



# Commercial Vehicles – Collaboration for Vehicle Design & Crewed Operations



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September 13, 2010**





# Background & Purpose



- ◆ **President's Budget emphasizes commercial vehicles "to provide astronaut transportation to the International Space Station (ISS), reducing the sole reliance on foreign crew transports and catalyzing new businesses and significant new jobs."**
- ◆ **Goal of Presentation: Provide description of the challenges and opportunities associated with potential commercial crew initiatives from a flight crew perspective**
- ◆ **Astronaut Office letter (March, 2010) describes Commercial Crew Vehicle Transition Concepts**
- ◆ **Astronaut Office letter (June, 2010) describes position on crew suit for ascent and entry**

- ◆ **It is imperative that NASA's broad experience in human spaceflight be used as a resource to expedite this transition to the commercial market**
  - The current astronaut corps can be used, leveraging the breadth of ISS experience brought by its current operator-astronauts in the complexities of working in close proximity to the ISS
  - Vehicle traffic to and from the ISS is complicated
    - International agreements and commitments
    - Launch & landing windows and docking opportunities





# Flight Safety



## ◆ Ascent & Aborts

- An Order of Magnitude Improvement over Shuttle during Ascent & Entry = **Predicted LOC of 1/1000**
  - Booster with high ascent reliability
  - Abort System for Crew Escape
- Full Envelope Abort/Escape Capability with **No Black Zones**





**NPR 8705.2b Section 1.2.2 states “Human-rating includes incorporation of design features and capabilities to enable safe recovery of the crew from hazardous situations.”**

- **Fault tolerance to catastrophic events (level derived from integrated design and safety analysis)**
- **Protection against fire, depress or toxic atmosphere**



# Pressure Suit History



**Vostok, Mercury , Gemini, Apollo, Soyuz, and Shuttle programs have used pressure suits for critical flight phases. When pressure suits were not utilized:**

- June 1971 Soyuz – During Re-entry a pressure equalization valve was inadvertently left open. The crew was not in suits and all 3 perished.
- July 1975 Apollo-Soyuz – Valve mis-configuration resulted in nitrogen tetroxide leak into the cabin during final descent. Crew elected to not wear pressure suits; all were hospitalized with chemical-induced pneumonia (which could have been fatal)
- January 1986 Shuttle (Challenger) – NASA determined that with a bailout system and with the crew module in a stable attitude, some portion of the crew might have survived. Accordingly, NASA once again made wearing the suits a requirement.



### Loss of Vehicle Pressurization Controls

- **Masks & resources to “feed the leak” can be used to allow the crew members time to don suits in event of failure or MMOD strike**
- **Hazards associated with vents, valves, or seals should be controlled (via on-orbit a design and redundancy)**
- **Adding redundant pressure vessels to the vehicle and tanks/lines is generally impractical due to mass constraints**
- **Pressure suits must be provided as an emergency system for ascent/entry (as those phases still represent the largest demonstrated risks to loss of life in human spaceflight)**



### Toxic Atmosphere/Fire Controls

- ◆ Flame-retardant materials
- ◆ Filtering masks can be used to provide good air to the crew in a toxic cabin atmosphere (ingestion coolant, propellants, smoke)
  - ◆ Limited when ppO<sub>2</sub> below breathable levels, requiring supplemental O<sub>2</sub> (from spacecraft supply)
  - ◆ Supplemental O<sub>2</sub> via mask leakage introduces additional risk of providing oxygen to fuel a fire
- ◆ Worst-case fire extinguishing method includes depressing the vehicle (at which time the crew would require a pressure suit)



# Definition of Black Zone



**During powered flight, a region in the ascent trajectory from which an abort is not survivable is a black zone**

## *Examples*

**An abort during a highly lofted portion of an ascent trajectory could result in loss of crew due to high G and heating during the entry portion.**

**Example Design Solution:** Depress the trajectory so that aborting at any portion in the ascent does not exceed G and heating limits. Cost is vehicle performance.

**An abort causing the vehicle to land in the North Atlantic Exclusion Zone or in Europe could result in loss of crew due to inability to recover the crew (weather and sea state) or land landing (vehicle not designed for land landing).**

**Example Design Solution:** Provide prop and vehicle guidance/steering to fly vehicle during the abort to a safer landing zone. Cost is mass/complexity of vehicle design.

