

# RISK MITIGATION APPROACH TO COMMERCIAL RESUPPLY TO THE INTERNATIONAL SPACE STATION

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## ABSTRACT

In August 2006, NASA awarded Space Act Agreements (SAAs) for Commercial Orbital Transportation Services (COTS) under the Commercial Crew and Cargo Project Office at Johnson Space Center. One of the goals of the SAAs is to facilitate U.S. private industry demonstration of cargo transportation capabilities, ultimately achieving reliable, cost effective access to Low-Earth Orbit (LEO).

Each COTS provider is required to complete International Space Station (ISS) Integration activities, which includes meeting the physical and functional interfaces, safety and mission assurance requirements, and other interface requirements between the ISS and COTS vehicles. These requirements focus on the areas of risk to the ISS during rendezvous and proximity operations, as well as the integration operations while the COTS vehicle is berthed to the ISS.

On December 23, 2008, NASA awarded Commercial Resupply Service (CRS) contracts to provide resupply services to the ISS following the Shuttle retirement. In addition to performing any ISS Integration activities, NASA will be performing independent assessments of the launch vehicle and orbital vehicle to evaluate the readiness of the contractor to deliver NASA cargo safely to the ISS.

This paper will address the activities of NASA Centers, JSC and KSC, in the oversight and insight function over commercial visiting vehicles to the ISS.

## 1. BACKGROUND

The International Space Station is the collaborative effort of numerous countries for the purpose of maintaining a long term human presence in space and creating an outpost for microgravity experimentation [1]. The STS-131 mission recently delivered laboratory facilities to the ISS, which included the Window Observational Research Facility (WORF). The WORF will utilize the optical-quality window in the Destiny Laboratory [2]. The STS-132 mission this month will deliver the 2<sup>nd</sup> of two Russian Mini-Research Modules [3].



Figure 1. ISS photographed by an STS-130 crew member on Space Shuttle Endeavour after the ISS and Shuttle began their post-undocking relative separation.

Resupply of cargo to the ISS is essential in order to maintain Earth orbiting international laboratory. NASA projected a shortfall in the resupply capabilities in excess of 6 tons before the planned Shuttle retirement in 2010. Using the existing resupply services offered by the Russian Progress vehicles, the European Automated Transfer Vehicle (ATV) and Japanese H-II Transfer Vehicle (HTV), the shortfall would continue to grow in excess of 60 tons by ISS retirement [4].

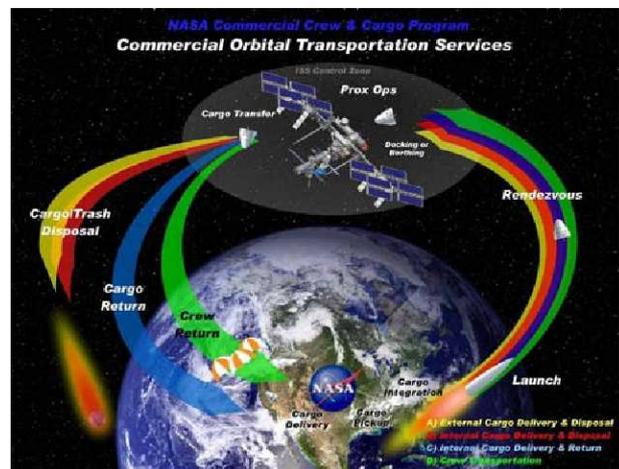


Figure 2. NASA COTS Capability Concept International Space Station Program

## 1.1 Commercial Orbital Transportation Services (COTS)

As a result of the forecasted resupply shortfall to ISS, a new market emerged for cargo delivery to and cargo return from the ISS especially following Shuttle retirement. The Commercial Crew and Cargo Project Office (C3PO) at NASA Johnson Space Center was formed and chartered with the responsibility to establish commercial capabilities and services to Low Earth Orbit (LEO), with a goal to support the resupply needs of the ISS [5].

