Astrotech Research & Conventional Technology Utilization Spacecraft (ARCTUS)

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As part of the Commercial Orbital Transportation Services (COTS) Phase I development program, NASA has initiated two development programs (SPACEX and Rocketplane/Kistler) to develop new launch vehicles and associated cargo and crew transportation spacecraft. NASA has encouraged other spacecraft developers to continue development of alternate systems that could compete for follow-on ISS cargo contracts after the conclusion of the COTS Phase I program. With this in mind, SPACEHAB/Astrotech is developing the Astrotech Research & Conventional Technology Utilization Spacecraft (ARCTUS) concept. The main goals of the ARCTUS program are to minimize risk, development schedule and cost by utilizing as many existing components and systems as possible. The ARCTUS philosophy will minimize non-recurring development costs as well as eliminate unnecessary financial and technical risks (e.g. the development of a new launch vehicle). ARCTUS will utilize existing components from the Centaur Upper Stage as well as other existing spacecraft hardware and be flown on existing U.S. based launch vehicles. In its smallest configuration, ARCTUS accommodates up to 3 mT of ISS external Orbital Replacement Units (ORUs) as well as providing accommodations for 1.9 mT of pressurized cargo. Low G reentry capability is provided using LARC IRVE inflatable heat shield technology combined with mid-air helicopter retrieval for the lowest cost, lowest G level retrieval system, and highest return mass fraction possible. This is likely the lowest cost, lowest risk approach to the COTS proposal to date.

Nomenclature

ARCTUS	= Astrotech Research & Conventional Technology Utilization Spacecraft
CBM	= Common Berthing Mechanism
COTS	= Commercial Orbital Transportation Services
FRAM	= Flight Releasable Accommodation Modules
HTV	= Hope Transfer Vehicle
ISS	= International Space Station
LARC IRVE	= Langley Aeronautical Research Center Inflatable Reentry Vehicle Experiment
mT	= Metric Ton (1000 kg)
ORUs	= Orbital Replacement Units
SSRMS	= Space Station Remote Manipulator System

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I. Introduction

Since the announcement of the Commercial Orbital Transportation Services Demonstration request for proposal in January 2006[i], SPACEHAB/Astrotech has continued to develop a solution to the International Space Station (ISS) cargo transportation system. Astrotech Research & Conventional Technology Utilization Spacecraft (ARCTUS) is a SPACEHAB/Astrotech developed Evolved Transfer Vehicle that will provide reliable, cost-effective access to space to serve a number of markets including the ISS, on-orbit manufacturing, satellite servicing, commercial customers, and orbital delivery of propellants.

