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Cargo Assured Access to International Space Station

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CARGO ASSURED ACCESS TO INTERNATIONAL SPACE STATION

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Abstract

Boeing's Cargo Assured Access logistics delivery system will provide a means to transport cargo to/from the International Space Station, Low Earth Orbit and the moon using Expendable Launch Vehicles. For Space Station, this capability will reduce cargo resupply backlog during nominal operations (e.g., supplement Shuttle, Progress, ATV and HTV) and augment cargo resupply capability during contingency operations (e.g., Shuttle delay and/or unavailability of International Partner launch or transfer vehicles). This capability can also provide an autonomous means to deliver cargo to lunar orbit, a lunar orbit refueling and work platform, and a contingency crew safe haven in support of NASA's new Exploration Initiative.

1. Introduction

In the year 2000, the United States Congress determined that it would be in the national interest to ensure an alternative means to deliver cargo to the International Space Station (ISS) in case the Space Shuttle was not available. Implementation of this approach, known as Alternate Access to Station (AAS), would also be commercial in nature. Twelve-month AAS contracts were awarded to four companies, including Boeing, in July of 2002 with the goal of producing a viable system design by August of 2003. At that point the intent was to down select from 4 contractors to 1, move forward into full system design and production, and demonstrate the service with a first flight by 2006. Congress originally funded AAS as part of NASA's Space Launch Initiative (SLI). However, by November 2002 most funding for AAS was transferred to the new Orbital Space Plane (OSP) program. Remaining funding was sufficient to continue the existing AAS contracts through the System Design Review (SDR) only.

Interest in AAS increased significantly after the destruction of the Space Shuttle Columbia in February 2003 and the grounding of the remaining Space Shuttle fleet. After the AAS System Design Review in July 2003, NASA extended the existing contracts by 4 months to allow the different contractors to evaluate a new AAS Design Reference Mission, which included transporting cargo from Earth to ISS and from ISS to back to Earth. This contract extension was completed after delivering an updated System Requirements Document, System Design Document and a priced Service Plan to NASA in January 2004. With the establishment of Project Constellation under NASA's new Exploration Initiative in February 2004, work in programs like AAS and OSP was halted awaiting new direction from NASA. At this time elements of Boeing's AAS system design are being evaluated for application to Project Constellation.

2. NASA AAS Service Requirements

The original AAS Design Reference Missions (DRM) were focused on delivering up to 18,000 kg of internal cargo (DRM1) or up to 18,000 kg of internal and external cargo to ISS. Boeing later defined a more realistic worst case backlog more in line with the actual ISS DAC-10 Traffic Model, ~7,000 kg (equivalent to ~1 Shuttle flight/year). In this mode, AAS was a supplement to Shuttle resupply of ISS, one that could be used as needed commercially to provide more affordable and more timely means to supply ISS on an as needed basis.

Boeing's AAS Team identified 3 potential service approaches to meet NASA's original DRMs. The least costly in terms of development and schedule was the use of an existing off-the-shelf transfer vehicle (Progress) and launch vehicle (Sea Launch) to deliver cargo to ISS. A costlier and longer lead time option was to procure a modified version of a new transfer vehicle currently under construction like the Automated Transfer Vehicle (ATV) from Europe or the H-II Transfer Vehicle (HTV) from Japan and fly it on an US launch system like Delta or Atlas. The most expensive option with the longest delivery schedule was to develop a totally new US transfer vehicle that would fly on a US launch vehicle. Due to the limited funding made available to implement AAS (less than $300M) and the desire by NASA for a first demonstration of the system by 2006, Boeing's initial AAS solution tended toward acquisition of a foreign transfer vehicle like the HTV. The Japanese HTV seemed to best meet the cargo resupply requirements of the US Segment of ISS because of its "Shuttle-like" capability to transport large external cargo and critical Orbital Replacement Units (ORU) in addition to internal cargo.

Reevaluation of this solution approach became necessary in November 2002 when most AAS funding was transferred to the OSP Program. This essentially eliminated the requirement for "quick" solutions to support an AAS service flight demonstration in 2006. Boeing then undertook additional analysis of ISS cargo resupply needs which revealed that the most critical need was not transporting cargo up, which could be performed by the Shuttle, Progress, ATV or HTV, but rather transporting cargo down (especially external cargo). Only the Shuttle is capable of returning any large external cargo to earth. Providing a cargo return capability became a accommodation priority and introduces a whole new operational regime.

