Abstract

Lance Cole - **Commercial Crew Cost Estimating - A Look at Estimating Processes, Challenges and Lessons Learned**

To support annual PPBE budgets and NASA HQ requests for cost information for commercial crew transportation to the International Space Station (ISS), the NASA ISS ACES team developed system development and per flight cost estimates for the potential providers for each annual PPBE submit from 2009-2014. This paper describes the cost estimating processes used, challenges and lessons learned to develop estimates for this key NASA project that diverted from the traditional procurement approach and used a new way of doing business.

MISSION AND PROGRAM INTEGRATION (MAPI) CONTRACT

Commercial Crew Services Cost Estimating - A Look at Estimating Processes, Challenges and Lessons Learned

Cost Estimating

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Introduction

- This paper provides a high level overview of the National Aeronautics and Space Administration (NASA) commercial crew activities and processes in support of International Space Station (ISS) requirements. We will describe some of the cost estimating processes used, challenges and lessons learned to develop estimates for this key service that diverted from the traditional program approach.

- This paper will provide the following:
  - Background
  - Commercial Crew Services Overview
  - Selected Estimating Processes
    - Estimating Methodologies
    - Hardware Definition
    - Gathering Weight Information
    - Commercial Way of Doing Business Impacts
    - System Reusability
    - Operations
    - Development Cost Amortization
  - Summary

Background

- We are Booz Allen Hamilton contractors, currently on the Mission and Program Integration (MAPI) contract, who support the ISS Program Planning & Control Office's ACES (Assessments, Cost Estimating, and Schedules) group at Johnson Space Center (JSC) in Houston, Texas.
- Please note: These are <u>not</u> the Independent Government Estimates used by the Commercial Crew Program.
- In 2009 - present, we were tasked to estimate commercial crew services to support the yearly ISS PPBE (Planning, Programming, Budgeting and Execution) submissions.
- While our focus was and continues to be estimating the recurring mission costs to assure adequate funding levels for crew transportation to/from ISS, development cost estimates were also important to calculate potential provider amortization costs which might be applied to future mission recurring costs.
- Our yearly cost estimating updates incorporated new technical and programmatic information as it became available, as well as our understanding of the commercial way of doing business on this program.

Commercial Crew Services Overview

MISSION AND PROGRAM INTEGRATION (MAPI) CONTRACT

Purpose & Major Goals

- Background:
  - With the retirement of the Space Shuttle in 2011, the U.S. does not have transportation capability to send astronauts to/from the International Space Station (ISS) without the use of Russian vehicles.

- Purpose
  - The purpose of this program is to provide U.S. capability for this service.