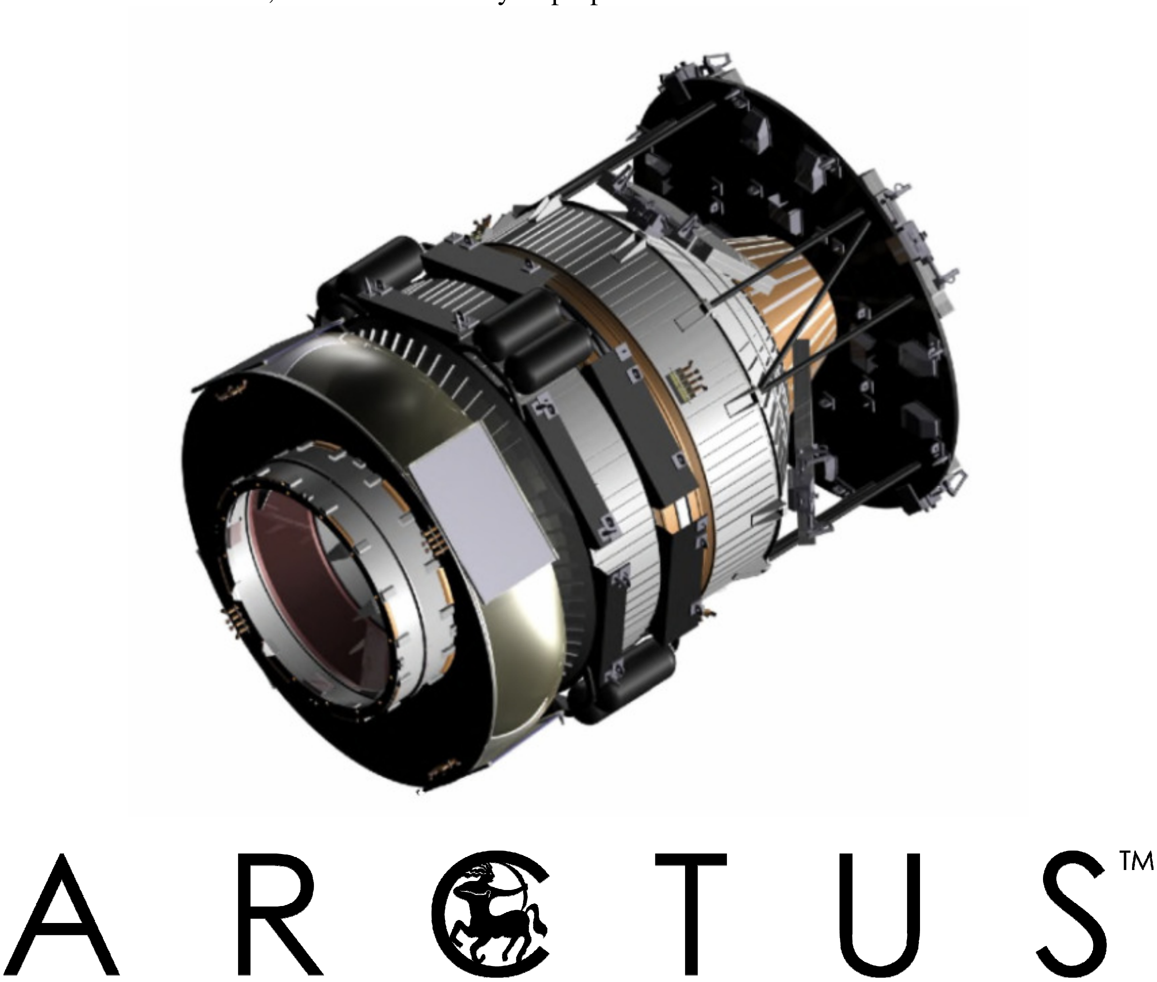


Figure 1. ARCTUS, an evolved transfer vehicle capable of supporting COTS capability A, B and C ISS servicing requirements

SPACEHAB/Astrotech has a long history of providing cargo services to NASA starting with the Commercial Mid-deck Augmentation Module project in the early '90's, going through the US Shuttle flights to Mir and into the ISS era. The SPACEHAB modules will have flown a total of 18 times. In addition to the SPACEHAB Module program, SPACEHAB has provided external ORU capabilities via their Integrated Cargo Carrier pallet (7 missions) and ISS permanently mounted ESP platforms (2 missions) on the ISS. In addition to the extensive history of space cargo transportation, SPACEHAB's Astrotech facilities have integrated (to date) 174 missions since 1984.

II. ARCTUS Design Tenants

The philosophy behind the design of ARCTUS is to utilize as many flight proven components as practical to reduce development cost, schedule and program risk (Figure 2). This will reduce/eliminate a majority of the non-recurring engineering labor and development and qualification costs, and will significantly reduce development risks as compared to a "clean sheet" approach. Modification of existing components to accommodate cargo requirements is minimized to reduce the engineering labor and cost to the overall system. Above all, the design is compatible with existing, flight proven launch vehicles, the payloads and ISS visiting vehicle requirements.