This cargo return transportation mode is based on ISS logistics and maintenance planning. For instance, the ISS uses four Control Moment Gyroscopes (CMG) on-orbit for attitude control with a fifth CMG held as a spare on the ground. When a failed CMG needs replacement, the Shuttle is to fly the spare up in the Payload Bay, switch out the spare for the failed unit, and bring the failed unit back to Earth in the Shuttle. This returned unit is then refurbished for a fraction of the cost and schedule required by production of a new CMG. It is then returned to ground inventory as the new "spare". Without a return capability for failed ORUs, NASA would have to restart closed production lines, reallocate funding and deal with longer ORU return to flight times.

The original AAS DRMs defined the need to return cargo to earth as an "option" with no additional definition of cargo mass, volume or environmental conditioning requirements. After the Columbia accident, NASA developed a new DRM, DRM-A, which specified the amount of cargo mass, volume and power to be delivered to ISS and for the first time, returned to earth. Annual deliverable mass to ISS increased to 49,000 kg (equivalent to 5 Shuttle, 1 ATV and 1 HTV flights per year) with annual returnable mass to Earth now established at 35,000 kg (equivalent to ~5 Shuttle flights). AAS had evolved beyond a logistics resupply service to supplement the Shuttle to one that could replace the Shuttle if needed.

3. Boeing AAS Service Design

Figure 1 depicts Boeing's Transfer Vehicle (XTV).

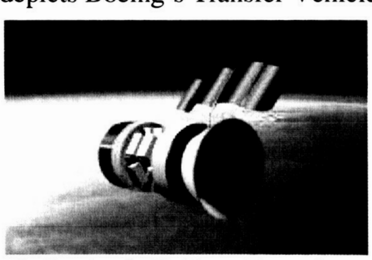

Figure 1. Boeing's X-Type Transfer Vehicle.

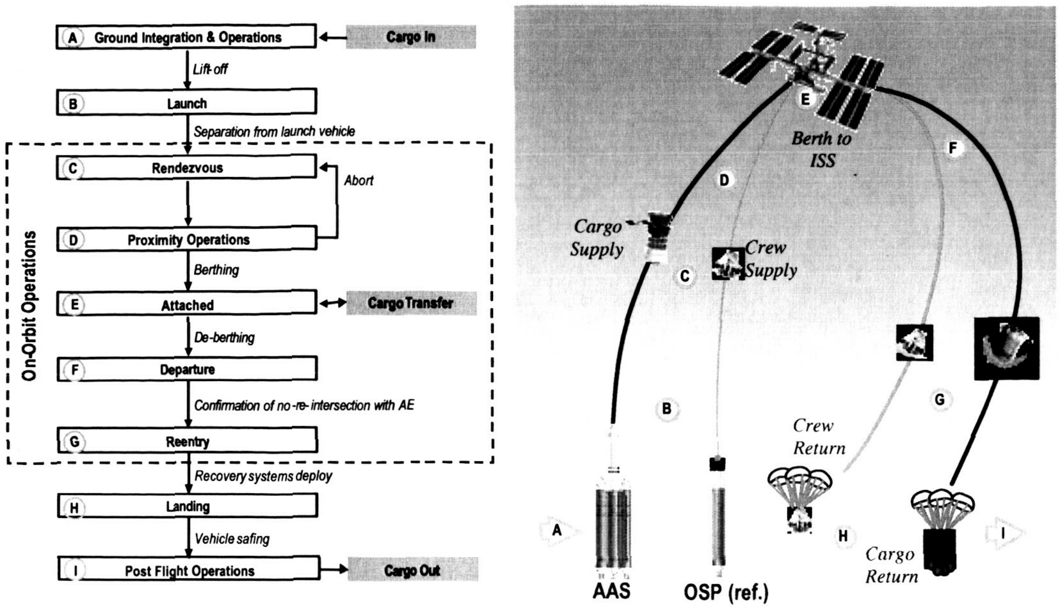

Figure 2. AAS Service Design and Mission Phases.