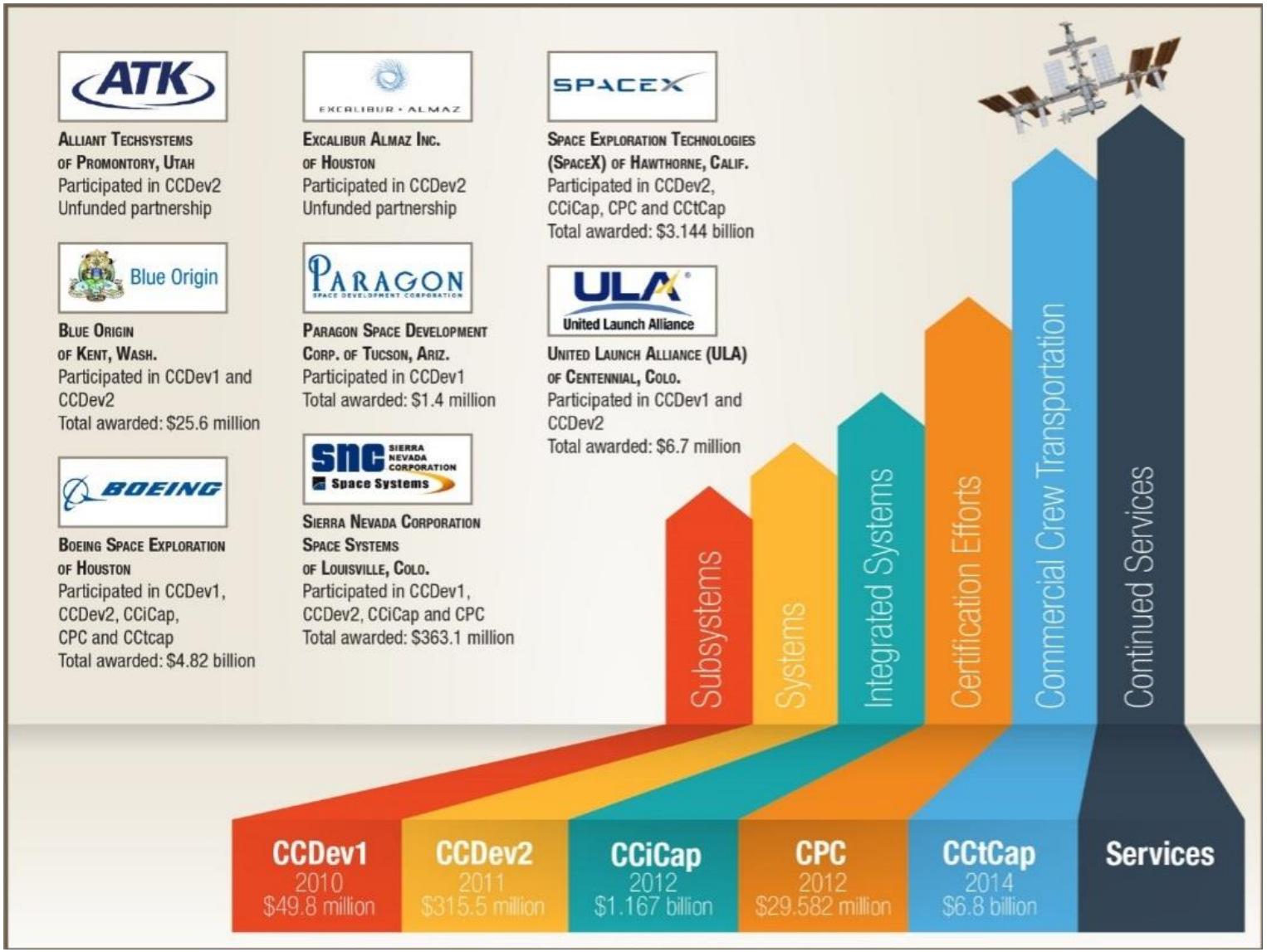
- Major Program Goals:
  - Facilitate U.S. private industry development of safe, reliable, and cost effective human space transportation to and from LEO and the International Space Station for use by the U.S.

  - Enable NASA to purchase commercial services to meet its ISS crew transportation needs; once the capability is mature and available.

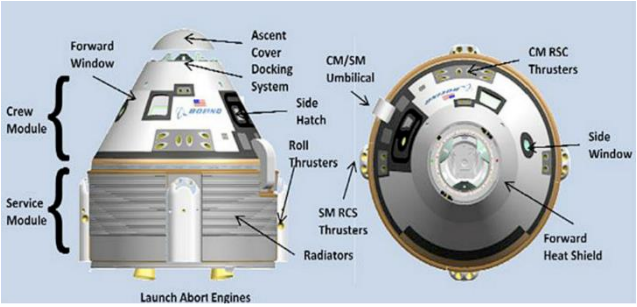
Commercial Crew Support to ISS

- Once commercial partners have achieved NASA certification, NASA will purchase services for station crew rotations to the industry providers
  - Transport four astronauts to expand station crew size
    - Doubling the amount of scientific research performed
    - Crew handover within one hour of landing
  - Powered scientific cargo
    - Live sample return within two hours of landing
  - 210 day duration on orbit
    - Station lifeboat capability
  - Ability to perform other low-Earth orbit missions

Commercial Crew Contract Evolution



Boeing



Artist concepts of Boeing's CST-100

Boeing's crew space transportation system is comprised of its reusable CST-100 spacecraft, the United Launch Alliance Atlas V launch vehicle, mission operations and ground systems.

Artist concept of integrated CST-100 and Atlas V rocket

CST-100 water contingency landing scenario testing

Launch abort engine hot-fire test in California

SpaceX

Dragon V2 at SpaceX headquarters

Dragon test article used for parachute testing

Astronaut fit-check in the Dragon

Falcon 9 first stage at SpaceX headquarters

SpaceX's crew transportation system is based on the Dragon spacecraft and Falcon 9 launch vehicle originally developed for International Space Station cargo missions.

Initially designed to carry cargo, the Dragon's components are being modified for added safety and crew accommodations.