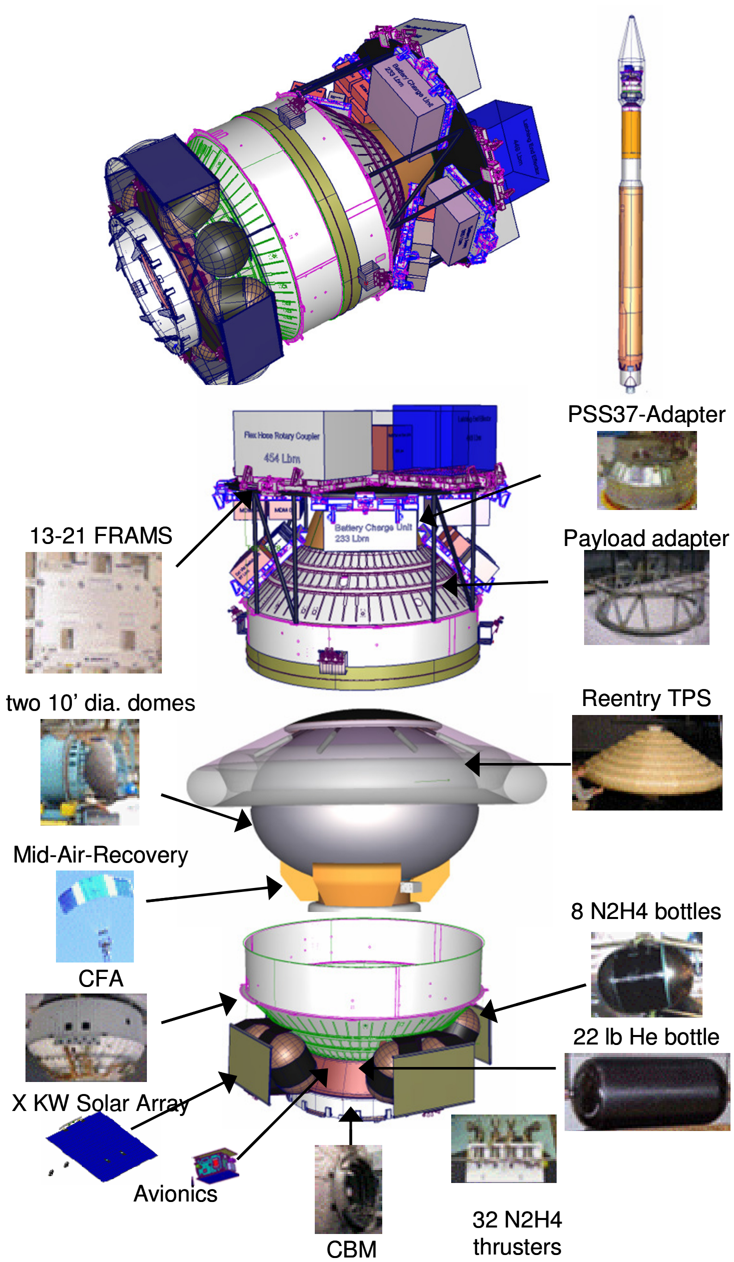


Figure 2. ARCTUS is primarily derived from existing, flight qualified components that are currently in production

III. ARCTUS Design

ARCTUS combines elements from Centaur, SPACEHAB module, Orbital Express and Inflatable Reentry Vehicle Experiment into a novel transfer vehicle capable of supporting ISS's cargo up (pressurized and vacuum) as well as down requirements. The use of existing flight proven elements for ~90% of ARCTUS significantly reduces development cost, schedule and program risk. ARCTUS is composed of three major subassemblies: The External Cargo Module, the Pressurized Reentry Module, and the Aft Service Module (Figure 3).

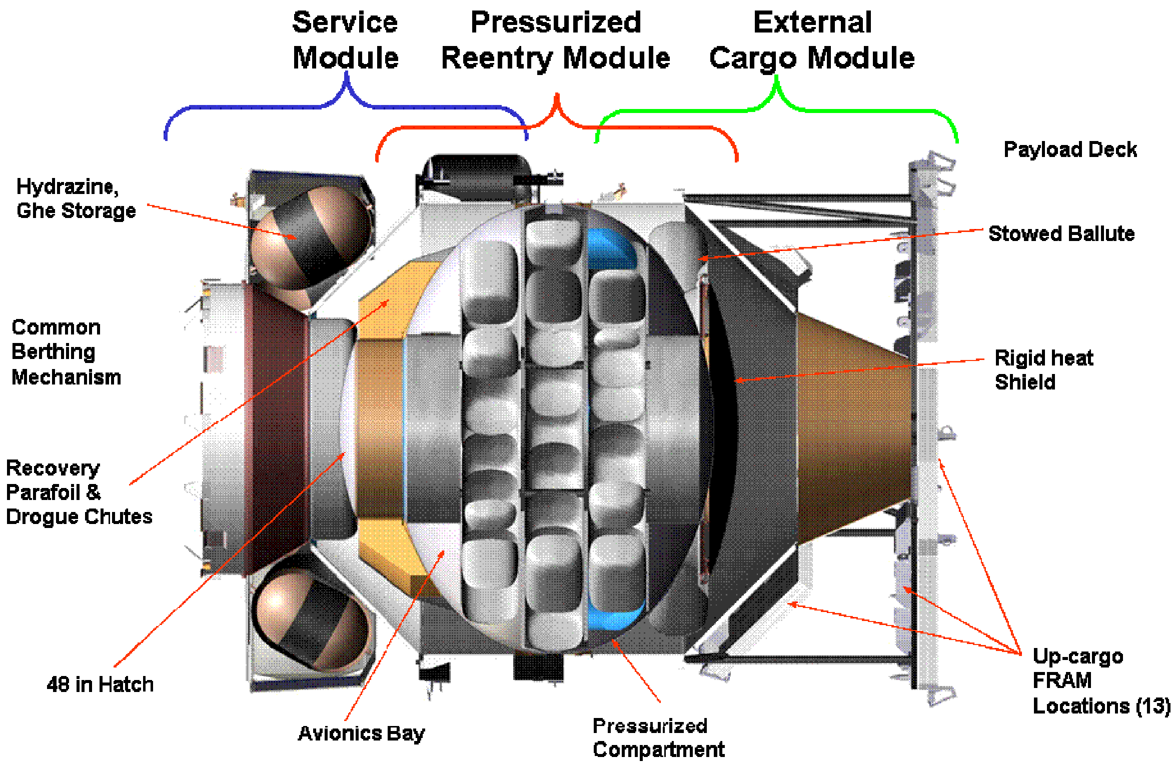


Figure 3. ARCTUS is composed of three primary elements, the external cargo module, pressurized reentry module, and the service module