The AAS service essentially evolved into a non-crewed, cargo analog of the crewed Orbital Space Plane. Figure 2 illustrates this approach where the AAS XTV and OSP would share much of the same infrastructure (ground processing, launch to Low Earth Orbit, mission operations and return) and subsystems (power, data and propulsion). Using the Delta IV Heavy Launch Vehicle, the XTV can maximize the mass and volume delivered to ISS on a single flight. By fitting within the existing 5-meter fairing of a Delta IV, the XTV is able to use all of the Delta's standard ground transportation, handling and processing resources at the Kennedy Space Center (Figure 3).

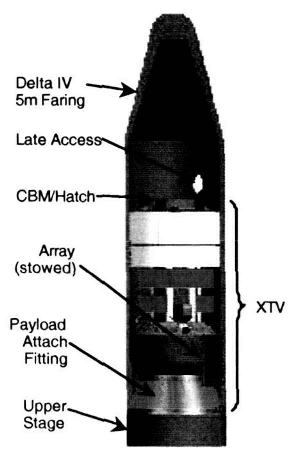

Figure 3. XTV within D IV-H 5m Fairing.

In addition, standard fairing access ports allow late access to internal cargo like Middeck Lockers via the XTV's Common Hatch hours before launch. The XTV can also fly on an Atlas V Medium Launch Vehicle although payload mass to LEO is reduced by roughly 50% over that of the Delta IV Heavy.

After Upper Stage separation, the XTV uses an Autonomous Rendezvous and Proximity Operations (AR&PO) sensor suite to acquire, track and mate with ISS that will be flight-tested on an Orbital Express Demonstration flight in 2006. During the ISS approach phase, which could take as long as 3 days, the XTV will deploy its solar array in order to supply up to 7,000 W of continuous spacecraft and payload power. XTV will approach and berth to ISS Node 2 Nadir Common Berthing Mechanism (CBM) in a manner very similar to that of Japan's HTV. XTV will remain berthed to ISS for up to 35 days to support the following baselined cargo operations:

- Delivery of up to 7,500 kg of cargo to ISS per flight
- Power and cooling to internal and external cargo as needed
- Pressurized Cargo Carrier (PCC) supports Intravehicular Activity (IVA) transfer of

internal cargo like International Standard Payload Racks (up to 4), Middeck Lockers (up to 32) and Crew Transfer Bags (up to 336)

- External Cargo Carrier (ECC) supports Extravehicular Robotics (EVR) and Extravehicular Activity (EVA) transfer of up to 98% of all ISS ORUs and 100% of all Flight Releasable Attach Mechanism (FRAM) mounted payloads (up to 9 FRAM locations)
- Extended stay for up to 180 days on orbit and/or repeated berthing with ISS
- Return to Earth of up to 7,500 kg of cargo per flight

The third element of the XTV, the Resource Carrier (RC), does not directly support orbital cargo handling, but includes the Orbital Maneuvering System (OMS) and redundant Reaction Control System for altitude and attitude control. The orbital configuration of the XTV is shown in Figure 4.

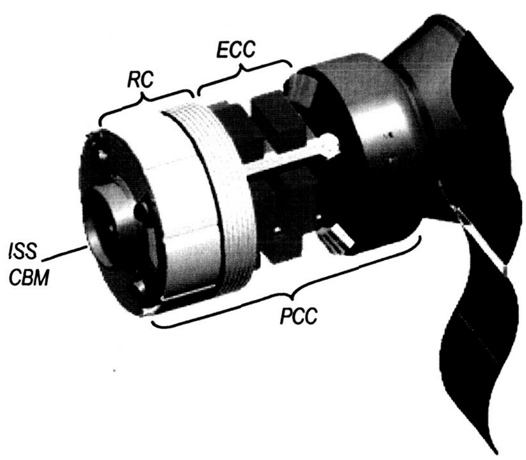

Figure 4. XTV Orbital Configuration.

