Leveraging Existing Space Assets for Delivery of Cargo to the International Space Station

Mark A. Foster[1] and Robert J. Sirko, PhD.[2]
The Boeing Company, Huntington Beach, CA 92647

A global team is studying the challenge of developing a low-risk cost-effective commercial service for delivery of cargo to the International Space Station (ISS). Rather than developing new space vehicles, the proposed approach seeks to leverage space assets that are existing or nearly complete, thereby avoiding substantial cost and risk. This approach would maximize utilization of more than $5 billion in domestic and international space capital investments in launch vehicles, transfer vehicles, ground infrastructure, processes, and personnel to support the ISS program. An international team comprised of key members of the global partnership that developed and continues to support the ISS has been assembled to address this challenge, including Boeing, Mitsubishi Heavy Industries, Arianespace, and Astrium GmbH.

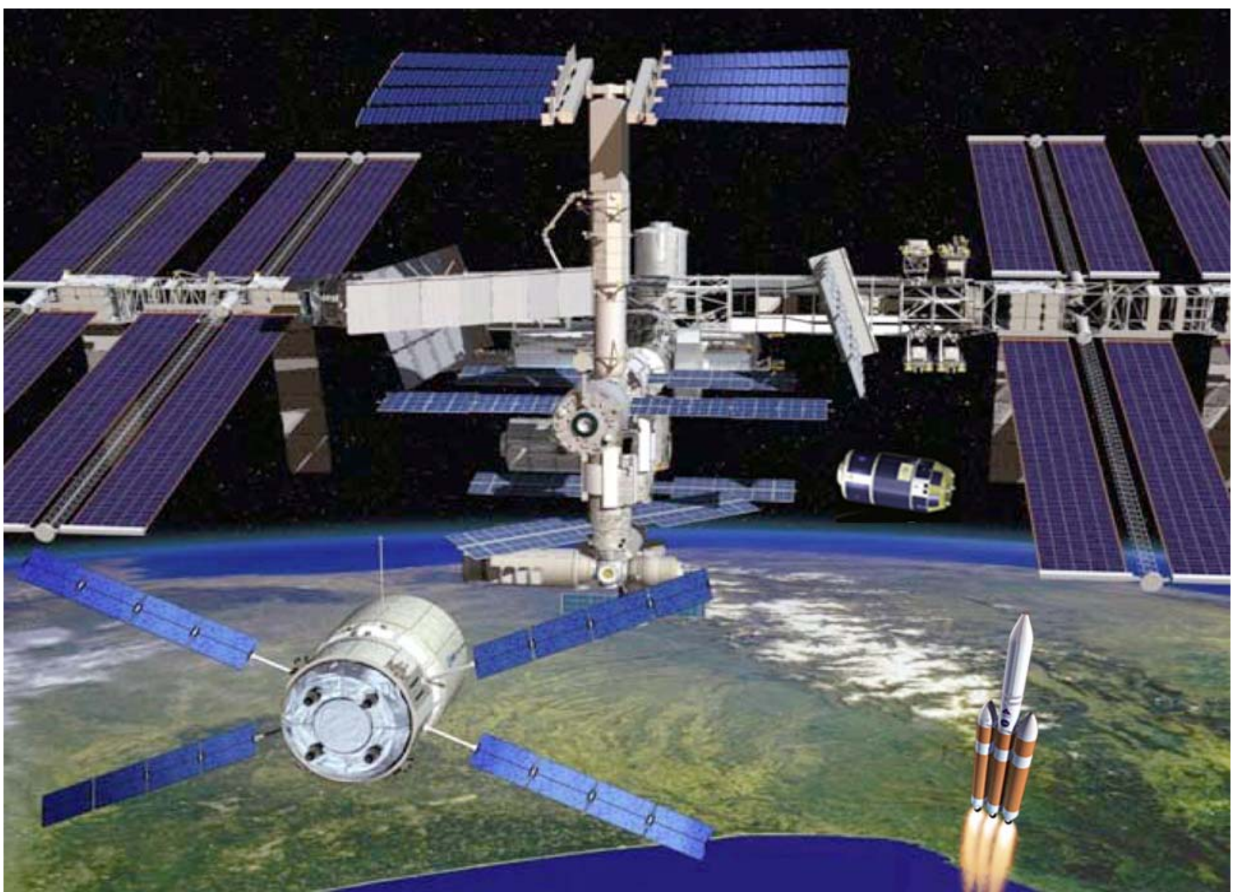

Figure 1. Existing U.S. and International space assets can efficiently deliver cargo to the ISS.

[1]Project Manager, Delta IV Launch Systems, 5301 Bolsa Ave/MC H014-C415, AIAA Professional Member.
[2]Director, Civil Space Programs, Boeing Launch Systems, 5301 Bolsa Ave/H014-C459, AIAA Professional Member.

I. Introduction

AS the Space Shuttle fleet approaches its planned retirement in 2010, NASA's COTS program is seeking innovative, low-cost commercial orbital transportation systems to meet the ISS re-supply requirements in the post-Shuttle timeframe[1]. The COTS phase I demonstration program is scheduled to run through 2010, limiting the timeline for development and demonstration of these new commercial space systems to less than 5 years. However, history has shown that space systems, especially man-rated space systems, routinely experience difficult development and test programs, escalating costs, and slipping Initial Operational Capability (IOC) schedules. Although several companies have proposed new commercial cargo delivery systems, there appears to be no conclusive indications that such systems will materialize, be fully qualified, and become operational in time to support the ISS.