In January 2006, Commercial Orbital Transportation Service Demonstrations Announcement Number COTS-01-05 was released. NASA committed approximately \$500M to support commercial space vehicle development over the time period from 2006 to 2010. In August 2006, NASA awarded two funded Space Act Agreements (SAA). One award was to Space Exploration Technologies (SpaceX) and the second award to Rocketplane-Kistler (RpK).



Figure 3. SpaceX Dragon

However, the RpK agreement with NASA was later terminated and a second Commercial Orbital Transportation Services Phase 1 Demonstrations, Announcement Number JSC-COTS-2, was released in October 2007. A funded SAA agreement was awarded to Orbital Sciences Corporation (Orbital) in February 2008.

Under the funded SAA agreements, the partners are responsible for their design, development, manufacturing, testing and operations of their systems. Each partner must meet vehicle interface and ISS integration requirements and demonstrate a mission to the ISS. The mission to ISS is contingent upon the partner meeting the ISS visiting vehicle requirements dubbed "ISS Integration", which include safety and mission assurance requirements.



Figure 4. Orbital's Cygnus

NASA's primary role is to monitor the progress of the partners against the agreed to milestones. NASA provides technical assistance in support of the partners versus the traditional technical NASA oversight function. The ISS Program works with C3PO and each partner in ISS Integration activities [5].

## 1.2 ISS Commercial Resupply Services (CRS)

In August 2007, NASA began laying the ground work with industry for the competitive procurement of cargo services to ISS with the release of a Request for Information (RFI). NASA utilized the feedback received from this phase of the procurement in the development of the Request for Proposal (RFP). The Final RFP was released on April 14, 2008 [6].

The procurement strategy was similar to that of the funded SAA for the demonstration missions. NASA was to procure an end-to-end resupply service to meet annual resupply requirements for calendar years 2010 through 2015, instead of the traditional procurement of a vehicle. The contractor would be responsible to perform all tasks necessary to execute the resupply mission to the ISS, including any necessary services, testing of hardware and software, and any mission specific elements requirement to integrate the cargo to their vehicle [7].

On December 23, 2008, NASA awarded two CRS contracts. One award was to SpaceX for pressurized and unpressurized upmass capability, as well as the capability for cargo return. The second award went to Orbital for pressurized upmass capability, as well as disposal [6].

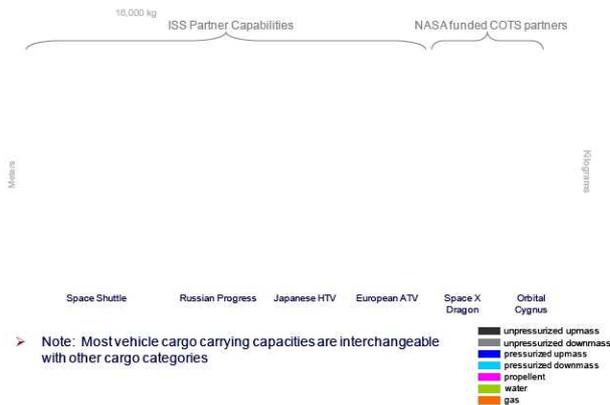


Figure 5. Russian Progress, European ATV, Japanese HTV and domestically developed commercial vehicles (average mission comparison – not maximum vehicle capabilities)[6]

SpaceX was awarded 12 flights over the time period of 2011 through 2015. The Dragon vehicle has a pressurized compartment, which is recoverable, and can hold up to 10m<sup>3</sup> of cargo. The pressurized compartment can accommodate bagged cargo, middeck lockers, and has other mounting capabilities, upon request. The unpressurized trunk, which is unrecoverable, can hold up to 14m<sup>3</sup> of cargo and accommodates Flight Releasable Attachment Mechanisms (FRAM) type pallet interfaces [8].