A number of optional "kits" exist to enhance the capability of the XTV. While not necessarily required by DRM-A, these kits offer following advantages:

- Accommodation of standard Shuttle Payload Bay trunnion mounted cargo
- EVR transfer time reduction by a factor of 4
- 100% increase in available power/cooling
- Ability to fly on non-Delta launch vehicles
- Reboost of ISS to a higher orbit
- Cargo upmass can be increased to 10,000 kg if the return system is deleted

Once cargo transfer is complete, the XTV departs ISS and prepares for reentry by closing the ECC lightweight door, ejecting the Payload Attach Fitting and solar array, and deploying a unique hybrid drag system (Figure 5).

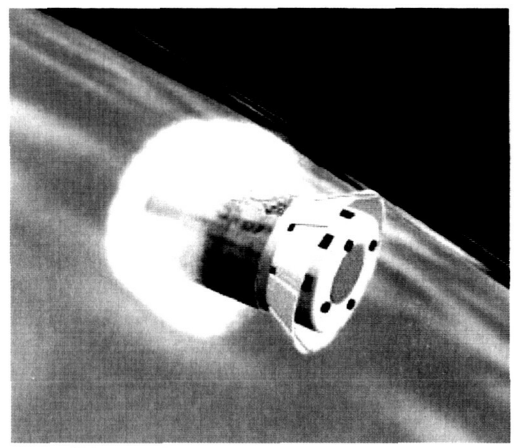

Figure 5. XTV Return to Earth.

The XTV lands at NASA Space Harbor at White Sands, New Mexico using a combination of parachutes and airbags. After vehicle landing, early access cargo can be retrieved as soon as Landing plus 3 hours.

4. AAS Service Implementation

AAS Service users would be able to drop off integrated racks and direct mount external payloads at Launch minus 11 months and Middeck Lockers, CTBs, and FRAM mounted external payloads at Launch minus 4 months. Using Kennedy Space Center facilities, Boeing would then perform all cargo analytical and physical integration activities. Users would have late access to cargo on the pad starting at 119 hours before launch. After XTV separation from the upper stage, the user can monitor flight operations with the XTV Flight Operations Team at a Johnson Space Center Payload Operations Control Center (POCC) until hand-off to the Mission Control Center (MCC) shortly before

XTV berthing to ISS. Upon XTV departure of from ISS, MCC would then hand-off control back to the XTV POCC which would handle all reentry operations. Upon landing, control is passed to the White Sands Control Center for XTV safing activities and early cargo access at Landing plus 3 hours. All internal and external cargo would be available to the user by Landing plus 3 weeks at the latest.

The service was priced in 2 parts: a 4 year design, development, test and evaluation of the first XTV beginning in 2007, and recurring integration and operations of the service on an annual basis starting in 2011. Cost estimates included different annual flight rates ranging from 7 to 5 XTV flights a year. For each rate the option to fly several XTVs on an Atlas V medium was included to allow tailoring of both upmass delivered and overall cost. Providing an AAS cargo delivery service equivalent to 5 Shuttle flights/year cost approximately 1/3 that of the Shuttle on an annual basis. Much of this difference can be attributed to a significant reduction in touch labor during fabrication and launch preparation as well as limiting the amount of equipment reused post flight.

5. AAS Applications to Project Constellation

Despite significant changes to the AAS DRMs during the system development, inclusion of return and increase of annual flight rate by a factor of 5, the core design of the XTV remained basically the same due to its inherent flexibility and robustness. Its modular core supports a host of options that can be used to optimize a particular mission. Sustained exploration will require robust, flexible vehicle core, much like that provided by the US Army's basic HUMVEE bus (Figure 6).

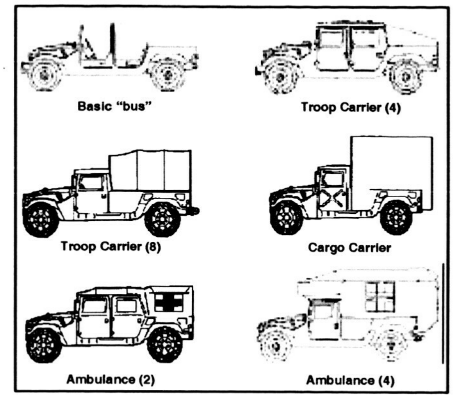

Figure 6. Optional HUMVEE Configurations.