Independent of the COTS program, Boeing and our international partners have been working on a cost-effective and low-risk approach for implementing an ISS cargo transportation system. Once implemented, this system, which could have an initial operational capability (IOC) in early 2010, would be capable of providing complete end-to-end cargo transportation to ISS using flight proven domestic and international space assets. Full operational capability (FOC), with an annual internal and cargo upmass capability exceeding projected requirements, could be phased in as early as 2011. This additional capacity could be used to deliver government and commercial utilization payloads and science hardware not currently manifested on any planned flight to ISS. As opportunities develop, the Boeing cargo transportation system could also be used to provide cargo delivery service to commercial orbiting space stations, logistics depots for exploration, or other space assets requiring reliable transportation of cargo to Low Earth Orbit (LEO). Customers, both government and commercial, would work directly with Boeing to define the specific cargo requirements and schedule desired, and Boeing's international team of space transportation experts would ensure their cargo and payloads are reliably and efficiently delivered to and/or removed from the space asset as scheduled.

II. Cargo Re-Supply of ISS with U.S. and International Space Assets

The Boeing team approach is based on maximizing utilization of U.S. and international space and infrastructure assets in cargo transport vehicles, launch vehicles, ground infrastructure, and trained personnel. Cargo transportation would be provided by derivatives of the Automated Transfer Vehicle (ATV), developed for the European Space Agency (ESA), and the H-II Transfer Vehicle (HTV), developed for the Japanese Aerospace Exploration Agency (JAXA). The European ATV undergoes final ISS certification in the second quarter of 2006, with space operations scheduled to start in 2007. The Japanese HTV will be certified in the second quarter of 2008, with space operations scheduled to commence in 2009. Both transfer vehicles (TVs) have been specifically designed to meet the complex and demanding Visiting Vehicle and stringent human-rating requirements of the ISS. Boeing's team members Mitsubishi Heavy Industries (MHI), Arianespace (AE), and the Astrium GmbH, have been working closely with NASA, JAXA, and ESA for many years to ensure that these and all other ISS requirements will be met by the ATV and HTV. By utilizing these ISS transfer vehicles, our approach avoids the considerable operational impacts and development costs and risks associated with embarking on the creation of completely new transfer vehicles to meet ISS requirements.

Boeing's flight proven Delta IV Heavy (DIV-H) is the launch vehicle chosen by the team to deliver the European ATV and Japanese HTV to low Earth orbit (LEO). The DIV-H is the *only* operational U.S. launcher capable of lifting up to 25mt (55,000lbs) to the ISS LEO transfer orbit (nominally 300 km circular at 51 degrees inclination).

Ground infrastructure assets domestically include Boeing's Delta-IV manufacturing, production, integration and launch facilities at Cape Canaveral Air Force Station (CCAFS), Kennedy Space Center (KSC), and Huntsville, AL. International ground infrastructure assets include extensive manufacturing, production, integration and mission operations facilities in Europe and Japan.

Leveraging more than $5 billion invested in existing space assets for delivery of cargo to the ISS, Boeing and our international partners concluded that we could implement a low-risk, cost-effective cargo space transportation system with IOC starting as early as 2010. Further, by utilizing existing space manufacturing, production, integration, launch, and mission operations facilities and personnel, the Boeing space transportation system would minimize the costs and risks inherent in the development of new space transportation systems.

III. Concept of Operation

The Boeing cargo transportation system concept of operations is naturally divided into three phases: **mission requirements analysis, ground operations,** and **flight operations**. In each phase, the Boeing cargo transportation system would rely on processes, facilities, equipment and personnel with experience on directly-related missions, thereby reducing or eliminating additional critical verification and certification requirements. The Boeing cargo transportation system would also benefit from existing systems, operations, and infrastructure already qualified and in-place for the ATV, HTV, and DIV-H.

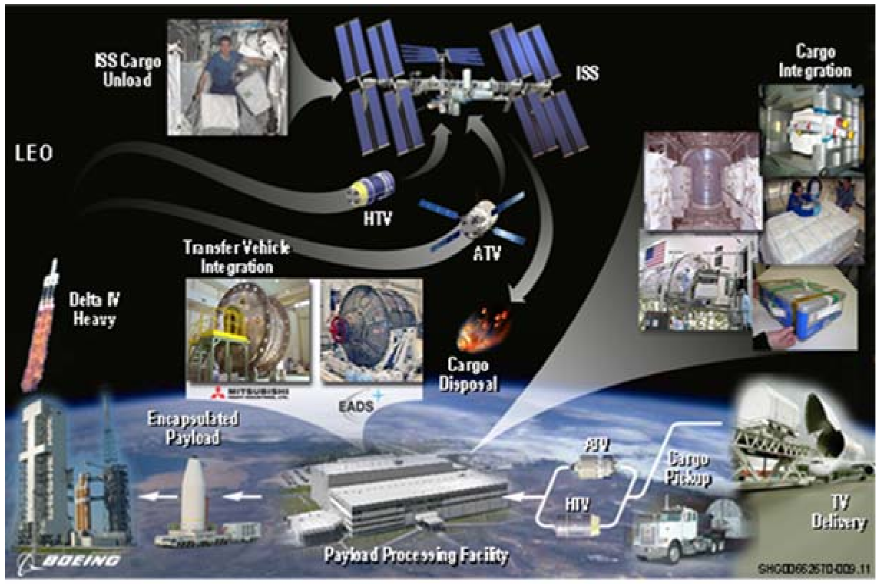

Figure 2. Concept of Operations.