Figure 6. Dragon Spacecraft in Cargo Configuration [8]

Orbital was awarded eight flights across the same time period, 2011 through 2015. Orbital’s Cygnus is a pressurized volume which can hold up to 18.9m<sup>3</sup> cargo volume. Cygnus can accommodate passive cargo, such as bags and middeck lockers, active middeck lockers, and can be used to dispose cargo reloaded on Cygnus prior to unberthing [9].

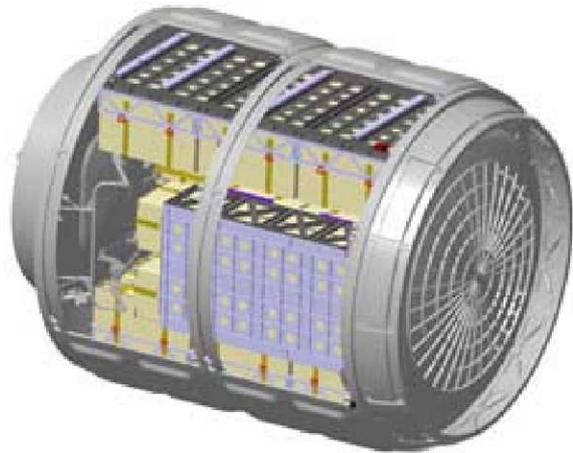


Figure 7. Cygnus[10]

## 2 ISS INTEGRATION

ISS Integration requirements paved the way for a paradigm change for the ISS Program from procuring a vehicle to procuring a service. NASA defined the critical interface for insight and approval to be at the ISS interface. The ISS Integration requirements focus on the areas of risk to the ISS during rendezvous and proximity operations, as well as the integration operations while the COTS vehicle is berthed to the ISS. ISS Integration requirements provide the interface and performance requirements between the ISS and COTS vehicle, the performance and design requirements for the COTS ground systems supporting COTS vehicle flights to ISS, and the design requirements on the COTS vehicle to ensure safe integration with ISS.

Prior to a demonstration mission to the ISS, the COTS partner must verify the requirements for ISS Integration have been met by means, such as analysis, test, inspection or a combination thereof. Each partner shall provide certification that their orbital vehicle can safely berth/unberth to/from the ISS and integrated operations following berthing to the ISS can be performed safely.

### 2.1 Scope of the ISS Visiting Vehicle Requirements

As previously mentioned, the scope of the ISS Integration requirements is at the interface. Each COTS vehicle will be captured by the Space Station Remote Manipulator System (SSRMS) and be berthed to the ISS at a Common Berthing Mechanism (CBM) interface at the Node 2 nadir port.

To ensure a safe integration with ISS, the interface must be defined beyond just the true physical interface between the vehicles. The virtual interface must extend to cover a period of approach of the COTS vehicles to

the ISS to protect the ISS vehicle from a collision hazard. Integrated operations start at 90 minutes prior to approach initiation (AI) of the orbital vehicle and lasts until the vehicle leaves the approach ellipsoid (AE) on a non-return trajectory.

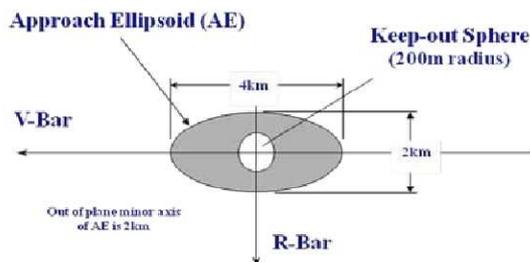


Figure 8. Approach Ellipsoid and Keep-Out Sphere

The approach ellipsoid is defined as the 4 x 2 x 2 km ellipsoid, centered at the ISS center of mass, with the long axis aligned with the V-Bar. The approach initiation is the first maneuver which will bring the orbital vehicle into the AE. The Keep Out Sphere (KOS) is defined as a 200m radius, centered at the ISS center of mass.