A. STRUCTURE

The External Cargo Module, supporting COTS Capability A (external cargo to ISS), is composed of a Centaur Forward Adapter combined with a Centaur 120-inch heavy lift payload truss and Centaur RCS thrusters (Figure 4). By utilizing SPACEHAB/Astrotech manufactured Flight Releasable Accommodation Modules (FRAMs) mounted to the Centaur derived heavy lift payload truss structure on the forward end of the vehicle ARCTUS is capable of carrying up to 21 independent vacuum cargo elements when flown in a 5m PLF. This structure is highly efficient due to years of development and design optimization provided and proven through the Centaur program. For example, the Centaur Forward Adapter (as seen in Figure 2) weighs only 81 kg yet is able to carry 10 mT under Atlas V launch loads[ii]. The dry mass of ARCTUS is 2.4 mT, with a hydrazine capacity of 1.2 mT. A fully loaded ARCTUS, launched on an Atlas V 401, can carry 4.9 mT of payload; with a total launch mass of 8.5 mT.

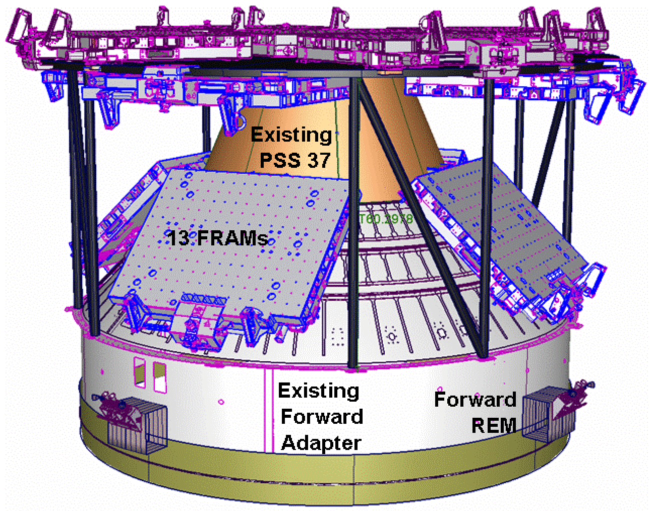


Figure 4. The ARCTUS Forward External Cargo Module enables carriage of large, oversized ORU's such as the rate moment gyros.

COTS Capability B (pressurized cargo to orbit) and Capability C (pressurized cargo reentry/earth return) are provided via the Pressurized Reentry Module. The Pressurized Reentry Module is built from two Centaur tank 10 foot diameter elliptical domes welded together in a back to back configuration. The existing dome flanges are used to interface with the forward and aft pyrotechnic separation bands enabling on orbit separation of the 3 ARCTUS modules (Figure 5). A tunnel is welded to the aft tank dome that interfaces with a flexible (and detachable) interface ring that bolts to the CBM interface.

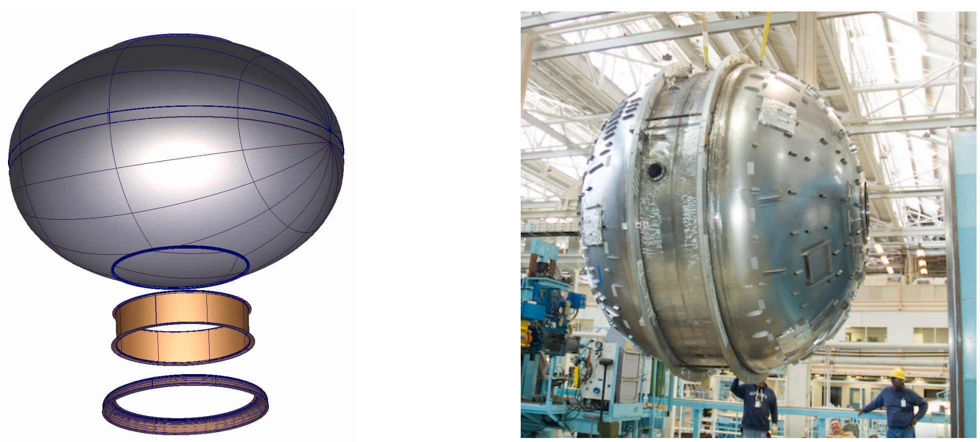


Figure 5. The ARCTUS Pressurized Reentry Module is built from 2 Centaur domes.