A. Mission Requirements Analysis

Pre-mission planning and preparation operations: A range of offsite activities would be performed concurrently, including launch vehicle and TV production; mission requirements and cargo manifest definition, and analytical integration of the cargo being manifested.

Cargo manifesting: The closed-loop cargo manifesting process schedules a customer's cargo and sequences it into the annual ISS traffic model. In support of the cargo transportation system, Boeing would work directly with the NASA ISS Program Office, drawing on extensive resources currently supporting both ISS and Shuttle cargo operations. Astrium GmbH, MHI, and the Boeing Checkout Assembly and Payload Processing Services (CAPPS) experts would work closely with their NASA counterparts to provide complete ISS cargo mission support, while the Boeing ISS Vehicle Integration Performance and Resources (VIPeR) team would be responsible for traffic modeling, cargo analysis, and related activities, as they do now in support of NASA JSC.

Figure 3. CAPPS personnel receive, and prepare all NASA payloads flying into space.

Cargo analytical integration: Boeing and NASA experts would establish the traffic model, detailed processes and schedules, and complete preparations for cargo handling. In addition, Boeing's international teammates would be directly involved in assisting in cargo operations: Astrium GmbH would provide fully trained personnel to perform cargo loading of the ATV at Boeing's integration facility; while MHI would train and supervise Boeing personnel to perform cargo loading operations of the HTV.

B. Ground Operations

Ground operations would commence with delivery of cargo from NASA. Once on dock at KSC, the ATV or the HTV would be transported to an existing integration facility (candidates include Astrotech and the NASA KSC Space Station Processing Facility [SSPF]), where transfer vehicle module integration and final assembly would be performed. The transfer vehicle would be checked out and final verification performed. Transfer vehicle and cargo integration are illustrated for the HTV in Figure 4. Similar ground operations would be conducted by Boeing and Astrium GmbH for the ATV. Assembly, cargo loading, processing, integration, and checkout of the HTV would be performed by experienced personnel from Boeing's Checkout, Assembly, and Payload Processing Services (CAPPS) program, while experienced Astrium GmbH personnel would perform these services for the ATV. ATV and HTV ground operations would use duplicate sets of Ground Support Equipment (GSE) which were developed for the ESA and JAXA TV programs, eliminating new design, development, and certification costs of the GSE. Launch site transfer vehicle processing would use existing Astrium GmbH, MHI, and KSC procedures to the maximum extent possible, further reducing operational costs.

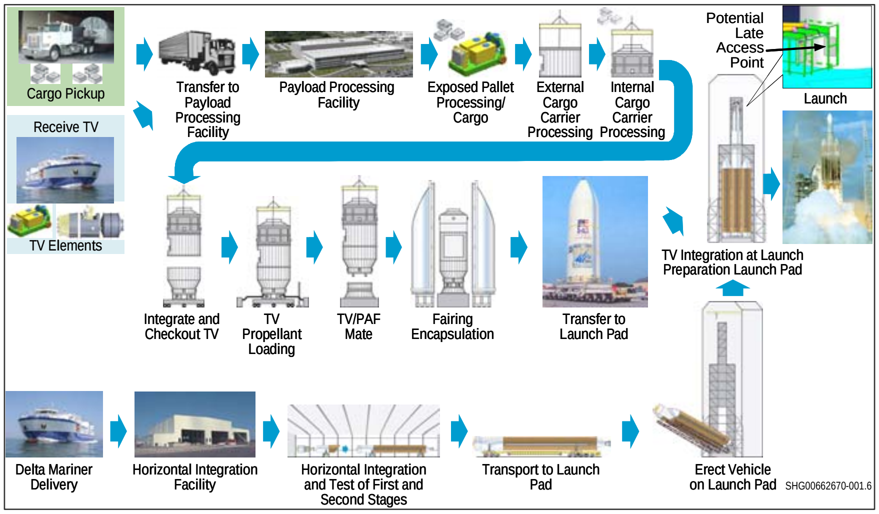

Figure 4. HTV Ground Operations flow.

Boeing's Delta team would prepare a DIV-H for launch of the TV using existing, proven processes and infrastructure. As shown in Figure 4, Boeing's *Delta Mariner* transport ship delivers DIV-H hardware to the KSC port, where it is then transported to the horizontal integration facility. The DIV-H first and second stages are integrated and tested, then transported to the Boeing's Launch Complex 37 at CCAFS, where the DIV-H is erected into launch configuration.

Once the TV and cargo complete integration processing, propellant loading would performed, and the transfer vehicle handed over to Boeing Delta launch team, who would mate the TV to the Payload Adapter Fitting (PAF), and encapsulate the TV-PAF in the Delta-IV 5-m fairing. The encapsulated TV would be lifted to the top of the vertical integration facility, and integrated with the DIV-H, where final checkout is conducted and any late access operations would be performed prior to launch.

C. Flight Operations

Launch Operations: Launch operations would use the mature capabilities of the DIV-H for successful deployment of the transfer vehicle in the ISS LEO transfer orbit (nominally 300 km circular at 51 deg inclination for ATV; and 200 km x 300 km at 51 deg inclination for HTV). For illustrative purposes an HTV mission is shown in Figure 5. ATV missions would be conducted in a similar manner.

