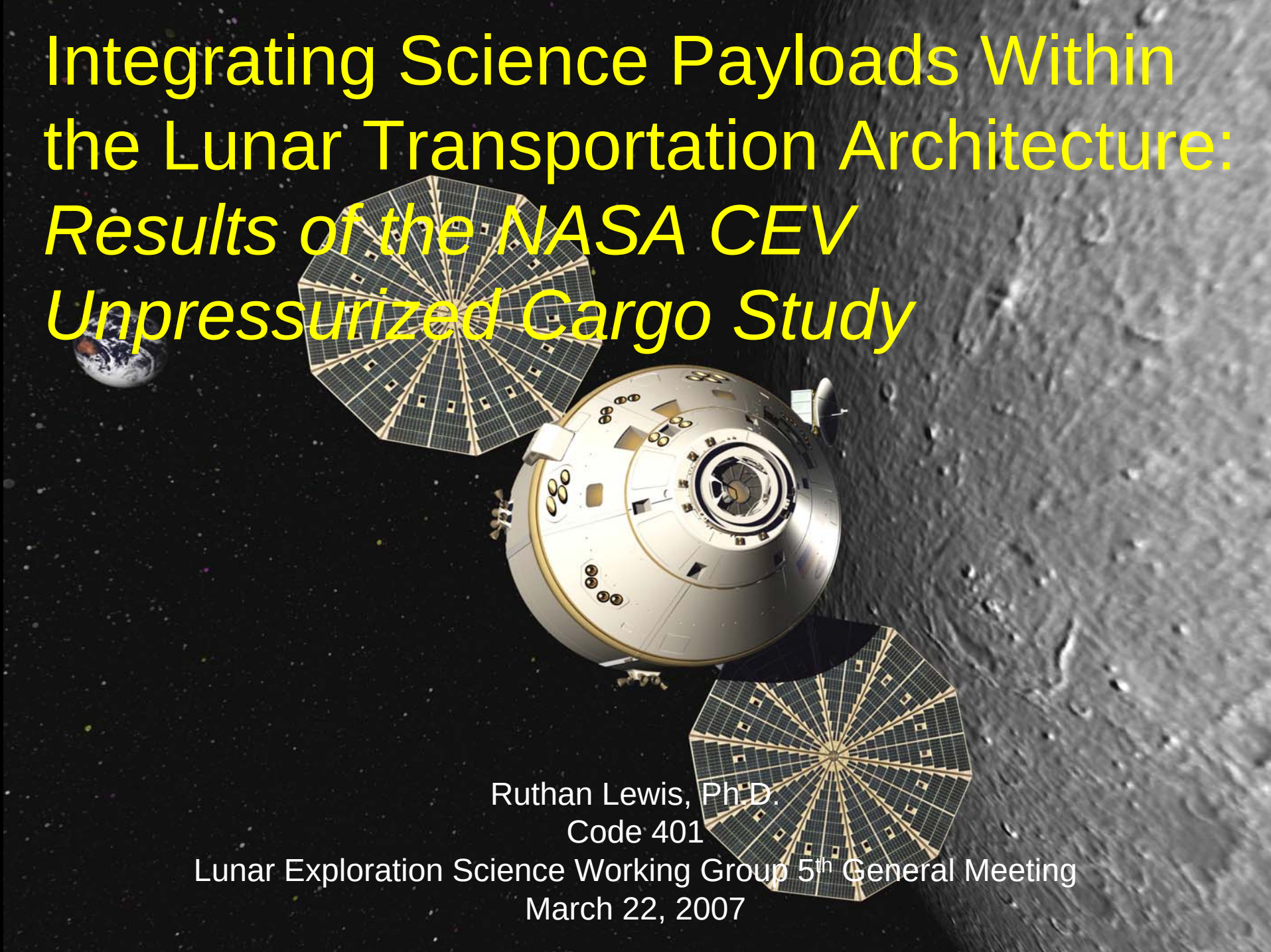
Integrating Science Payloads Within the Lunar Transportation Architecture: *Results of the NASA CEV Unpressurized Cargo Study*