There are many requirements within the ISS Integration document that reduce the overall risk to ISS and its crew during Integrated Operations. As an example, during the approach phase to the ISS, decision points will be used to assess the performance of the orbital vehicle to ensure the vehicle will meet the nominal mission objectives without causing damage to or creating potential hazards for the ISS and its crew. There will be at least one decision point during the Integrated Operations while the vehicle is outside of the AE. The vehicle will hold and not continue on the nominal approach until authorization has been received from NASA Mission Control – Houston (MCC-H). Once inside the AE, there will be at least one decision point prior to the vehicle continuing with the nominal approach and enter the KOS. Again, the vehicle will hold at the decision point location and await authorization from MCC-H before entering the KOS.

The ISS Integration requirements cover subject areas on:

1. ISS Cargo Accommodations
2. ISS Crew Accommodations
3. ISS rendezvous and Proximity Operations
4. Vestibule Pressurization/Depressurization
5. Micro-gravity
6. Command and Data Handling
7. Communication, Command, and Control
8. EVA and Robotics
9. On-Orbital Environmental Conditions
10. Safety and Mission Assurance

The requirements levied on the commercial partners are consistent with the requirements levied on our International partners.

## 2.2 Safety Requirements and Process

ISS Program safety requirements were derived from existing Shuttle safety policy and requirements. Shuttle safety requirements utilize a proven approach to the control philosophy for catastrophic and critical hazards, as well as a design for minimum risk approach for such items as windows and structure.

In the development of ISS Integration requirements, the safety requirements were derived from ISS Program safety requirements. The safety requirements documented in the applicable IRDs for other visiting vehicles to ISS, such as ATV and HTV, were also derived from ISS Program safety requirements.

In addition, any visiting vehicle to the ISS must comply with the phased ISS Program safety review process. As levied upon the COTS/CRS partners in order to meet ISS Integration requirements, the COTS/CRS partners must adhere to ISS Safety Review process and perform all safety analyses in accordance with the ISS Program safety analysis and risk assessment process. The ISS Safety Review Panel will review and approve the hazard analysis, which addresses all ISS-related mission phases. All potential hazards are to be identified and controlled in accordance with standard ISS safety requirements.

The integrated safety of the ISS is not compromised by the commercial ventures. Each commercial partner must meet the same stringent safety requirements and follow the same well established safety review processes as all other visiting vehicles to the ISS.

## 2.3 Certification of Flight Readiness (CoFR)

For Shuttle missions to ISS, NASA performs Certification of Flight Readiness (CoFR) reviews to certify the Shuttle and the ISS are ready for the flight. These reviews culminate with a Flight Readiness Review (FRR) Board conducting an assessment of the Shuttle Program readiness of all flight and ground systems and supporting personnel. In support of the FRR Board, the ISS program conducts a comprehensive readiness assessment of the Launch Package/Cargo Element (LP/CE), ground hardware/software support facilities and personnel to support the flight, stage and increment during the readiness of the on-orbit stage to accept the LP/CE and return items. Upon concurrence from the FRR Board and completion of planned open work, the Space Shuttle Program attests they are ready to execute the Shuttle mission. The ISS Program attests

they are ready for launch and on-orbit operations for all Shuttle-ISS missions [11].

COTS and CRS launches are commercial launches and will be certified by the Federal Aviation Administration (FAA). In addition, range safety is the responsibility of the range from which these commercial vehicles are utilizing. The CoFR process for COTS and CRS mission to ISS will, therefore, not include a “go” or “no/go” for launch as the FRR Board concludes for Shuttle missions to ISS. However, the ISS Program will continue to assess the readiness of the cargo on these missions and the readiness of the ISS to support the flight, stage and increment, as described above. In addition, the ISS Program will assure that all the requirements for ISS Integration have been satisfied, ensuring safe integrated operations of the COTS/CRS vehicles with the ISS.