**An abort in an aerodynamic region where abort system cannot safely control the vehicle could result in loss of crew.**

**Example Design Solution:** Design and test abort and attitude control motors to handle aborts from all anticipated altitudes and attitudes. Cost is mass and complexity in the abort system.



# Requirements for Crew Transport



- **ISS Must Have Continuous US Presence Onboard at All Times**
  - Intergovernmental MOUs
- **Must be able to transport a crew of up to 4 USOS crew on ISS**
- **Must have assured crew return capability**
  - Medical emergency
  - ISS emergency requiring evacuation
- **Must have safe haven – a safe environment isolated from ISS (e.g. smoke/toxic atmosphere/debris avoidance)**
- **Each crew must have 2 people trained to pilot the vehicle**  
*(this should not preclude the vehicle design which would hopefully allow operation by a single crew member)*
  - Could be commercial pilots, astronaut pilots, or a mix of both
  - Historical space and aviation precedence



## “Taxi” Versus “Rental Car”



### ◆ “Rental Car” – ISS Crew as Vehicle Operators

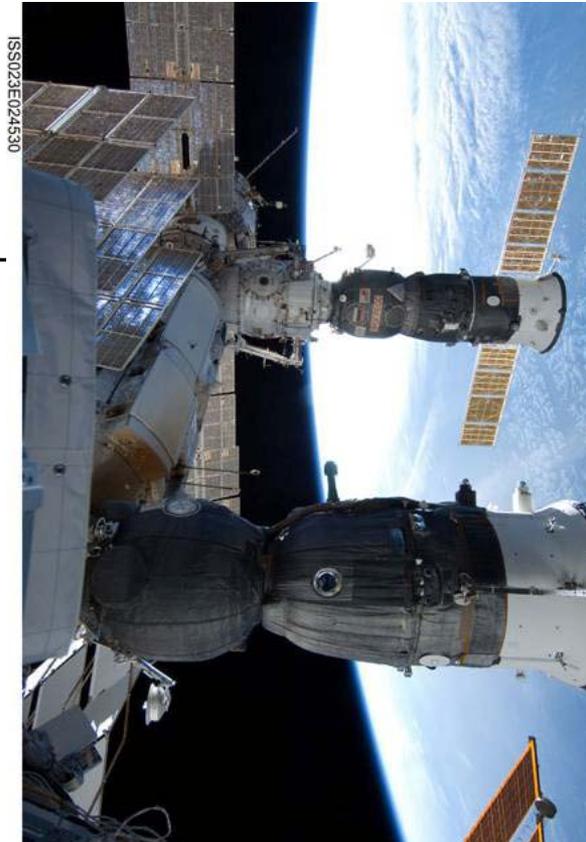
- Optimized for direct handover with minimal extra consumables required
- Leverages NASA operating experience in close operations to ISS

### ◆ “Taxi” - Commercial Operator to Ferry ISS Crewmembers

- Uses valuable up and down mass to support the dedicated commercial operator(s) to fly the vehicle to and from ISS and consumables necessary to support their stay during handover
- Additional non-NASA Flight Crew and Space Flight Participant Costs (Food, Water, O<sub>2</sub>, N<sub>2</sub>, CO<sub>2</sub> scrubbing, Prop, etc...)
  - Crewmember “weight” includes suit/emergency hardware/consumables
  - Safety training for ISS would also be required
- One additional vehicle must be flown at the beginning of the program if Assured Crew Return (ACR) is same vehicle



- ◆ **Assured Crew Return (ACR) for ISS crewmembers - a ready vehicle (lifeboat attached to ISS)**
  - Option 1 – Leaving the crew transportation vehicle docked to station for full expedition
  - Option 2 – 2 separate vehicles (one for nominal transport; one for emergency crew rescue)
    - Additional Cost & Risk Associated with 2 separate vehicles - slip/failure/anomaly of one vehicle affects both
- ◆ **ACR also serves as safe haven**
  - For debris within close proximity to ISS
  - For emergency situations on-board the ISS
    - Fire, depress or toxic atmosphere scenarios require time to assess/clean atmosphere
- ◆ **ACR may be used for medical emergency**