Previous NASA Programs vs. Commercial Crew Services

Area	Previous NASA Programs	Assessment of Commercial Crew Services
Requirements	Numerous NASA requirements that included how to do the work. Scope and requirement creep.	Far fewer requirements. CWoDB focuses on crew safety and system performance. NASA open to use of alternate process standards. Testing requirements are still as robust as traditional programs.
NASA Involvement	NASA deeply involved in all aspects of system development, certification and operation. Frequent requirement changes typical in the traditional approach programs.	NASA will certify the system and is available for technical assistance. Interested companies are able to design, manufacture and operate the systems as they determine best to meet requirements and mission goals. To appropriately balance government insight, NASA utilizes access to contractor systems to reduce the number and magnitude of formal reports.

Previous NASA Programs vs. Commercial Crew Services (Continued)

Area	Previous NASA Programs	Assessment of Commercial Crew Services
System Ownership	NASA	Contractors
Contractor Investments	NASA typically pays all program costs.	Development costs shared between NASA and the contractors. Contractors may amortize unfunded development costs on their price for recurring missions.
Organizational / Overhead Approach	Management and overhead scaled to meet NASA requirements, NASA oversight, company practices and contract type. Prime contractors had numerous subcontractors.	Lower overhead costs due to the reduced # of requirements, lower management levels, NASA insight, organizational changes to address the competitive business environment, lean manufacturing, and fixed price contracts. Fewer subcontractors. Co-location and/or use of Engineering, Manufacturing, Management IPT's enables design for manufacturability and efficiency.

Previous NASA Programs vs. Commercial Crew Services (Continued)

Area	Previous NASA Programs	Assessment of Commercial Crew Services
Contract Types	Cost plus contracts requiring cost and pricing data.	Combination of Space Act Agreements and firm fixed price contracts for the various development phases and recurring mission funding. Cost and pricing data not required.
Funding	Not always stable.	Once awarded, funding has been stable to date.
Heritage	Low-level heritage hardware.	Maximize use of heritage hardware for defined requirements.

Selected Processes to Estimate Commercial Crew Services

MISSION AND PROGRAM INTEGRATION (MAPI) CONTRACT

Estimating Methodologies

- Our primary estimating methodologies were:
  - Parametric modeling for System development, build and test
    - NAFCOM parametric cost model
      - Note that NAFCOM is in the process of transitioning to the Project Cost Estimating Capability (PCEC); which utilizes similar information and capability.
    - PRICE-H parametric cost model and analogies for cross checks
  - Operations:
    - Bottoms up estimating utilizing subject matter experts
    - Analogies to historical programs

Hardware Definition

- The starting point for developing a cost model WBS for each design was to collect vehicle configuration and description information at the system and subsystem levels.

- System Level:
  - Launch Vehicle
  - Crew Transfer Vehicle
  - Other systems depending upon the provider

  - Without initial system level configuration information, we developed it through:
    - Internal resources
    - Historical systems
    - Internet sites

- Our initial assumptions for system level configurations have remained constant since our initial estimate.

Configuration Internet Sites
- Contractors Websites
- www.space.com
- www.ulalaunch.com
- www.spaceref.com
- www.spacedev.com
- www.nasaspaceflight.com

Hardware Definition (Continued)

- Subsystem Level:
  - Initially used the NAFCOM Crewed Vehicle WBS template; which includes subsystems
    - Tailored to each design:
      - Historical space missions
      - Subject matter experts
      - Added subsystems to NAFCOM using list of additional subsystems from a large list in model

- Major modifications to the NAFCOM WBS included:
  - Engines for the launch vehicles, crew transfer vehicles, and service modules (as appropriate).
  - Launch abort systems

- Definition at the component level has only recently been made available as the designs have matured.

NAFCOM Crewed Vehicle WBS

System/Subsystem

- **Stage 1**
  - Stage 1 Subsystems
    - Structures & Mechanisms
      - Vehicle Structures & Mechanisms
      - Tank Structures & Mechanisms
    - Thermal Control
      - Environment/Active Thermal Control
      - Induced Thermal Protection
      - Tank Thermal Control
    - Main Propulsion System (less engines)
    - Electrical Power and Distribution
    - Command, Control & Data Handling
  - Stage 1 System Integration
- **Stage 2**
  - Stage 2 Subsystems
    - Structures & Mechanisms
      - Vehicle Structures & Mechanisms
      - Tank Structures & Mechanisms
    - Thermal Control
      - Environment/ Active Thermal Control
      - Induced Thermal Protection
      - Tank Thermal Control
    - Reaction Control Subsystem
    - Main Propulsion System (less engines)
    - Electrical Power and Distribution Group
    - Command, Control & Data Handling
- **Crew Transfer Vehicle (CTV)**
  - CTV Subsystems
    - Structures & Mechanisms
    - Thermal Control
      - Environment/Active Thermal Control
      - Induced Thermal Protection
    - Main Propulsion System
    - Reaction Control Subsystem
    - Electrical Power and Distribution
    - Command, Control & Data Handling
    - Guidance, Navigation and Control
    - Environmental Control and Life Support
    - Crew Accommodations
    - Recovery and Auxiliary System
    - Landing System