### **3 WHAT IS NEW UNDER CRS**

Under the COTS demonstration missions to the ISS, demonstration cargo may be used to demonstrate the commercial partner’s ability to execute the cargo missions. The risk to the ISS Program is during the Integrated Operations of the commercial partner’s vehicle with the ISS and that risk is mitigated by the partner’s vehicles and operations meeting the ISS Integration requirements.

However, cargo flown on the CRS missions will be of more value to the ISS Program. This cargo may include high dollar value critical spares required to perform crucial on-orbit repairs of the ISS. The CRS missions will also be flying experiments, perhaps one-of-a kind, to the ISS. The FAA and range are the ultimate decision makers in the launch readiness for public safety. However, NASA has retained its right to remove their cargo from the commercial partner’s launch vehicle or to not allow the vehicle to perform rendezvous and proximity operations with the ISS.

NASA reserves the right to perform technical assessments of the launch and cargo vehicles. These assessments will evaluate the commercial partner’s readiness to deliver NASA cargo safely to the ISS. Insight into the orbital vehicle will largely be accomplished by NASA’s role in the ISS integration activities, additional insight is gained through vehicle production insight for each CRS mission.

#### **3.1 Insight vs. Oversight**

The review and approval of the commercial partner’s hazard analysis, which addresses Integrated Operations with ISS, by the ISS Program SRP is an oversight function. From a safety and mission assurance perspective, some traditional oversight functions are

Government Mandatory Inspection Points (GMIPs). There are no GMIPs imposed on the COTS/CRS agreements/contracts.

Long before the COTS agreements or CRS contracts, NASA had begun reducing and eliminating GMIPs on other NASA contracts. The approach to transition traditional government oversight to an insight surveillance function placed the responsibility on the NASA contractor to assure the quality of their own products/vehicles. The new NASA paradigm also involved other factors, but not limited to the review of the contractor’s quality management system and audit/process surveillance type activities, in determining the extent of GMIPs on a contractor [12].

To reduce the risk to the ISS Program from placing the quality of the commercial partner’s vehicle on the partners themselves, the commercial partners are required to maintain a Quality Management System that is AS9100 compliant. NASA also reserves the right to monitor NASA-selected audits with the partner’s auditors and inspectors in order to provide understanding of the partner’s quality system and insight of their processes [7]. NASA will be assessing the contractors’ ability to “do” as they “say” as documented within their QMS processes.

In addition, the partners are required to provide all quality data necessary to support NASA insight, such as, but not limited to, Material Review Board (MRB) reports, discrepancy reports, and deviations and waivers. Assessment of this data will provide NASA insight into areas where the partner may be accepting more risk. There are many other “hooks” in the CRS contracts to allow process audits/surveillance to gain insight into the partner’s readiness.

#### **3.2 Teaming with NASA Kennedy Space Center (KSC)**

Independent assessments will be performed on both the launch and orbital vehicle based on the data, observations, and other sources of information available to NASA. The ISS Program, recognizing that their area of expertise lies more with the orbital vehicle as applicable to integrated operations with the ISS, has teamed with Kennedy Space Center to support the independent assessments of the launch vehicle.

The NASA Launch Services Program (LSP) based at Kennedy Space Center (KSC) is responsible for managing the large majority of expendable launch services acquired by NASA from commercial launch service providers for science and exploration. In this capacity, NASA exercises technical insight and approval for such launches, primarily from Cape

Canaveral Air Force Station, Florida (CCAFS) and Vandenberg Air Force Base, California (VAFB).

In support of this responsibility LSP receives matrixed support from the KSC Engineering Directorate (NE) and the Safety & Mission Assurance Directorate's Launch Services Division (SMA-LS). In some cases ELV launches are managed by other organizations in order to capitalize on special competencies. In these situations it is normal for LSP to enter into agreements to provide advisory support to the launch managing project.