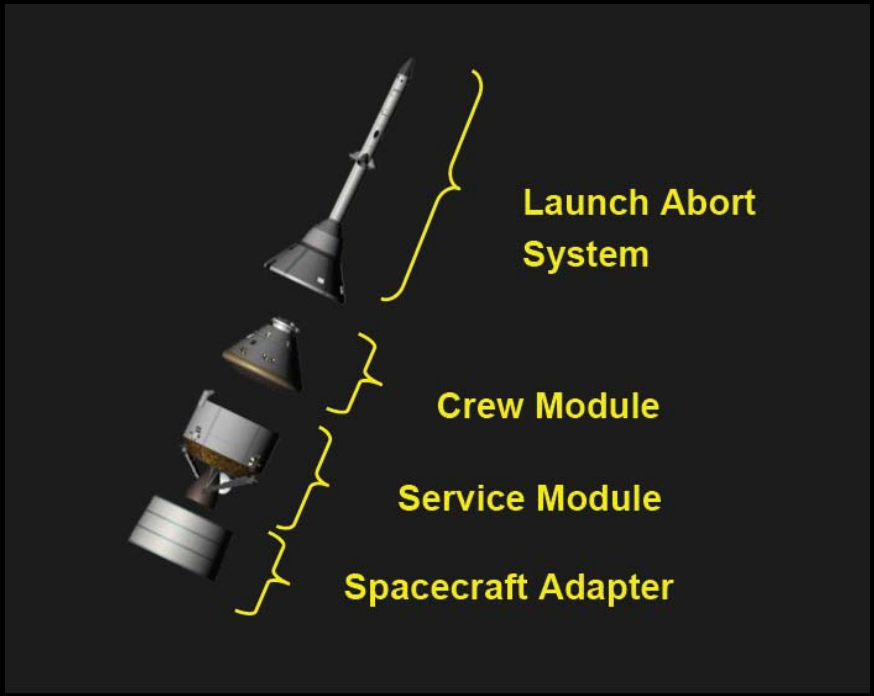
Ruthan Lewis, Ph.D.
Code 401

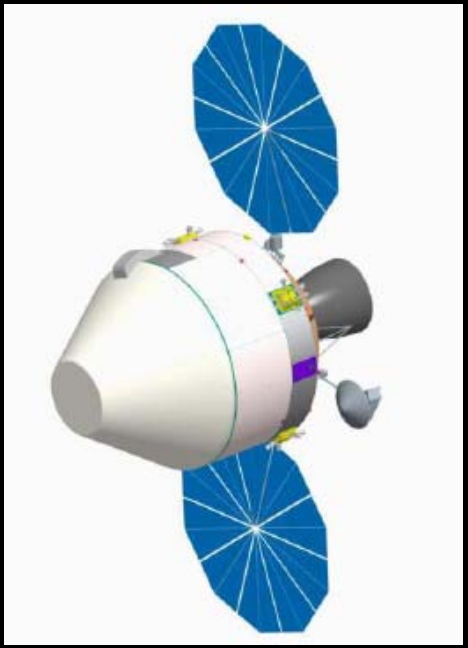
Lunar Exploration Science Working Group 5th General Meeting