Hardware Weight Information

- Obtaining weight information is key to developing NAFCOM and other parametric cost models. Our initial weight data sources included:
  - System Elements:
    - Internal information on similar spacecraft
    - Internet sites
  - Subsystem Elements:
    - Launch Vehicle
      - Atlas Launch System Mission Planner's Guide
      - Internet sites
      - Allocation of stage subsystem weights
        - Human Spaceflight – Mission Analysis and Design book by Wiley J. Larson and Linda K. Pranke
        - Engineering judgment
    - Other Systems (CTV, other):
      - Internal information from similar historical programs to assess subsystem weight allocation
      - Engineering judgment

Weight Info Internet Sites
- www.spaceflight101.com
- www.astronautix.com
- www.spacelaunchreport.com

Hardware Weight Information (Continued)

- As product development matured, system and subsystem level information including configuration, weight and mass growth allowances became available through various technical / design reviews.
- For one of the provider's CTV, we observed a reduction of 33% between the initial cost estimate and our most recent. Weight/cost mix changes by subsystem summarized below:

Subsystem	Weight Analysis		Cost Analysis	
	Initial %/Tot	Rec %/Tot	Initial %/Tot	Rec %/Tot
Structures and Mechanisms	22.0%	37.8%	3.8%	7.8%
Active Thermal Control	9.0%	3.4%	0.3%	0.2%
Attitude Control	2.0%	0.0%	31.6%	0.0%
Main Propulsion System	8.0%	3.9%	3.6%	2.4%
Reaction Control Subsystem	5.0%	17.7%	1.3%	3.4%
Electrical Power and Distribution	12.0%	3.7%	3.2%	7.1%
CC&DH	5.0%	6.9%	20.8%	38.1%
GNC	5.0%	3.4%	23.4%	24.7%
ECLS	8.0%	7.8%	8.7%	13.0%
Crew Accommodations	6.0%	8.9%	0.9%	1.7%
Recovery and Landing	18.0%	6.6%	2.5%	1.7%
Total	100.0%	100.0%	100.0%	100.0%

Commercial Way of Doing Business Impacts

- Commercial Crew Services utilizes different approaches from previous NASA human space programs.

- Initially, it was very uncertain what workscope areas would be affected by the commercial way of doing business (CWoDB) on Commercial Crew Services and the level of costs impacts in each area.

- User inputs for typical manned space applications in cost models such as NAFCOM and PRICE-H overstate cost estimates relative to CWoDB on Commercial Crew Services. CER's in those models were based upon traditional NASA and DOD space programs.

- While the impacts of the "commercial" approach remains a learning process, below is our current assessment of considerations to make in major input areas of NAFCOM to normalize for the CWoDB.

CWoDB Impacts on Parametric Modeling

- Subsystem Multi-Variable Inputs

Modeling Inputs	Input Description	CWoDB Attributes	Modeling Impacts
Manufacturing Methods	Level of advanced manufacturing techniques used.	Lean manufacturing, design for manufacturing through development/manufacturing IPT's.	Higher manufacturing capabilities.
New Design	The amount of new design expected for a subsystem is dependent upon the amount of inheritance received from previous projects.	Maximum use of heritage hardware, lower level of NASA oversight, lower number of requirements, requirement stability.	Lower percentages of new design.
Funding Availability	Anticipated funding availability.	Stable funding.	More certain than most traditional programs.

CWoDB Impacts on Parametric Modeling (Continued)

- Subsystem Multi-Variable Inputs (Continued)

Model Inputs	Input Description	CWoDB Attributes	Modeling Impacts
Test Approach	Amount of risk being accepted and indicated by the planned test program.	Qualification testing approach.	Similar to traditional programs.
Integration Complexity	Expected number of interfaces involving multiple contractors and/or centers.	Lower number of subcontractors.	Setting reflective of fewer subcontractors than traditional programs. Not applicable to both contractors.

CWoDB Impacts on Parametric Modeling (Continued)

- Systems Integration Inputs

Model Inputs	Input Description	CWoDB Attributes	Modeling Impacts
Integration, Test & Checkout	Labor and material required to physically integrate (assemble) the various subsystems into a total system. Includes final assembly, design and manufacture of installation hardware, final factory acceptance operations.	Lean manufacturing, testing similar to traditional programs.	Marginally lower factor than traditional.
Systems Test Operations	Development testing, including integration and testing of all qualification units. Also included is the design and fabrication of test fixtures.	Lean manufacturing, testing similar to traditional programs.	Marginally lower factor than traditional.