On-Orbit Operations: Once the transfer vehicle is deployed to LEO, in-space operations would rely on established facilities, procedures, and personnel to guide the transfer vehicle to the ISS approach ellipsoid.

JAXA's Tsukuba Control Center would serve as the mission control center for HTV on-orbit operations from Delta IV deployment up to HTV arrival at

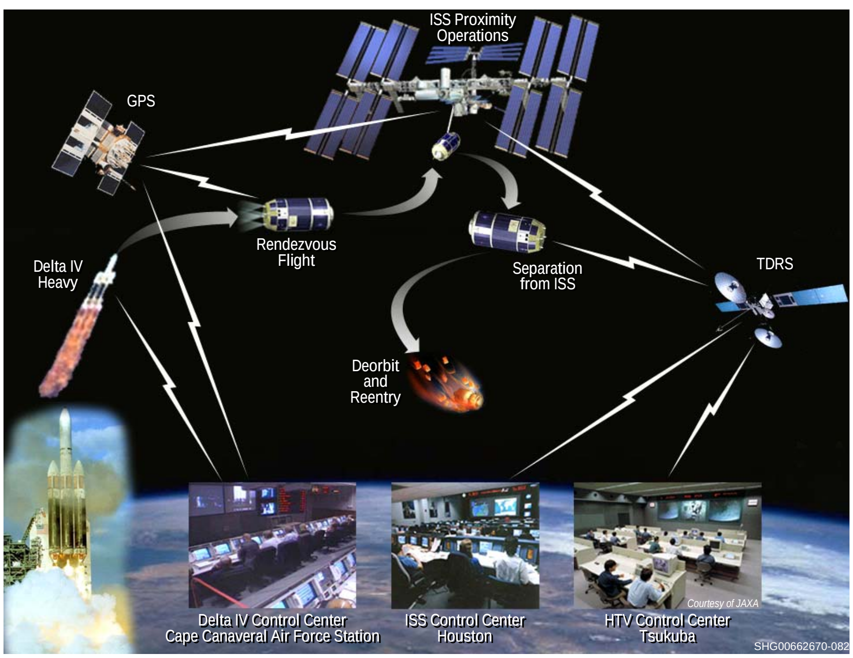

Figure 5. Flight Operations.

the ISS approach ellipsoid. The HTV uses robotically assisted berthing via the Space Station Remote Manipulator System (SSRMS), under the control of the ISS Crew, the NASA JSC Mission Control Center, and supported by the JAXA Tsukuba Control Center.

An equivalent infrastructure would perform ATV in-space operations. The ATV Control Center located in Toulouse, France would serve as the mission control center for ATV on-orbit operations from Delta IV deployment up to ATV arrival at the ISS approach ellipsoid. The ATV autonomously docks at the Service Module (SM) aft port on the Russian Segment, with NASA and Roscosmos coordination.

ISS Activities: Cargo unloading, storage, and loading of disposal cargo would be conducted while the TV is attached to the ISS, as is currently defined for both the ESA and JAXA TVs. A distinct feature of the Boeing team cargo transportation system is the use of existing, fully human-rated transfer vehicles that serve as extensions of the ISS while they are attached. ATV missions currently provide the capability for stays of up to 6 months or more, and can provide significant cargo storage during its residence. The HTV has similar capabilities with on-orbit stays of up to 3 months.

Departure Operations: The Boeing cargo transportation system would rely on the same TV departure operations as worked out directly between NASA and the space agencies of Japan and Europe for their national missions. This commonality of operations essentially removes new on-orbit operational risks from the Boeing cargo transportation system.

IV. Adaptation of Existing Space Assets

The U.S. Space Shuttle was expected to fill the role of primary cargo delivery system for the planned life of ISS. However, with the impending retirement of the Shuttle in 2010, the ISS program is seeking other means to reliably deliver crew and cargo. Although many concepts are being considered, currently only the Russian Progress, ATV, and HTV are expected to be fully qualified and operational for cargo delivery to ISS by 2010. As the ATV and HTV become operational, they will carry cargo to meet requirements worked out between NASA and ESA, and between NASA and JAXA. These requirements, however, were established when the Shuttle was assumed to be the primary cargo delivery system for NASA. As a result, the ESA and JAXA missions, as currently planned, do not address the bulk of NASA’s post-Shuttle cargo delivery requirements.

NASA estimates more than 8000 kg of internal cargo and up to 5000 kg of external cargo will need to be delivered annually during the fully-assembled phase of ISS, post 2010[2]. The actual number of ATVs and HTVs required to meet this requirement is dependant on the mix of pressurized and unpressurized cargo—not simply on the gross cargo mass delivery capabilities of these spacecraft. Based on current estimates, up to five or more ATVs and HTVs (combined) would be needed to transport the annual internal and external cargo requirements of ISS. This potential disparity is a direct consequence of the mismatch between the assumptions that drove the original transfer vehicle designs and the new reality of post-Shuttle ISS operations. Recognizing and responding to this fact was a critical requirement in the development of the Boeing cargo transportation system approach.