LSP has entered into such an agreement with the ISS Program. As part of this agreement, SMA-LS will perform specific risk assessments related to launch vehicle mission assurance issues. The ISS Program will supply data to SMA-LS, such as mission analysis requirement excursions and violations, MRB "use as is" and "repair" actions, launch vehicle hardware/software/systems concerns, anomalies and failures, and other data that may increase risk to the launch vehicle.

Neither LSP nor SMA-LS has any NASA CoFR responsibility for CRS missions. However, the risk assessment data provided by SMA-LS will be used to help the ISS Program determine the overall readiness of the commercial partner to successfully delivery cargo to the ISS in a timely and safe manner.

#### 4 CONCLUSION

In assessing the risk to the NASA mission of the U.S. privatization of cargo transportation capabilities to ISS, NASA has identified areas of risk and developed either an oversight or insight surveillance strategy to mitigate the risk, based upon the severity of the risk.

ISS Integration activities will be completed and approved by NASA prior to any of the demonstration missions to ISS, as well as for CRS missions. These activities focus to mitigate the risk to the ISS during the commercial vehicle's integrated operations with the ISS and ensure the safe integration of the COTS/CRS vehicles with the ISS.

ISS Integration activities include the review and approval of the commercial partner's hazard analyses, addressing all integrated operations, by the ISS SRP. The safety review process and analysis methods are proven and mature and have been utilized with International Partners.

NASA will utilize the existing CoFR processes to assess the readiness of ISS to accept the COTS/CRS missions and its cargo and return items and the ground hardware/software support facilities and personnel to

support the flight, stage and increment. As NASA does not participate in the final launch countdown, NASA reserves the right to have its cargo removed from the vehicle or wave off the vehicle from the approach to or berthing to ISS. NASA will utilize its technical assessments of the commercial partners' readiness to deliver cargo safely to the ISS in making this decision.

In addition, NASA capitalizes upon their expertise at both Johnson Space Center and Kennedy Space Center to maximize the success of CRS missions to ISS.

NASA's oversight and insight strategy for commercial resupply mission has allowed commercial space providers to enter into a financially feasible market, while maintaining a safe environment for the ISS and its crew.

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# **Risk Mitigation Approach to Commercial Resupply to the International Space Station**

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NASA ISS S&MA/PR Office

**May 2010**

**International Association for the  
Advancement of Space Safety:**

***“Making Safety Matter”***



# Overview

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- Purpose
- Background
- ISS Integration
- What is New Under CRS?
- Conclusion



# Purpose

- **International Space Station**

- ◆ A multi-nation collaborative effort
- ◆ Maintain a long term human presence in space and creates an outpost for experimentation in microgravity
- ◆ Resupply essential to maintaining ISS
- ◆ Logistics shortfall beyond Shuttle retirement



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# Commercial Orbital Transportation Services (COTS)

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- NASA helps industry develop and demonstrate cargo space transportation capabilities
  - ◆ Industry leads and directs its own efforts
  - ◆ NASA providing technical and financial assistance
- 1<sup>st</sup> COTS competition completed in August 2006
  - ◆ Space Exploration Technologies (SpaceX)
  - ◆ Rocketplane-Kistler (RpK)
    - Failed to complete financial and technical milestones. Terminated
- 2<sup>nd</sup> COTS competition completed in February 2008
  - ◆ Orbital Science Corporation



# Commercial Resupply Services (CRS)

- An end-to-end resupply service encompasses all work required to integrate launch vehicle, orbital vehicle, and cargo to perform cargo resupply missions to the ISS.
- On December 23, 2008, NASA awarded two CRS contracts
  - SpaceX – twelve missions with pressurized, unpressurized, and return capability
  - Orbital – eight missions with pressurized and disposal capabilities



Dragon Spacecraft with Solar Arrays Deployed



Artist rendering of Cygnus spacecraft approaching the International Space Station