Application of the XTV as an Autonomous Cargo Vehicle (ACV) separate from a Crew Exploration Vehicle (CEV) to a new lunar exploration mission would provide the following benefits:

- Operational readiness schedule compatibility with Shuttle retirement in 2010
- Separation of crew from cargo during Low Earth Orbit and Lunar transit transportation phases
- Use of autonomy and robotics to support lunar logistics missions
- Affordable and sustainable using current generation of Expendable Launch Vehicles
- Supports spiral development of unique cargo carriers, in-space habitats and fuel depots as needed
- Potential of supporting ISS logistics needs in tandem with exploration mission

Figure 7 shows one notional approach to delivering an Exploration ACV to lunar orbit using a total of 3 Delta IV Heavy flights (2 Translunar Injection Stages and 1 ACV).

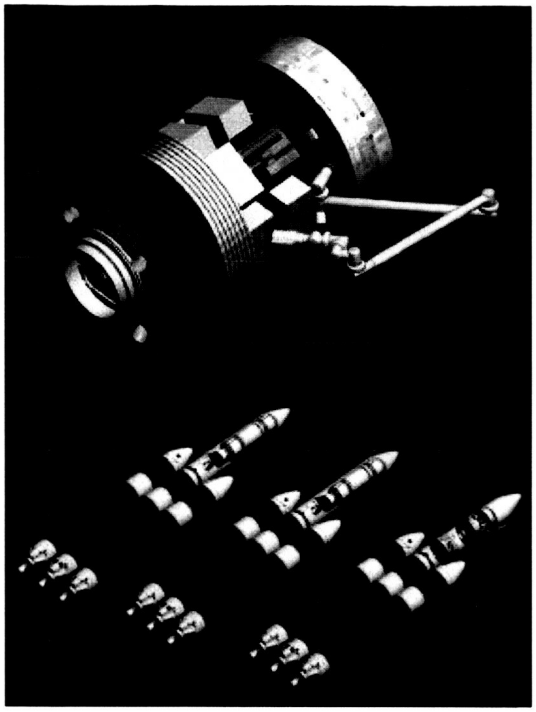

Figure 7. ACV to Moon using Delta IV-H.

Once at a Earth-Moon libration point or lunar orbit, multiple ACVs could autonomously dock to form a lunar Gateway, fuel depot and crew safe haven as shown in Figure 8.

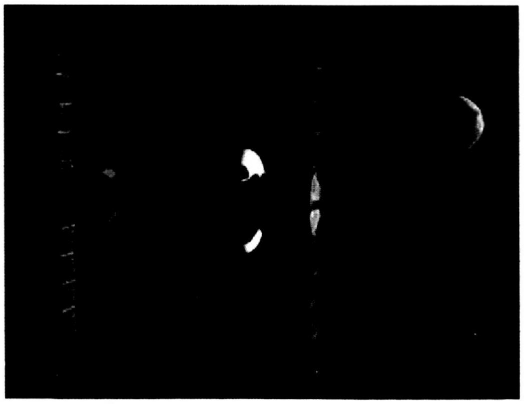

Figure 8. ACV Lunar Gateway/Safe Haven

Boeing is currently using data from both its Orbital Space Plane and Alternate Access to Station programs to support ongoing Moon/Mars architecture trades. Each serves as a unique and valuable benchmark for validating exploration affordability, sustainability and reliability goals.

6. Conclusions

At this time most if not all of the 16 month AAS design activity is being applied to the development and understanding of a viable Project Constellation architecture. Major findings can be summarized as follows:

- Bigger launch vehicles are better by maximizing upmass while minimizing flights to station (saving crew time and ISS hardware life)
- ORU return to earth is essential to long term ISS maintenance and sustaining activities
- Efficient, accessible external cargo accommodations are critical to long term space endeavors using EVR and EVA
- Use of existing technology and limiting reusability supports overall affordability goals
- Like the OSP/CEV, XTV/ACV spiral development could support ISS in addition to enabling exploration to the Moon
- XTV could serve as less expensive, unmanned testbed for CEV technologies prior to crewed CEV flight

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