The objective of the Boeing team was to create a responsive ISS cargo delivery system to meet NASA post-Shuttle requirements using the least number of launches. Boeing and our team members are evaluating alternate methods of packaging, packing, and accommodating cargo into the ATV and HTV. Our team has also been performing trade studies and traffic model analyses of cargo requirements to determine the best concepts for adapting each transfer vehicle. Our studies have shown that relatively minor modifications to the baseline ESA ATV and JAXA HTV would be required to more nearly align TV capabilities with the new NASA cargo delivery requirements. Our design goal was to meet the yearly ISS cargo requirements with only three HTV and ATV (combined) launches annually. Thus, value would be created by reducing launches; matching cargo manifests with NASA post-Shuttle needs; and fully utilizing the inherent capabilities of the HTV and ATV. Details on the ATV and HTV and our approach to adapting each TV is described further in the following sections.

A. Automated Transfer Vehicle

The Automated Transfer Vehicle (ATV) (Figure 6) is a 20-metric-ton unmanned expendable space transport vehicle, in development since 1994 by ESA as their commitment for logistic servicing of ISS.

The ATV docks at the rear ISS Russian port and is capable of delivering up to 7700 kg of a variable mix of pressurized cargo, refueling propellants for the Russian Segment of the ISS, as well as additional ATV propellants required to boost the ISS. While current ATV mission requirements dictate a long docking period, the ATV is capable of docking durations as short as 1 week and can perform multiple docking, undocking, maneuvering away from the space station, loitering and re-docking operations.

This short-duration docking and loiter capability would minimize impacts from the Boeing cargo transportation system operations to ISS operations that have already been planned.

The general architecture of the ATV is simple, modular, and designed for easy manufacturing, testing and assembly within the existing European Space Industry as well as on the launch base.

The ATV upper section, or Integrated Cargo Carrier (ICC), is the portion directly docked to ISS and carries the dry and fluid cargo needed for the mission. It is an ISS human-rated, pressurized volume, allowing astronauts shirt-sleeve access. Its interior is fully compatible with the NASA manned vehicles specifications. It also carries on its front cone all the sensors and ranging cues needed for the final approach and docking to space station, as well as eight attitude control thrusters.

The lower section of the ATV, or spacecraft subassembly, comprises all the services needed to support and execute the mission, including eight main propellant tanks, two large helium tanks, the propulsion tank pressurization system, propulsion and attitude control command system, four main thrusters, twenty attitude thrusters, power generation and storage, navigation, control, command, and telecommunications systems, and the launch vehicle payload adapter containing the separation system.

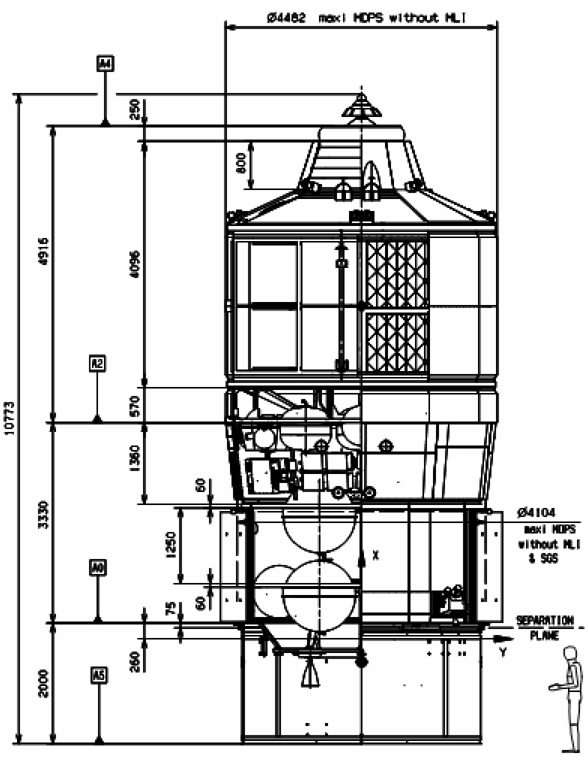

Figure 6. Automated Transfer Vehicle.

ATV Development and Demonstration: The expensive and high risk development effort associated with creating a transfer vehicle capable of visiting the ISS has largely been completed for the ATV (Figure 7).

The first flight spacecraft, named *Jules Verne*, is schedule to perform an ISS cargo mission for ESA in May 2007. This working flight will provide full checkout of all ATV ground and flight operations, including all aspects of cargo processing, integration, launch, orbit rendezvous and docking with ISS, ISS crew cargo loading and unloading, ISS departure, and deorbiting. The *Jules Verne* will also demonstrate the new ATV laser docking system, which will replace the Russian KURS, and will perform several safe escape modes from ISS.

NASA has been heavily involved in the development of the ATV. For the last 6 years, all design evolutions occurring under ESA management have been closely followed and evaluated by the Safety and Engineering teams of NASA JSC; NASA engineers have been reviewing ATV data packages and have been participating as review board members in all the major ATV Flight Segment Reviews; and NASA has assigned a permanent “launch package manager” (LPM) within the ESA design team in Europe.

ATV Adaptation: The ESA ATV structural design limit provides for up to 5500 kg of pressurized internal cargo per flight. The cargo is packed into standard Cargo Transfer Bags (CTBs) and stored in 8 racks for launch and transfer. The characteristics of the cargo are such that the volume one kg of cargo occupies varies significantly with the density of the type of cargo being transported. Some types of cargo,

Figure 7. ATV Development.

such as clothing, are very bulky and use all of the CTB volume but not only a relatively small amount of the mass capability. As a result, the available ATV volume is often filled before the structural mass limit of the ICC is reached. Based on historical cargo densities for a standard mission mix of ISS pressurized cargo, the actual usable upmass capability of the ATV due to volumetric loading has been estimated to be much lower than could be accommodated by the ATV's 5500 kg structural capability.