CWoDB Impacts on NAFCOM Modeling (Continued)

- Systems Integration Inputs (Continued)

Model Inputs	Input Description	CWoDB Attributes	Modeling Impacts
Systems Engineering & Integration	Systems engineering, logistics engineering and planning, monitoring, measuring, evaluating, and directing of the overall technical program.	Lower number of requirements, lower NASA oversight, requirement stability, use of heritage hardware.	Lower factor.
Program Management	Effort required for management direction to assure cost and schedule goals are met. Includes finance, contracts, scheduling, QA, documentation, and planning/control functions.	Lower level of management and overhead, competitive environment, lean manufacturing, lower NASA oversight.	Lower factor.

CWoDB Impacts on NAFCOM Modeling (Continued)

- Rates

Model Inputs	CWoDB Attributes	Modeling Impacts
Burden Rates	Lower level of management, competitive business environment, firm fixed price contract, lean manufacturing.	Lower burden rates.
Fee	Competitive business environment.	Inputs based upon assessment of competitiveness.
Direct Rates	Labor Rates.	Currently do not see CWoDB having an impact on direct rate assumptions.

CWoDB Impacts on NAFCOM Modeling (Continued)

- Other comments
  - While our Commercial Crew Services findings required modifying our typical manned space modeling inputs to account for CWoDB, potential impacts may be different for future contractors on future NASA “commercial” programs. The estimator will need to assess each input based upon best available information each specific project.

  - Based upon current knowledge, CWoDB input considerations for PCEC, the NAFCOM replacement, should be similar to NAFCOM.

System Reusability

- The reuse of major space craft components such as the Crew Transfer Vehicle and Launch Vehicle Stages can provide the opportunity to greatly reduce costs rather than building expendable units for each mission. We considered the following in cost estimating the impacts of the hardware reuse:
    - Which providers and which of their subsystems are assumed to incorporate reusability?
    - After how many flights using refurbished units will a new unit be required?
    - What percentage of a new unit will it cost to refurbish and test one that was previously flown?
        - Our current assumption is that the major areas of a Crew Transfer vehicle that will require refurbishment are: heat shields, parachutes, and landing systems.
    - A consideration for the last question depends upon the environment in which the unit landed. For example, a unit that lands in the water will cost considerably more to refurbish than one that lands on land.
    - Until more information becomes available, we are using SME judgment on the above calculations.

System Reusability (Continued)

- The hypothetical information below illustrates the cost sensitivity of five hardware reusability/refurbishment scenarios:

New System Assumption	% Refurbishment $ Of A New Unit	Saving vs. Expendable	Likely Profile
Every 4th Unit	70%	22%	High refurbishment $, moderate new unit replacement requirement
Every 12th Unit	70%	28%	High refurbishment $, low new unit replacement requirement
Every 4th Unit	25%	55%	Moderate refurbishment $, moderate new unit replacement requirement
Every 12th Unit	25%	70%	Moderate refurbishment $, low new unit replacement requirement

Operations

- Operations covers support before, during and post mission, and the development effort required for this support. Because this is a full services contract, these costs are an element of mission pricing.
  - Examples of workscope includes:
    - Space suits
    - Crew training
    - Launch site operations
    - Mission operations
    - Sustaining engineering
    - Return operations
    - Mockups and miscellaneous hardware
  - Estimating methods:
    - Bottoms up using information from subject matter experts
    - Analogies to current and historical programs