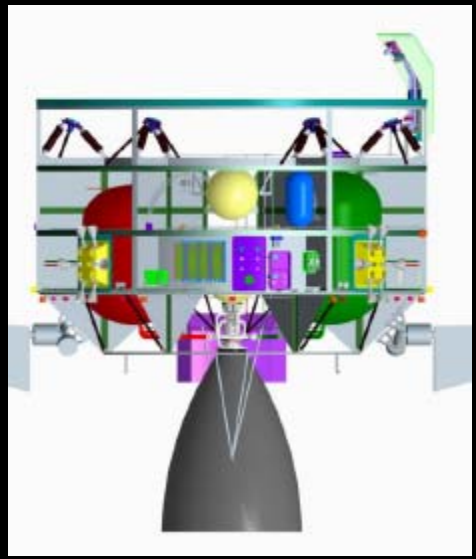
March 22, 2007

CEV Unpressurized Cargo Study

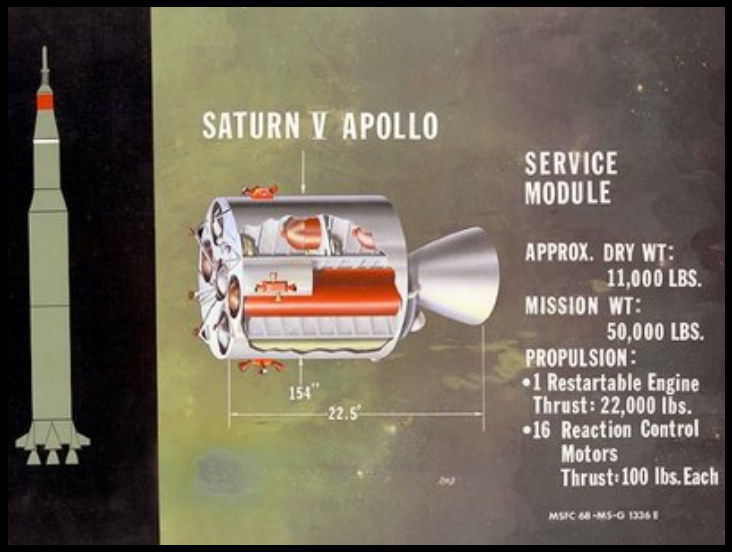
- Challenge: Bring unpressurized payloads to the International Space Station (ISS), cis-lunar, low lunar orbits, and beyond
- Action: Examine feasibility and capability of CEV Service Module to accommodate payloads
  - Take advantage of excess CEV “delta-v” capacity on ISS mission
  - Meet ISS cargo need
  - Possibly facilitate Low Impact Docking System (LIDS) use (adapter as cargo)
- Study Timeframe: October and November of 2006
- Deliverable: Present to the Crew Exploration Vehicle (CEV) Systems Requirements Review (SRR) Board
  - Proposed Level II Requirements
  - Operations Concept
  - Cost and Risk Assessment
- Why Now?
  - Make the case while requirements are being defined and vehicle scarring can be planned