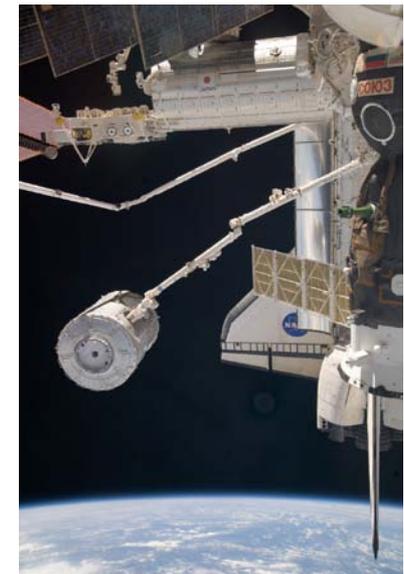


## ◆ Expedition Lengths similar to that with Soyuz ~ 6 months

- Maximum 210 days (>6 months to account for vehicle traffic and associated handover contingencies)

## ◆ Number of ISS Docking/Berthing Ports

- Currently the US has 2 docking ports & 2 berthing ports
  - HTV, commercial cargo carriers (Space X, Orbital) will use berthing ports
  - A dedicated Assured Crew Return (ACR) vehicle will fill one docking port full-time
- If ACR is separate from crew transport vehicle, will require 2 ports at time of swap (old to new)
- Design should allow flexibility for relocating the vehicle to any number of docking ports



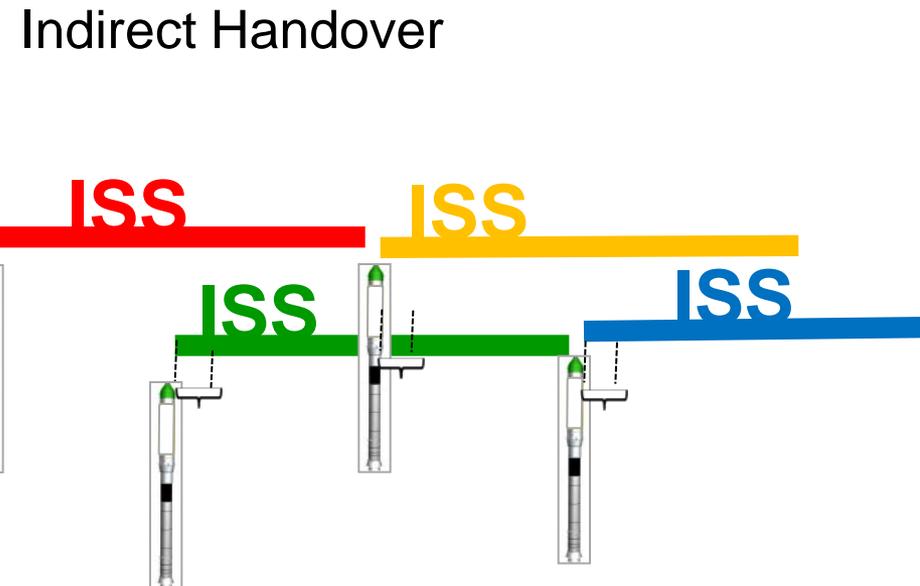
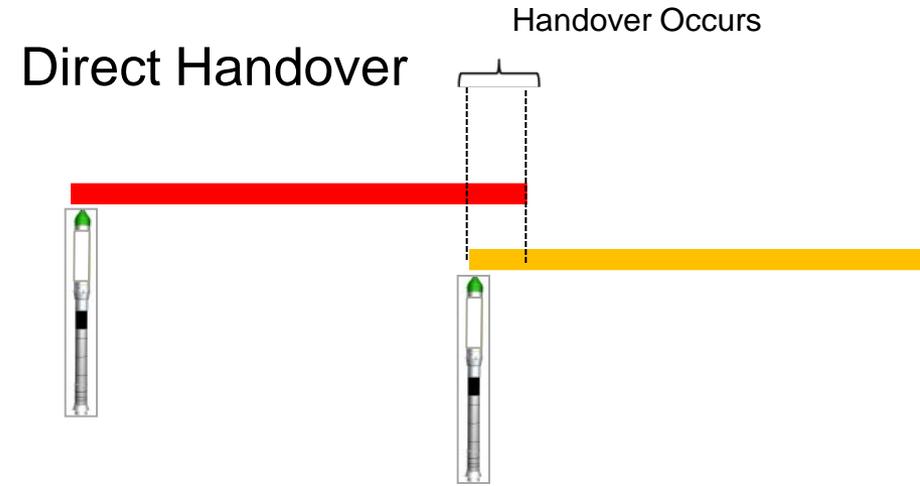