Development Cost Amortization

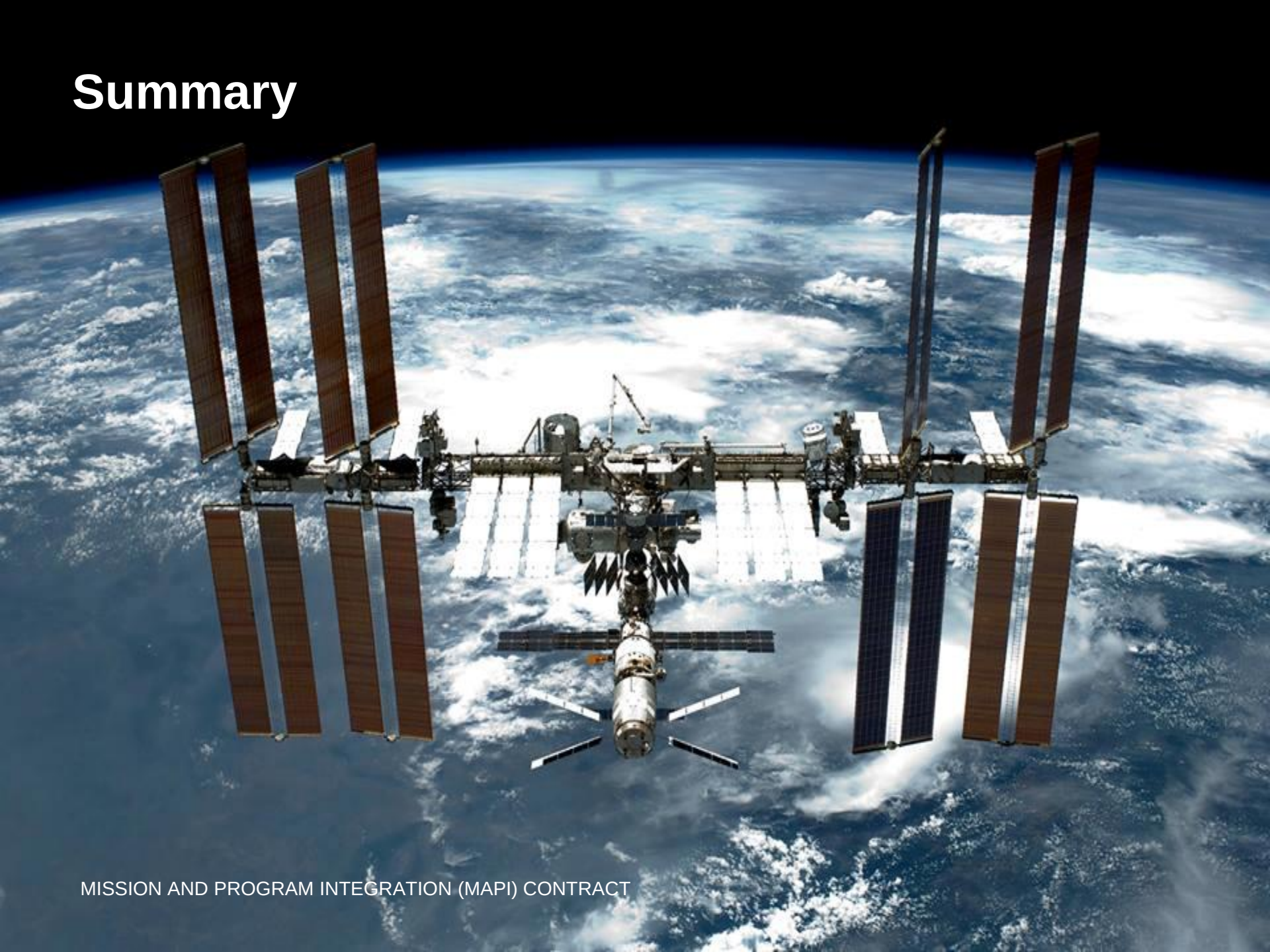
- An aspect of the Commercial Crew Services different than traditional government programs is the cost sharing of development costs between NASA and the contractors. Because we expected that at least part of the unfunded amount would be added to the mission prices, we assessed the amortization impacts to be included in our recurring cost estimates. Our assessments considered the following:
  - Estimated development costs for each design.
  - How much did NASA fund the contractor over the various development phases of the program?
  - Calculating the potential development costs funded by each contractor by subtracting the NASA funding from the contractor development costs.
  - How much of that amount is assumed to be covered by other customers or company IR&D (independent research and development)?
  - The remaining amount would be the costs to be considered to be amortized on top of the estimated recurring mission costs.
  - Of those assumed amortization costs, how might those costs be spread across the identified missions? Evenly across all missions or front loaded (higher percentage on the initial missions)?

Development Cost Amortization (Continued)

- Using very hypothetical costs and the assumption of six missions, below is an example of amortization calculation:

  - Contractor Development: $100,000
  - NASA Funding: $50,000
  - Contractor Funded: $50,000
  - Covered by Other Customers or company IR&D: $20,000
  - Amount to Amortized to the Commercial Crew Services contract: $30,000
  - Potential Amortization to Mission Pricing:
    - Scenario A – amortize equally over all six missions: $5,000 per mission
    - Scenario B – amortize over the first three missions: $10,000 per mission

Summary



Summary

- Key takeaway points:
  - Major areas of differences between Commercial Crew Services and previous manned space programs:
    - Requirements
    - NASA involvement
    - Crew Transportation System ownership
    - Company investments
    - Organization/overhead approach to be competitive
    - Contract Type
    - Use of heritage hardware

Summary (Continued)

- Key takeaway points (continued):

  - Hardware definition/weights:
    - Accuracy of both are important to develop a more accurate cost estimate; especially when using weight based parametric cost models such as NAFCOM.
    - In the absence of data, internet sites can be leveraged for space system configuration and weight information; however, this data should be used only as a starting point.