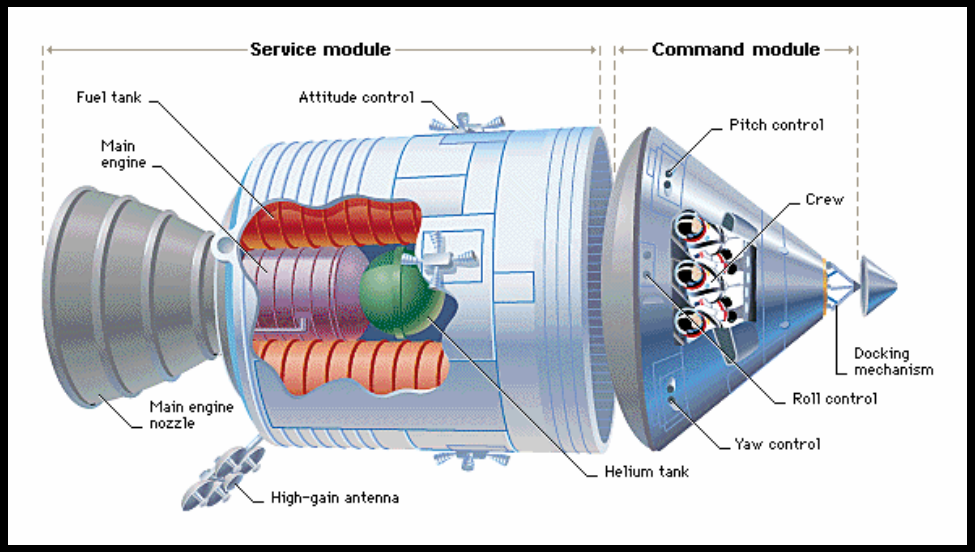

Launch Abort System
Crew Module
Service Module
Spacecraft Adapter

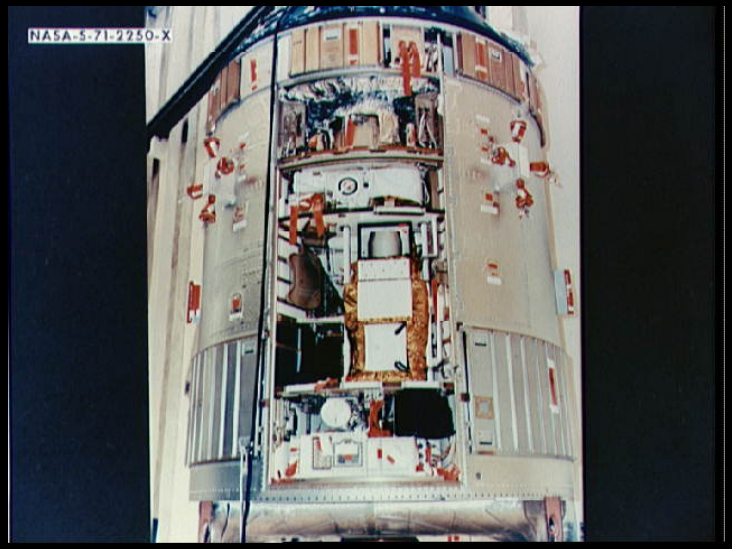


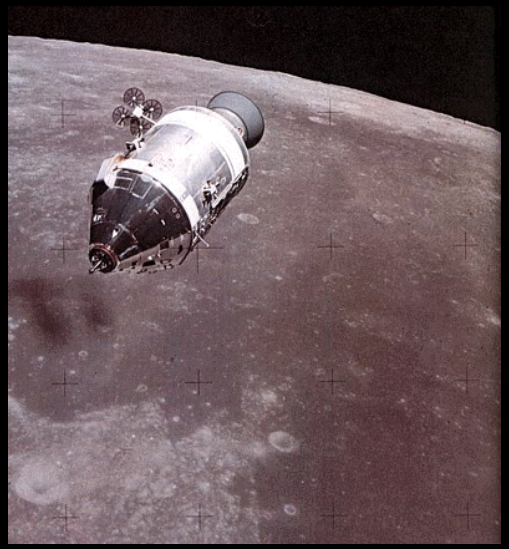


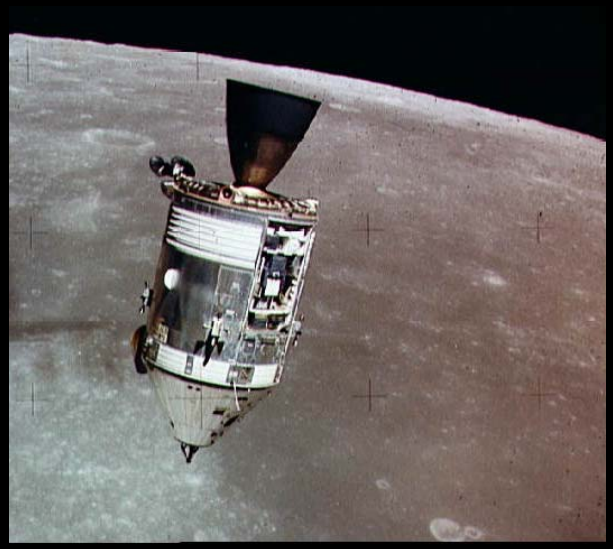
Precedence: Apollo



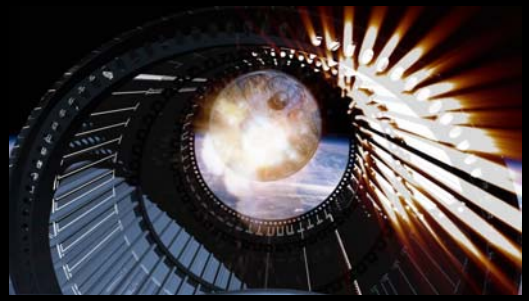


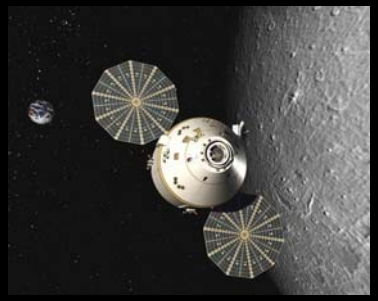


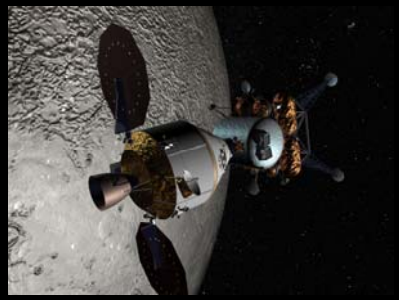




Precedence:
GSFC's Hitchhiker, Space Experiment Module, Get Away Special, and Spartan

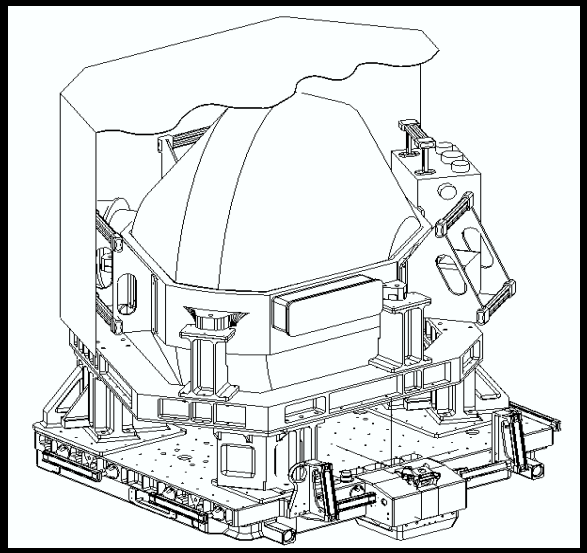






Boundary Point: ISS Control Moment Gyroscope

- CMG used as reference size for carrier capacity
  - Mass = 270.86 kg (~600 lbs)
  - Volume = 1.82 m^3
  - Dimensions (without interface hardware): *52.0 in X 47 in X 45.5 in*



Goddard's Role in the Study

- User case
  - Identify and collate potential payloads that may utilize CEV Service Module provisions to Low Earth Orbit, ISS Orbit and Exchange, Translunar Orbit, Lunar Orbit and beyond, including deployment
  - Poll payload developers, payload organizations, ISS, science, technology points of contacts
- Payload configuration options

Datapoints

- Payload Name
- Payload Objectives
- Payload Developer / Organization / Point of Contact
- Customer (e.g. NASA, Other Agency, DoD, Commercial, Institutional)
- Payload Type (e.g. Science, Technology, Engineering, Education)
- Current Technical Readiness Level (TRL)
- Flight Repetition (e.g. Pathfinder, Iterative, ISS Repair/Replacement)
- Mass (kg)
- Average Power (W)
- Peak Power (W)
- Length (m)
- Width (m)
- Height (m)
- Volume (m3)
- Heat Load (W)
- Data (Kbps)
- Data (Mbps)
- Viewing (N/A, Space, Earth, Moon)
- Pointing (deg)
- Jitter
- Stability
- Gravity Load Dependent (Y/N?)
- IVA Crew Time (Hrs)
- EVA Crew Time (Hrs)
- Return to Earth?
- Crew Systems
- Robotic Systems
- Structure
- Power
- Thermal
- Communications and Data Handling