The Boeing cargo transportation system approach would seek to adapt the ATV internal secondary structure to more fully utilize the existing unused volume of the ICC. Preliminary concepts developed by Boeing's team showed that a significant increase in pressurized cargo could be achieved, ensuring maximum pressurized cargo upmass and volume on every adapted ATV mission. Since, these design modifications would be limited to secondary structure and would not change the qualification status of the ATV, limited technical and programmatic risk would be introduced by the adaptation of the ATV to support the Boeing cargo transportation system.

B. H-II Transfer Vehicle:

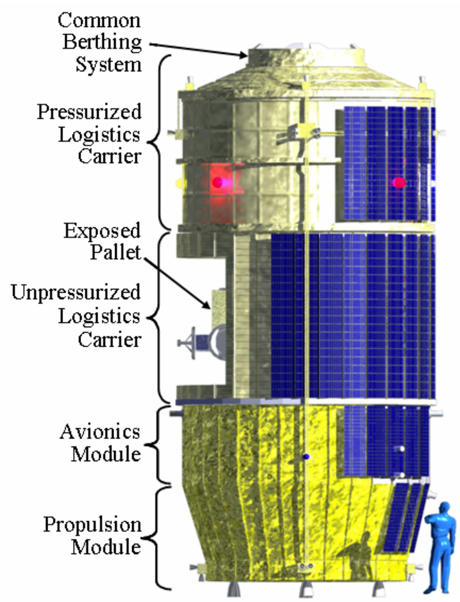

Figure 8. H-II Transfer Vehicle Design.

Japan's H-II Transfer Vehicle (HTV) is a 16.5 metric-ton expendable space transportation vehicle for logistic support of ISS. When used for its JAXA customer to meet Japan's commitments to ISS, it is launched on an H-IIB.

The HTV (Figure 8) is designed to deliver up to 6.5mt of pressurized and unpressurized cargo to the ISS, and dispose of waste materials through destructive reentry into the Earth's atmosphere upon departure from ISS. The HTV is 4m diameter and about 10m long. Weighing about 16.5 tons on the ground fully loaded, it is designed to berth at the United States On-Orbit Segment (USOS) Node common berthing mechanism (CBM) ports.

The upper section, called the pressurized logistics carrier (PLC), is berthed to the ISS at one of the USOS Nodes and carries the dry and fluid cargo needed for the mission. It is pressurized and human-rated, meeting all NASA human-rating requirements, allowing astronauts shirt-sleeve access to the cargo.

The middle section, called the unpressurized logistics carrier (ULC), provides a 3.0m x 2.5m x 4.0m protected volume that accommodates the exposed pallet (EP) which is designed to carry external cargo. There are two main types of EPs: Type I is designed to carry the JEM Exposed Facility payloads, and Type III is designed to interface to the standard Flight Release-able Attach Mechanism (FRAM) mounted USOS payloads, with provisions for berthing to the payload ORU accommodation (POA) interface.

Operationally, the EP is designed to be removed from the ULC with a space station remote manipulator system (SSRMS), as shown in Figure 9, and berthed to the Mobile Base Servicing System (MBSS), where the external cargo can be then transferred to ISS. Similarly, waste cargo mounted on FRAMs will be loaded onto the EP prior to installation in the ULC, in preparation for HTV deberthing. The Type III EP, therefore, is being designed to meet the critical requirements for transfer of external cargo to ISS, and disposal of spent external cargo from ISS.

The third section of the HTV incorporates a separate avionics module, which houses all the electrical services needed to support and execute the mission, including the attitude control command system, power generation and storage, navigation, and control, command, and telecommunications systems.

The fourth section of the HTV is the propulsion module which employs four main propellant tanks, four helium tanks, the propulsion tank pressurization system, and the propulsion and control subsystems. HTV has two sets of 14 roll control thrusters, 28 in total. Two sets of 6 forward thrusters are installed on the PLC and two sets of 8 thrusters are installed on the propulsion module.

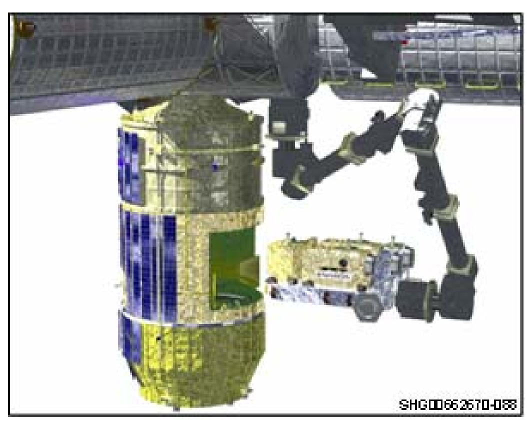

Figure 9. EP removal from HTV-ULC.

When completed, the system offers a low-cost, highly reliable means of cargo delivery to ISS.

HTV Development and Demonstration: As with ATV, the expensive and high-risk development effort necessary to create a transfer vehicle certified for visiting ISS will be completed under JAXA's commitment to ISS. JAXA and its Japanese contractors' commitment to ISS ensures NASA a fully developed and flight-proven transfer vehicle in the 2009 timeframe. Beyond the development program already well underway for JAXA, no additional prototyping or demonstration flights would be required for full operational capability and use in support of Boeing's proposed cargo transportation system.