  - Hardware Reusability/Development Cost Amortization:
    - Both were key each areas on Commercial Crew Services.
    - Calculating the cost impact of reusability, where applicable, and developing cost amortization led to the development of a more realistic mission pricing.

Summary (Continued)

- Key takeaway points (continued):
  - CWoDB Impacts:
    - User inputs for typical manned space applications in cost models such as NAFCOM and PRICE-H overstates cost estimates. CER's in those models were based upon traditional NASA and DOD space programs.
    - CWoDB for Commercial Crew Services means lean management, NASA insight (versus oversight), fewer requirements, lean manufacturing, maximum use of heritage, etc.

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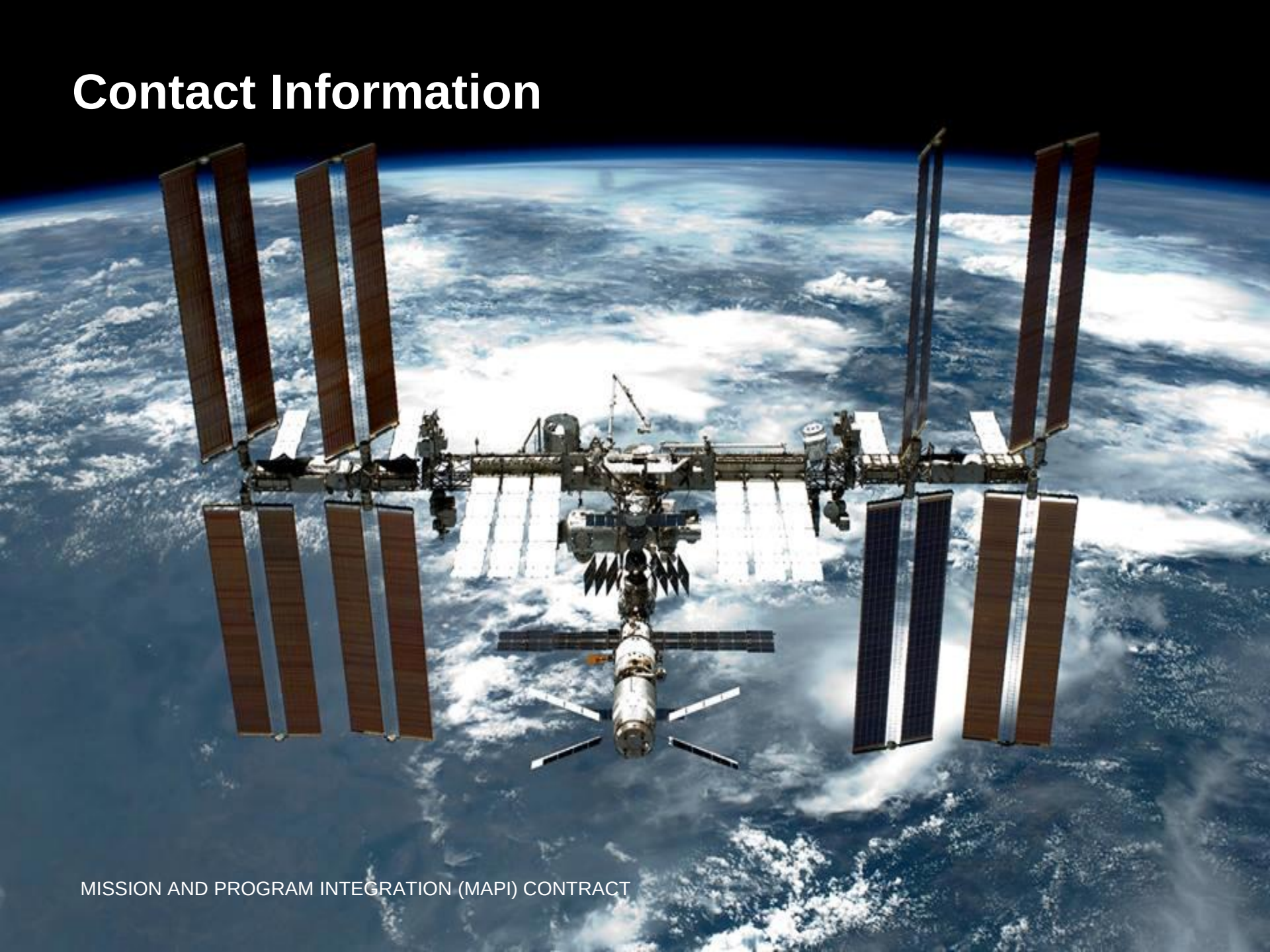