The Aft Service Module, in similar fashion to the External Cargo Module, is composed of an aft facing Centaur Forward Adapter and houses the external avionics, propulsion tanks, engines and Common Berthing Mechanism (CBM) (Figure 6). Interface to the launch vehicle is through a C22 launch vehicle adapter that is concentric with and inside the CBM. The C22 adapter interfaces directly with the rearward facing Forward Centaur Adapter. Thus no launch loads are transmitted through the CBM structure yet this side of the vehicle is used for ISS berthing purposes enabling ARCTUS's robust vacuum cargo capability. The aft avionics/propellant tank segments are covered with MLI blankets for thermal stability.

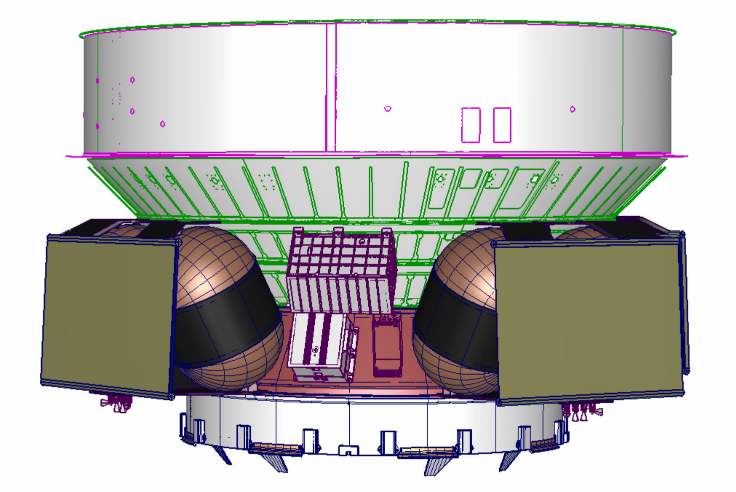


Figure 6. ARCTUS Aft Service Module houses the propulsion and avionics systems.

B. Avionics

Several currently available space qualified options for the ARCTUS avionics suite are under evaluation as part of an on-going trade study, including the Boeing Company Orbital Express (OE), the existing Centaur avionics suite, and Neptec's TriDAR system. The backbone of the ARCTUS avionics system will be comprised of a fully integrated dual redundant on-orbit automated guidance and relative navigation rendezvous system that is capable (with the assistance of operational constraints) of meeting the challenging two fault tolerance requirements of the ISS Visiting Vehicle Requirements[iii]. The ARCTUS avionics suite will include: a Master Computer (command and data handling), fault tolerant Inertial Navigation Unit (INU), a visible sensor suite, an infrared sensor suite, a laser rangefinder, TT&C uplink/downlink system, and the electrical power system.

Additional avionics will be added to ARCTUS to perform all of the required cargo transport and spacecraft functions. The add on systems will be composed of payload control electronics, thermal control electronics and Environment Control and Life Support systems.

The power supply system is based on four, twin panel fixed solar arrays, mounted on the RCS modules, and is capable of supplying approximately 2.4 kW at full insolation. Lithium-ion batteries will round out the system and provide dual redundant power during the proximity operations phases of the mission. Figure 6 shows the launch (stowed) solar array configuration.

The primary avionics are housed in the Pressurized Reentry Module to provide reentry guidance. This provides the added capability of avionics reusability, a major cost driver.

The ARCTUS will be berthed to the ISS through the Common Berthing Mechanism (CBM), which will provide the ARCTUS with ISS power, command and control, caution and warning systems and ECLSS while berthed.