# Key Design Drivers – Direct Vs. Indirect Handover



## ◆ Direct vs. Indirect Handover

- Direct – required if all US crews are rotating on the same vehicle
  - Requires on orbit overlap time of on-coming and off-going ISS crews of 7-10 days
- Indirect – options are feasible, but must be designed to ensure continuous US presence on station
  - Fewer crew to change at any one point in time, but 2X more launches of crew transport vehicles required
  - Minimal on orbit overlap time <24 hr or no overlap required (Red to Yellow, Green to Blue)



- ◆ **Long duration ISS crews require time to exchange real-life (on-orbit) configurations and processes**

- Emergency hardware
- Current System Statuses
- Experiment and On-orbit Payload Statuses
- Vehicle performance issues



- ◆ **Typically involves dedicated face-to-face exchanges**

- Stowage configurations and pantries
- Trash handling/disposal and inventory procedures
- Current status of food and food handling procedures



- ◆ **Operational handover includes joint scheduled activities**

- Robotics
- EVA hardware processing
- Integrated O<sub>2</sub> and water processing



## ◆ Space Flight Resource Management (SFRM)

- Many examples in aviation accidents where poor crew resource management (CRM) was cause or contributor for loss of crew/aircraft
- Spaceflight involves time-critical decision making with potentially life threatening consequences
  - Crew cohesion, emergency training, survival and training methods , simulator training
  - Depending on nature of emergency, every crew member's action may have a significant impact
- Integrated simulations with MCC and crew
- The taxi scenario will require supplemental SFRM training with the non-ISS crew





# Training Challenges (cont.)



- ◆ **Taxi Model training for passengers does not alleviate significant time**
  - Soyuz Space Flight Participant (SFP) model is 6-12 months of technical training
    - FE2 370 & SFP 238 technical training hours vs. CDR/FE1 of ~880 hrs
    - Suit, life support, rescue survival, motion control emergency descent, comm
  - If ACR same vehicle as transport >80% generic systems or emergency de-orbit and entry training is already performed (minimizes additional ascent training)
    - Nominal descent training overlaps ACR emergency descent training
  - If ACR is separate vehicle, more training time will be required for descent in 2 vehicles



# Operational Assumptions – Governmental Collaboration



## ◆ Government Collaboration in the development process

- Expect FAA Office of Space Transportation & NASA to collaborate in determining rules & regulations for commercial licensing
  - Currently FAA covers Range Safety only
  - NPR 8705.2b Human Ratings
    - Graceful Degradation of Capabilities When Failures Occur
    - Fail Ops/Fail Safe should be standard
      - **Fail operational** - the vehicle can incur a single failure and still perform its mission
      - **Fail Safe** - the vehicle can incur a second failure and still safely return the crew
      - Single failure tolerance to loss of crew is a minimum in the design





# Operational Assumptions – Design, Development



## ◆ Encourage NASA representation at Commercial Developer's facility

- Value-added expertise
- NASA –developed vehicles have insight and oversight at significant cost
- Soyuz model, NASA accepted risks associated with the lack of insight and oversight because of vehicle flight history
- Commercial model, a balance between insight/oversight and flight test will be required
  - This represents a departure from the standard government acquisition strategy and will require very close monitoring to ensure success



## ◆ Crew collaboration in the design process (operability and habitability)

- Recommending “Combined Test Force” – integrates commercial crews with NASA crews to determine if vehicle is meeting requirements
  - Displays & Control development
  - Ability to perform In-flight tasks