# Dragon CRS Mission Capabilities

- **Pressure Vessel Interior (pressurized/recoverable)**
  - ◆ 10m<sup>3</sup> payload volume
  - ◆ Typically middeck locker accommodations
  - ◆ Other mounting accommodations available
- **Trunk (unpressurized/unrecoverable)**
  - ◆ 14 m<sup>3</sup> payload volume
  - ◆ “FRAM” type pallet interface mounted to a strong back
- **Total Cargo Mass**
  - ◆ 6000 kg total combined up-mass capability
  - ◆ Up to 3000 kg down mass

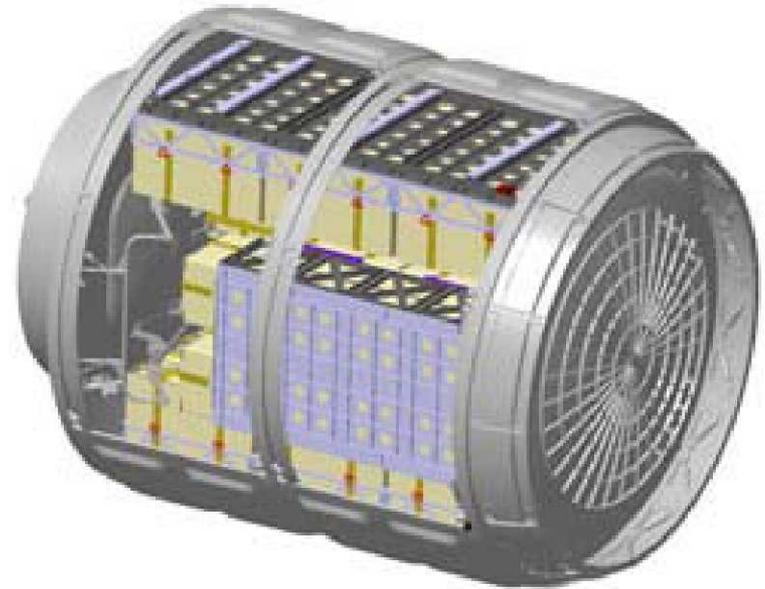


**Dragon**



# Cygnus CRS Mission Capabilities

- **Pressurized Volume**
  - ◆ 18.9 m<sup>3</sup> payload volume
  - ◆ Total Cargo Mass:
    - 2,000 kg (standard)
    - 2,700 kg (enhanced)
- **8 Flights over period 2011-2015**
- **Standardized Active and Passive Cargo Accommodations**
  - ◆ **Passive Cargo:** Cargo Transfer Bags (CTBs) M-bags, Mid-Deck Lockers (MDL)
  - ◆ **Active Cargo:** Two single MDL or one Double MDL sized payloads
  - ◆ **Disposal cargo** reloaded into Cygnus prior to unberthing