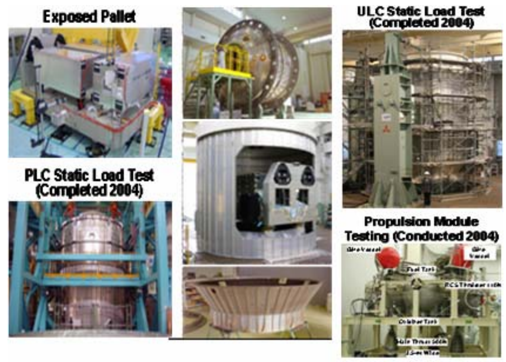

Figure 10. HTV Development.

HTV Adaptation: The JAXA HTV structural design limit provides for up to 3500 kg of pressurized internal cargo per flight. The cargo is packed into Cargo Transfer Bags (CTBs) and stored in 8 racks for launch and transfer. As with the ATV, the HTV-PLC volume is filled before the structural mass limit is reached. Based on historical cargo densities for a standard mission mix of ISS pressurized cargo, the actual usable upmass capability of the HTV due to volumetric loading has been estimated to be lower than could otherwise be accommodated by the PLC's 3500 kg structural capability.

The Boeing team analyzed ways of adapting the HTV internal secondary structure to utilize the existing unused volume of the PLC. Preliminary concepts developed by Boeing's team showed that a significant increase in pressurized cargo could be achieved, ensuring maximum pressurized cargo upmass and quantity on every adapted HTV mission.

The JAXA HTV is designed to carry up to 1500 kg of unpressurized external cargo per flight (structural design limit of the ULC and EP). The Type III EP is currently designed to accommodated six FRAM mounted USOS external payloads. The Boeing team studied ways of adapting the HTV external secondary structure to increase the load carrying capability of the ULC and the cargo capacity of the EP. Preliminary concepts developed by Boeing's team showed that a dramatic increase in both external cargo mass and payload quantities could be achieved, ensuring maximum unpressurized cargo upmass and quantity on every adapted HTV mission.

By combining the PLC internal cargo adaptations with the ULC external cargo adaptations, and balancing the overall internal and external cargo mission upmass, the Boeing team could significantly increase the total cargo delivered on every flight of an adapted HTV. Since these design modifications would be limited to secondary structure, and do not change the qualification status of the JAXA HTV, limited technical and programmatic risk would be introduced by the adaptation of the HTV to support the Boeing cargo transportation system.

C. Delta IV Heavy Launch Vehicle

Boeing's Delta IV Heavy (DIV-H) launch vehicle is flight proven and currently in production. The Delta IV launch system has successfully launched six times, including its commercial inaugural launch in November 2002, the first DIV-H launch in December 2004 (Figure 11), and the most recent launch from the Vandenburg Air Force Base (VAFB) in June 2006. The first DIV-H launch from Boeing's Launch Complex 37 at CCAFS (Figure 12) demonstrated many key systems including the launch and staging of a three liquid booster core vehicle, long-duration direct geostationary launch of a satellite, and the successful first use of the Delta IV 5-m cryogenic second stage and payload fairing. Four additional DIV-H launches are scheduled before 2010.

Boeing designed and developed the Delta IV family of launch vehicles to meet the USAF Evolved Expendable Launch Vehicle (EELV) requirements. The Delta IV currently meets the needs of the U.S. government space launch markets, including the national security and civil space market segments.

Figure 11. Delta IV Heavy.

Figure 12. Launch Complex 37 at CCAFS.

Boeing's DIV-H is currently in production at our world-class, 1.5 million square foot Delta manufacturing facility in Decatur, Alabama (Figure 13). The Decatur manufacturing facility could easily increase production to meet projected ISS cargo transportation requirements with no additional infrastructure investment.

Figure 13. Delta Production Facility, Decatur Alabama, U.S.

Delta IV Performance

The current DIV-H is compatible with the mission lift capability requirements of both the current and adapted ATV and HTV, providing a U.S. heavy lift launch capability of up to 24 tons to the 51.6 deg inclination ISS orbit (300 km circular reference orbit). The DIV-H capability provides considerable performance margin for the HTV, enabling opportunities for enhanced science or commercial market use. The DIV-H is the only U.S. launcher capable of launching a fully loaded ATV, and further permits the ATV to increase total cargo capability up to 1-2 metric tons, providing NASA greater useful cargo to ISS on every DIV-H–ATV mission.

Launch Vehicle—Transfer Vehicle Compatibility

Beginning in 2004, Boeing and our team members Arianespace and MHI committed significant resources to establish compatibility between the ATV and Delta IV, and HTV and Delta IV. Boeing has worked closely with MHI, Mitsubishi Electric Corporation (MELCO), IHI Aerospace (IA), Japan Manned Space Systems Corporation (JAMSS) and JAXA, to verify physical and operational compatibility with the HTV; and, with Arianespace S.A. (AE) and Astrium GmbH to verify physical and operational compatibility with the ATV.

The teams have completed initial assessments of launch vehicle to transfer vehicle integration, processing facilities, and operational and programmatic compatibility. Payload adapter designs have been developed and assessments of payload fairing integration completed. Flight environment analyses, including coupled loads analysis, have also been completed for each transfer vehicle launched on a DIV-H to determine the structural behavior of the integrated LV-TV systems during flight. Thermal conditions were analyzed, electromagnetic compatibility assessments completed, and electrical interfaces defined and analyzed. In addition, mission trajectory analysis and flight sequence of events were created, along with orbital injection dispersion predictions. These assessments have largely demonstrated the technical and programmatic compatibility of each of the TVs with the DIV-H. Boeing continues to work with our team members to identify and mitigate technical issues between the DIV-H and the TV's.