C. Rendezvous and Proximity Operations System

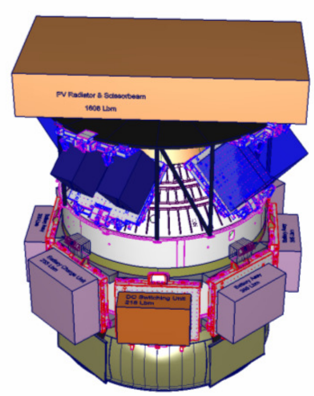
The Atlas Centaur or Delta IV Cryogenic Upper Stage (DCUS) will deliver ARCTUS to just outside of the ISS visiting vehicle stay out zone. Updated Atlas Centaur guidance is currently being developed to enable precise orbital rendezvous while accommodating flight dispersions. The on-board rendezvous and proximity operations system will take the ARCTUS vehicle from the outside of the ISS stay-out zone (approximately 3 km radius) to the ISS rendezvous "berthing box". ARCTUS will be grappled by the SSRMS and berthed on a CBM. The guidance and relative navigation rendezvous system, which is composed of a fully integrated visible & IR sensor suites and a laser rangefinder, provides passive range and attitude determination as well as long wavelength, IR, and visible situational awareness imaging to the ARCTUS. The guidance and relative navigation rendezvous system is designed for non-cooperative target applications, such as the ISS. No expensive targets on the ISS are required. A dedicated dual redundant navigation processor will accomplish proximity operations navigation using inputs from the guidance and relative navigation rendezvous system and PROX system as well as input from the ISS crew via the PROX system. The ISS crew will be able to manually override the rendezvous sequence at any point in the timeline when ARCTUS has entered the 3km ISS stay-out zone. Rendezvous will occur using a traditional nadir R-bar approach which will provide operational redundancy in the event of failed off thruster problems, as well as a fully-redundant fail-safe operational system in the event of unseen anomalies.

D. Propulsion

The propulsion system is derived from Centaur's extremely reliable, flight proven hydrazine monopropellant reaction control system (RCS). The Aft Service Module utilizes four RCS modules to provide up to 1.2 mT hydrazine monopropellant in eight bottles. The RCS system is pressurized by twin 4000 psia He bottles through a 500 psi regulator. Each module feeds four 9 lbf thrusters, two axial, 1 pitch and 1 yaw. The four RCS modules are interlinked providing full two-fault tolerance in all regards. There are four additional RCS thruster modules located on the forward External Cargo Module that provide full six degrees of freedom control.

E. Cargo Accommodations

The External Cargo Module can accommodate well over 5 mT of unpressurized cargo (ISS ORUs) mounted on up to 21 FRAMS. Additional FRAM plates are located on the equator of ARCTUS to hold old ORUs before the new ORUs are placed on the ISS. These old ORUs can then be moved to the External Cargo Module for eventual reentry disposal.



5m PLF Outfitting

Figure 7. The ARCTUS external cargo module provides 21 FRAMS in a 5m PLF launch configuration.

Using the Pressurized Reentry Module up to 1.9 metric tons of internal ISS cargo can be carried in the 400 cubic foot volume (Figure 8). This pressurized volume is accessible via the access trunk, which feeds to a common berthing mechanism (CBM) mounted on the vehicle aft end.

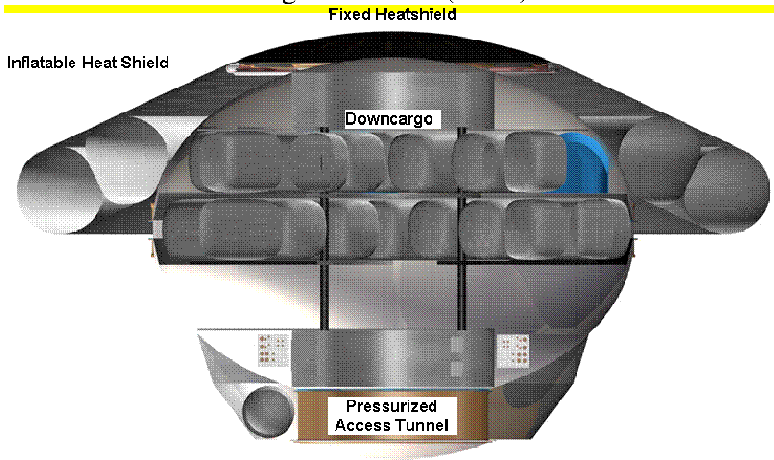


Figure 8. ARCTUS Pressurized Cargo Accommodations provide 400 ft^3 of conditioned payload volume supporting both up and down mass.

F. Reentry System

Capability C (pressurized return to earth) is achieved by separating the forward External Cargo Module, pressurizing the inflatable heat shield, performing the final deorbit burn and releasing the Pressurized/Reentry Module from the Aft Service Module. The inflatable reentry system is based on the NASA Langley developed IRVE system[iv] adapted to the ARCTUS pressurized shell (Figure 9). Most of the reentry heating load is taken up by the ablative cap on the leading edge of the spacecraft. Lifting entry is accomplished by offsetting the center of gravity of the internal cargo thus reducing the entry loads for delicate cargos. This also permits roll modulation via aft mounted hydrazine roll thrusters for accurate reentry targeting in similar fashion to Gemini, Apollo and Soyuz systems.