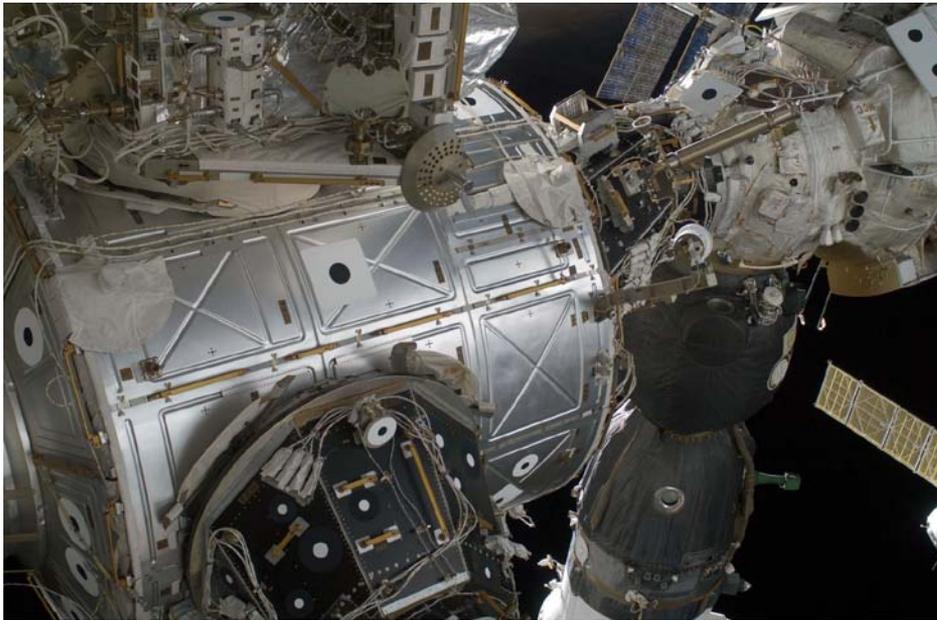
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## ◆ Training & Simulations

- Requirement – at least one vehicle simulator be located at JSC for astronaut proficiency
- Training at JSC would be more efficient since a large portion of ISS, EVA, & Robotic training and simulations will also be required in the ISS crew's training template
  - For initial test flights training may be at JSC or at the Commercial Provider Site



- ◆ Reduce dependency on foreign assets
- ◆ New ideas from new partners involved
- ◆ Rethink how we (NASA) apply requirements



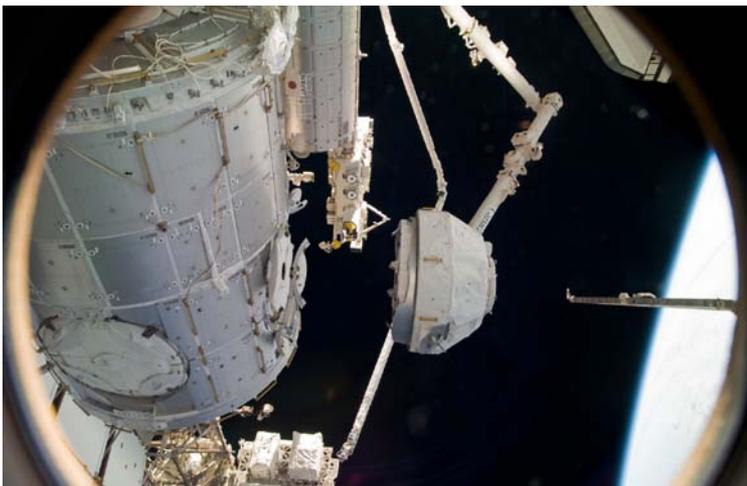


# Concerns – Many Areas Not Clearly Defined



- Commercial companies providing the only US crew transport to ISS–
  - Poses additional risk if company chooses to walk away if profitability vs. risk is no longer business-savvy or forces government to intervene
- Increased risk if separate Assured Crew Return (ACR) in addition to a Crew Transport Vehicle – requires both vehicles in order to have a functional system (increased complexity)
- Unknown risk management processes to assess safety of commercial transportation system or service
  - Commercial model, a balance between insight/oversight and flight test will be required
- ITAR and EAR regulations may interfere with Flight Rule development, Launch Commit Criteria, training materials, etc.
  - Non-Russia International Partner crewmembers make up our crew complement
- Training NASA and the commercial team for proximity operations will need to be defined

- ◆ There are many programmatic and safety-related uncertainties with relying solely on the commercial crew concept
- ◆ The foremost concern is a potentially extended period during which the US does not have indigenous access to low Earth orbit
- ◆ A strong NASA-Commercial relationship is needed for the expeditious transition to a commercially developed, human-rated launch system



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