**Cygnus**



# ISS Integration Requirements

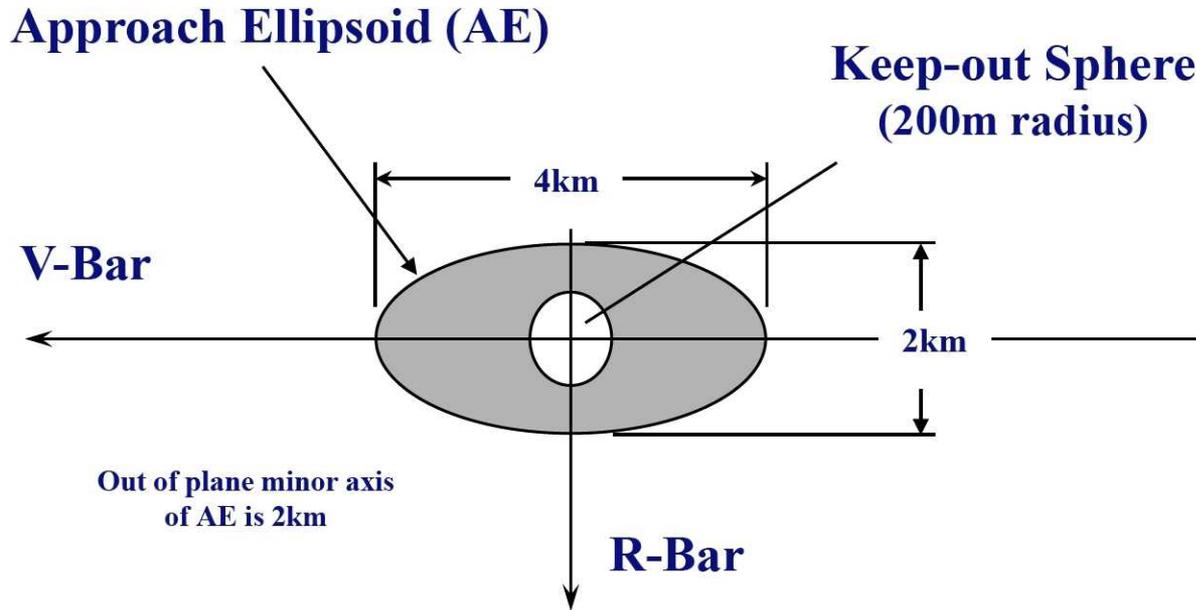
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- Provides interface and performance requirements between ISS and COTS vehicle
- Provides performance and design requirements for the COTS ground systems supporting COTS vehicle flights to ISS
- Provides design requirements on the COTS vehicle to ensure safe integration with ISS

**The critical interface for insight and approval is at the ISS interface.**



# Scope of ISS Visiting Vehicle Requirements



Approach Ellipsoid and Keep-Out Sphere



# **ISS Integration Requirements Summary**

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- **ISS Cargo Accommodations**
- **ISS Crew Accommodations**
- **ISS Rendezvous and Proximity Operations**
- **Vestibule Pressurization/Depressurization**
- **Micro-gravity Requirements**
- **Command and Data Handling**
- **Communication, Command and Control**
- **EVA and Robotics**
- **On-Orbit Environmental Conditions**
- **Safety and Mission Assurance**



# Safety Requirements and Process

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- **ISS Program safety requirements derived from Shuttle Safety Policy and Requirements**
  - ◆ Utilizing a proven approach for control philosophy for catastrophic and critical hazards, as well as for design for minimum risk approach
- **ISS Integration safety requirements derived from ISS Program safety requirements**
- **Any Visiting Vehicle to ISS:**
  - ◆ Must comply with phased ISS Program Safety Review Process
  - ◆ Must adhere to ISS Safety Review Process
  - ◆ Must Perform safety analyses in accordance with ISS Program safety analysis and risk assessment requirements process
  - ◆ The ISS Safety Review Panel will review and approve the hazard analysis, which addresses all ISS-related mission phases.
- **Integrated safety of the ISS is not compromised by commercial ventures**



# **Certification of Flight Readiness (CoFR)**

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- **Missions will be FAA licensed commercial launches.**
  - ◆ NASA does not have go/no-go authority for launch.
- **The ISS Program will CoFR that the contractor has met the ISS Integration requirements, that the ISS Program has met its stage requirements, and that the contractor is meeting the contractual requirements for vehicle readiness and capability.**
- **NASA GO/NO-GO Decision Points**



# What is New Under CRS?

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- **NASA reserves the right to perform technical assessments of the launch and cargo vehicles**
  - ◆ Evaluate readiness to deliver NASA cargo safely to the ISS
- **Insight vs. Oversight**
- **Teaming with NASA Kennedy Space Center**



# Conclusions

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- **Oversight or insight surveillance strategy determined based of severity of risk**
- **ISS Integration activities completed and approved by NASA before demonstration missions**
- **ISS Integration activities include safety review and approval of hazard analysis addressing all integrated operations**
- **NASA will utilize its technical assessments of partner's readiness to deliver cargo safely to the ISS in making decisions**



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