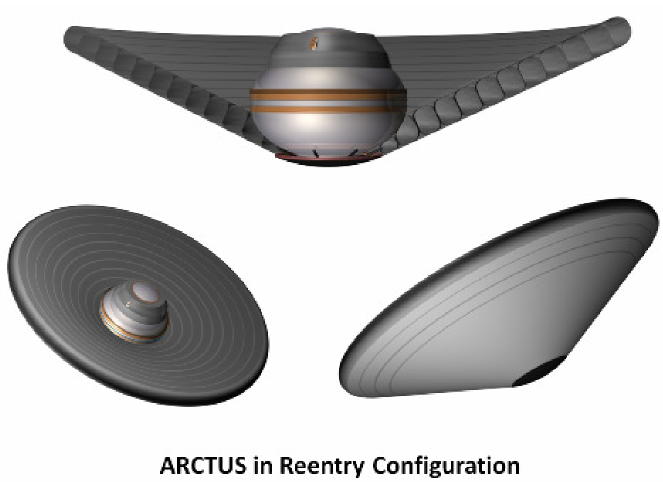


Figure 9. ARCTUS Inflatable Heat Shield enables low acceleration and heating descent.

G. Recovery System

A conventional transonic drogue parachute will slow ARCTUS to subsonic speeds after reentry heating loads have subsided (~100,000 ft altitude). A ring slot parachute will be deployed to further reduce speed prior to deployment of the primary parafoil. At lower altitudes (~ 20,000 ft) the parafoil will deploy bringing the Pressurized/Reentry Module into the vicinity of a recovery helicopter. Mid Air Retrieval (MAR) by a helicopter with the parafoil results in a zero relative velocity capture which will result in very low recovery loads. This is critical for recovery of sensitive microgravity experiments. MAR eliminates heavy retrieval hardware (retrorockets/airbags) from being carried on the spacecraft and provides a very high returned payload mass fraction. MAR also enables rapid recovery and delivery to the end customer of time sensitive returning payloads.

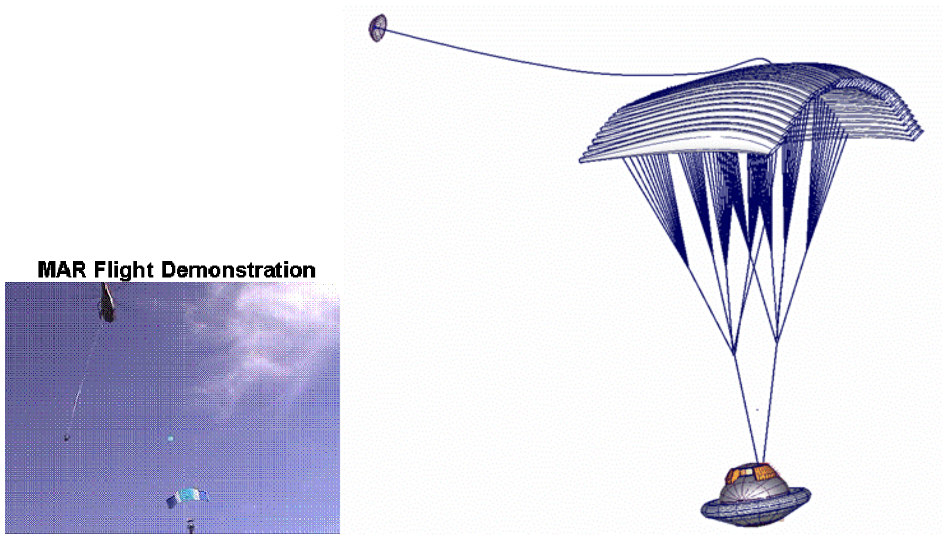


Figure 10. Mid Air Recovery provides very benign environments for the returning cargo.

H. Launch Vehicle Compatibility

Since ARCTUS is mainly constructed from Centaur components, it is naturally compatible with the Atlas V family (400 and 500 series) of launch vehicles and provides mission performance tailored to meet specific customer demands (Figure 11). In addition, the standard interface plane is also compatible with a long list of launch vehicles: Delta IV, Ariane V, HII-A, HII-B, Zenit (Sea Launch and Land Launch systems), Soyuz-Fregat, and Long March (Figure 12).