V. Teaming Arrangements, Roles, and Contributions

The Boeing cargo transportation service team consists of Arianepsace, Astrium GmbH, and MHI. This team includes the prime contractors for the ISS, ATV, HTV, and the Delta launch vehicle.

Personnel in all phases of operations, from the Boeing CAPPS staff supporting ISS payload integration, to the Astrium GmbH flight controllers, are the same trained personnel currently used for ISS operations. This reduces program risk and cost associated with training new people and re-training flight crews to new systems.

Arianespace, is a leading provider of commercial launch services, holding more than 50 percent of the world market for satellites delivered to geostationary transfer orbit. Created as the first commercial space transportation company in 1980, Arianespace has signed contracts for more than 265 satellite payloads. Arianespace is responsible for the production, operation and marketing of the Ariane 5 launchers, and is a partner in the commercial operations of Starsem's Soyuz launch vehicle from its launch facility in Kourou, French Guiana.[3] Arianespace has agreed to make its launch services available on a backup basis, providing assured access to space for our proposed adapted ATV cargo delivery to ISS.

Astrium GmbH is the manufacturer of the Ariane family of launch vehicles. Astrium GmbH combines the vast and unrivalled experience, resources and facilities of the major space companies of two of Europe's principal space nations, France and Germany. With expertise in all space applications, especially in launch vehicles and orbital infrastructure, Astrium GmbH Bremen is prime contractor and responsible for several subsystems of the European *Columbus* laboratory and the follow-on production of the ATV transportation system. This includes concept definition, design, development and production of systems/subsystems, delivery of flight units, and support of ground and flight operations to support of the life cycle of more then ten years of the ISS. Astrium GmbH, Bremen has also been contracted by SPACEHAB Inc. to develop and operate the ICC unpressurized logistic carrier—a robust, modular, flexible and capable commercial carrier for external payload accommodations that is compatible with both Space Shuttle and ISS applications.[4]

Mitsubishi Heavy Industries, Ltd. is a Japan-based manufacturing company. MHI's Aviation and Space division is the prime contractor to JAXA, with end-to-end responsibility for the manufacture, integration and launch of the H-IIA and H-IIB family of launch vehicles, and the HTV in support of national missions of Japan. Recently MHI has embarked on the commercialization of H-IIA to address the needs of the commercial Earth to orbit market. MHI is currently undertaking the design and development of the H-IIB, a launch vehicle matched to the requirements of the HTV. MHI is also the prime integration contractor for the JAXA HTV. MHI also is prepared to make available to NASA backup launch services, providing assured access to space for our proposed adapted HTV cargo delivery to ISS.

Boeing is a leading global supplier of manned and un-manned space systems and services. The organization's legacy began in the late 1950s with the X-15, spanned to the Apollo missions, Skylab, and the Delta II. Boeing's legacy continues today with the Delta IV, the Space Shuttle, and the International Space Station. In addition, Boeing has more than 35 years of successfully implementing complex space projects with international partners on the scale of the proposed Boeing cargo transportation system. The extensive experience of the Boeing–MHI—Arianespace—Astrium GmbH strategic partnership and provides flight-proven systems, control centers, and ground systems that can be used to proved ISS with a stable transportation solution well into the future.

VI. Conclusion

Boeing, Mitsubishi Heavy Industries, Arianespace, and Astrium GmbH are working together to provide a low-risk, integrated approach that can meet and exceed NASA's requirements for ISS cargo delivery in the post-Shuttle era. The Boeing cargo transportation system team has devised a cost-effective commercial cargo delivery approach utilizing space assets that are either in operation or nearing completion—the European ATV, the Japanese HTV and the Boeing Delta IV-H—avoiding substantial cost and risk inherent in development of new space systems.

These assets—plus ground support equipment, infrastructure, operations and support personnel—have been developed over the past two decades with more than $5 billion (U.S. dollars) invested by both commercial industry and international governments. The Boeing cargo transportation system is a unique global system-of-systems solution that stands ready to meet the large and demanding cargo delivery requirements of the ISS after the Space Shuttle is retired.

References

[1]"Commercial Orbital Transportation Services Demonstrations," *NASA Announcement Number COTS-01-05*, Commercial Crew/Cargo Project Office, Lyndon B. Johnson Space Center, Exploration Systems Mission Directorate, Houston, TX, 18 January 2006, URL: **http://procurement.jsc.nasa.gov/cots/** [cited 18 January 2006].

[2]"Commercial Orbital Transportation Services Demonstrations: Demonstration Performance Goals," *NASA Announcement Number COTS-01-05*, Commercial Crew/Cargo Project Office, Lyndon B. Johnson Space Center, Exploration Systems Mission Directorate, Houston, TX, 18 January 2006, URL: **http://procurement.jsc.nasa.gov/cots/** [cited 18 January 2006].

[3]Arianespace, [online website] URL: **http://www.arianespace.com/site/index2.html** [cited 17 August 2006].

[4]Astrium GmbH (formerly EADS) [online website],
URL: **http://www.eads.net/web/lang/en/1024/content/OF00000000400004/6/91/517916.html** [cited 17 August 2006].