to repair. For this reason, the entire vehicle propulsion system needs to be treated as a whole, not a collection of parts, and reliability and maintainability considerations need to be analyzed as thoroughly as performance.

While it is impossible to design propulsion system components to never fail, it is possible to design them to last for a reasonable length of time, be fault tolerant, and minimize the difficulty of maintenance. Thus, reliable, fault detection and isolation is of paramount importance for a system with this many components.

The need for either reusable or expendable propulsion operability to provide adequate redundancy and minimize the operational impact reinforces that subsystems must be as simple and modular as possible, and use components designed, and tested, for high reliability. Propulsion systems should design in leak, damage, and corrosion tolerance. Fault detection and isolation must be included, as well as designs for simple umbilical attach/detach. Fill & drain of fluids and gases should be simplified (automated) as much as possible, with a single type of propellant(s).

Propulsion systems and vehicle design interface will need to be considered to facilitate turn-times. Easy access to components will be required. Connections, LRUs, etc., should be easy to manipulate with a minimum of tools required. Inspection and flightline servicing should be kept to a minimum.

Avionics

Advanced avionics, including guidance, navigation and control (GNC), both hardware and software, will be required to provide adaptive, flexible flight control operations, with a small flight crew, and adaptive mission planning. These developments will enable autonomous, fault tolerant operations providing fast, reliable access to vehicle systems status and providing data for informed maintenance.

The vehicle Integrated Vehicle Health Monitoring (IVHM) system will be used to gather information from each component's operations data as well as information from various sensors throughout the vehicle. This information can then be analyzed to determine required maintenance actions, equipment modifications or changes to the vehicle mission profiles. The system will likely include in-flight downlinks to operations personnel, real-time maintenance and corrective action planning

The vehicle IVHM system will be an extensive, highly distributed architecture of advanced sensors to monitor almost every facet of the vehicle systems and subsystems. These sensors, along with intelligent built-in test algorithms, help enable the IVHM to determine subsystem (LRU) degree of failure and system availability as well as assist informed maintenance in detailed diagnostics and prognostics during servicing. Stand-alone sensors might be used for structural or other components that have no self-diagnostic capability.

Avionics systems will likely require advances in thermal management/cooling systems, both for active and passive systems. These systems, especially active (non-toxic, cooling fluids) systems, will also need to require a minimum of routine servicing and be easily accessed and maintained

Ground Systems

Both advanced reusable spacelift vehicles and expendable systems will likely require highly robust and reliable automation systems for turning a reusable vehicle and for the ground systems during re-launch operations. The conceptual launch facility design will most likely incorporate an automated umbilical system (primarily for fueling operations) to facilitate rapid turn times. Multi-stage booster systems might likely benefit from automated, or at least operator-in-the-loop assisted, vehicle and/or launch site mating capabilities.

Automation technology advances in sensors, smart instrumentation and algorithms, may provide for maintenance man-hour per sortie reductions, and provide safety improvements by elimination of manpower exposure to hazardous propellants and environments. Some of these advances might include rapid umbilical alignment capabilities, as well as mechanical connect/disconnect systems.

Other Vehicle Systems

Having to make vehicle/payload-bay interface configuration changes for each mission payload will certainly impact the vehicle's sortie generation capability. One means to address each future spacelift payload's unique size, shape, power, and command requirements is with a payload container with standard interfaces. The payload container can be reconfigured for each mission in a separate payload processing facility.

A payload container, which can be plugged into and out of the vehicle, will also simplify support equipment and handling operations. The container should have simple structural connections. The number of connections between the vehicle and payload container should be kept to a minimum. Clear, visual feedback will need to be provided to indicate proper container installation.

Advances in other, more standard, reusable vehicle subsystems reliability and maintainability will certainly contribute to overall turn time. Advanced electrical/mechanical actuators replacing more standard hydraulics; high-speed landing gear structures/ brakes/tires to reduce maintenance burden, etc., may also be of benefit.

Recent Activities

The Requirements Directorate of HQ Air Force Space Command (AFSPC/DR) is currently conducting an Analysis of Alternatives (AoA) as a prerequisite for any new potential acquisition program. For the ORS system this AoA is being conducted in two phases. Phase one is focusing on identifying and quantifying the utility of having an operationally responsive spacelift system. This phase is currently ongoing and should reach completion by March 2003. Phase two will start immediately following phase one completion. In phase two AFSPC/DR will identify various potential architectural concepts and evaluate them in terms of their cost effectiveness, technical risk, feasibility, and military utility. If military utility is identified for a given, cost effective, architectural concept, then plans for a potential development and acquisition program will be made.

The Air Force is also planning to execute flight demonstrations of the common aero vehicle and an associated small launch vehicle by 2007. These flights will demonstrate the technical feasibility of these concepts as well as potentially being used in a spiral development program for a fully operational system.

Summary and Conclusion

This paper identified the need for responsive spacelift capability for the U.S. Air Force. Current Air Force space launch operates under a launch-on - schedule concept of operations, where-by launch manifests are planned months to years in advance. Launch-on-demand brings a new transformational capability to the warfighters. This transformational capability transcends across all four-space mission areas: force application, counter space, force enhancement, and space support. Launch-on-demand brings rapid "aircraft-like sortie" launch rates. This transformational launch capability is meant to augment, not replace, current Air Force launch systems.

This transformational launch concept will drive many new technology challenges. No longer will performance be the main technology requirement driver. Instead, a new emphasis will be placed on operability and its associated enabling technologies, for both the space vehicle and its supporting infrastructure.

Air Force Space Command is currently conducting an Analysis of Alternatives (AoA) to identify and quantify the military utility of responsive spacelift. This AoA will also identify potential architectural concepts that will satisfy the operational need for responsive launch. These potential concepts include reusable rockets, expendable rockets, and air-breathing/rocket hybrids. The results of the AoA study are still at least a year away. However, whatever the AoA outcome is one thing is certain: this launch-on-demand capability will revolutionize military space launches of the future.

Endnotes and References

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