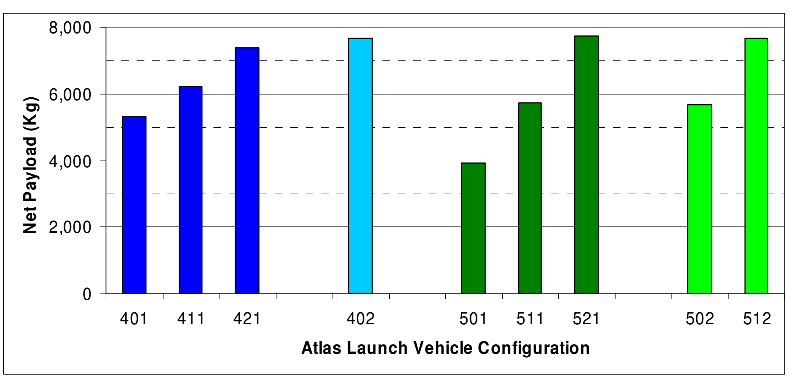


Figure 11. ARCTUS can take advantage of the modularity of the Atlas launch vehicle to support the customer required payload mass

Figure 12. ARCTUS will be compatible with numerous launch systems including Atlas V (shown), Delta IV and Ariane.

I. Ground Launch Support System

Construction of ARCTUS vehicles will occur at the Astrotech SPACEHAB Payload Processing Facility located just outside of the Cape Canaveral Air Force Station (CCAS) in Florida. Final loading, assembly and encapsulation of ARCTUS for CCAS launches will occur in the Astrotech Space Operations facilities.

J. Mission Operations

Astrotech will utilize an offsite Houston based mission control center near the Johnson Space Center (JSC) for ARCTUS operations via the NASA GSTDN network which will include the TDRSS constellation during ISS rendezvous operations. Astrotech plans to have a small mission operations cadre located in the JSC Mission Control Center to provide collaborative rendezvous and proximity operations with JSC personnel.

IV. ARCTUS Applicability to Other Missions

A. Fuel Depot

Being significantly derived from Centaur hardware, the ARCTUS vehicle is inherently compatible with the LO2 and LH2 propellants required to support future high energy in-space missions such as exploration of the moon and Mars. The use of settled cryogenic propellant transfer [v] enables the near term transfer of such propellants from ARCTUS to a cryo propellant depot or orbiting propulsion stage.

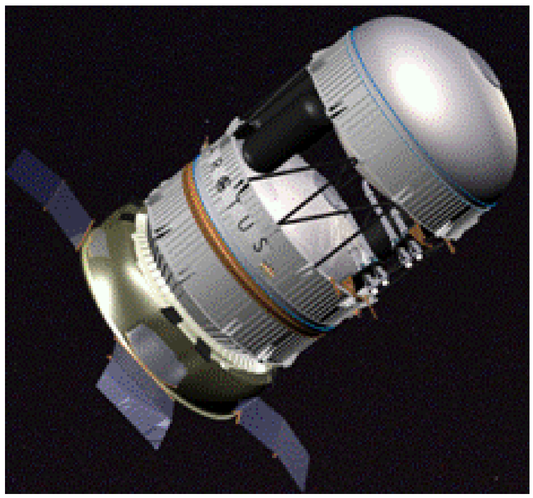


Figure 13. ARCTUS can support propellant resupply of orbiting fuel depots.

B. On-Orbit Manufacturing

The robust up and down capability, reasonable pricing and frequent launch opportunities inherent in the ARCTUS concept make it ideal to support orbital manufacturing. The ARCTUS can provide required utilities such as power, control and communication to support payload requirements.

V. Conclusion

ARCTUS is SPACEHAB/Astrotech's answer to NASA's COTS Phase II program. ARCTUS minimizes risk and cost by utilizing existing flight proven components and systems wherever practical. The ARCTUS philosophy minimizes non-recurring engineering costs and development time as well as eliminates unnecessary financial and technical risks. The use of existing and immediately available launch vehicles eliminates the critical risks associated with the development of a new launch vehicle. The ARCTUS accommodates the NASA COTS Capabilities A, B and C with up to 3 mT of ISS external ORUs and 1.9 mT of pressurized cargo when launched on an Atlas 401, or more payload with the use of increased capacity launch vehicle. The ARCTUS also provides more than 1.4 mT cargo return capability.. The low G reentry capability is provided using NASA LARC IRVE inflatable heat shield technology combined with mid-air helicopter retrieval for the lowest cost, lowest G level retrieval system, and highest return mass fraction possible. The unique cargo capabilities provided by ARCTUS make it ideal to support numerous additional markets including on-orbit manufacturing, satellite servicing, commercial customers and support of future propellant depots.

Because of the design philosophy and the extensive use of heritage flight hardware and existing launch vehicles, the ARCTUS concept likely provides the lowest cost, lowest risk approach to supporting ISS and a wide array of developing space markets.

References

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