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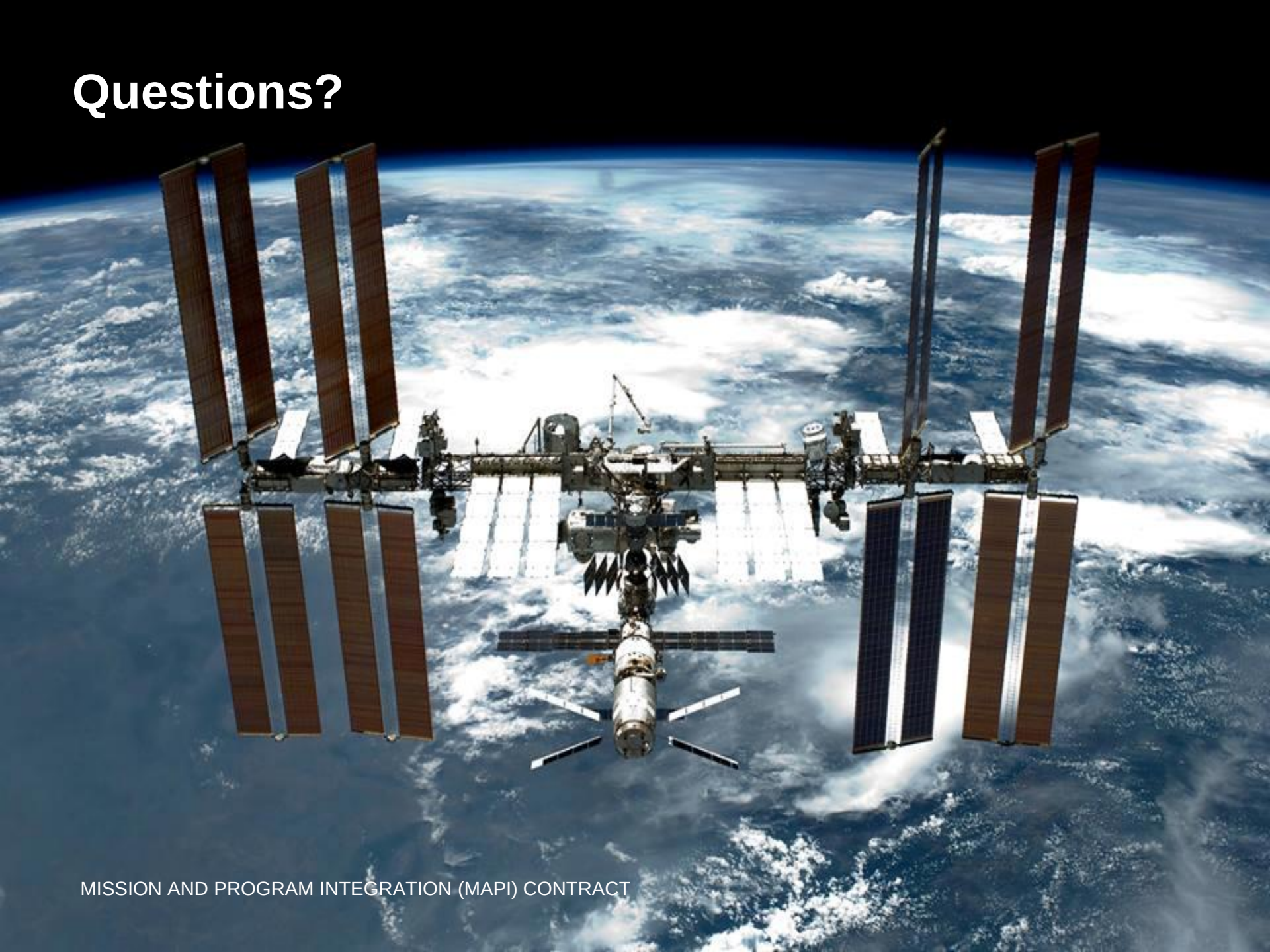
Questions?