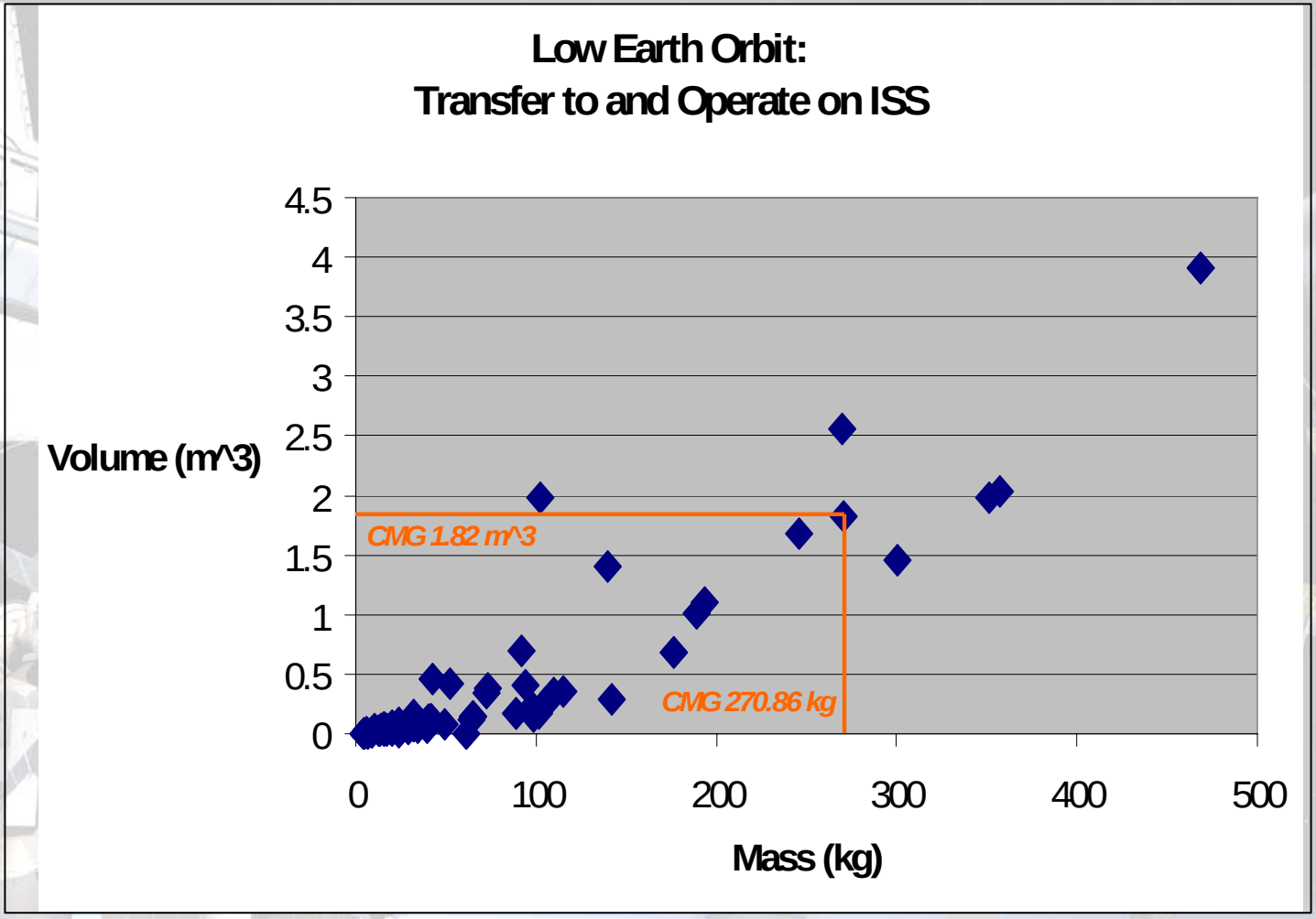
ISS Orbital Replacement Units

- 69 ORU types reported
- 88 ORUs to be exchanged or pre-positioned
- 91.43% of ISS ORUs can be accommodated

Ammonia Refill Bottle (ARB)
Arm Computer Unit (ACU)
Battery Charge Discharge Unit (BCDU)
Bearing, Motor, Roll Ring Module (BMRRM)
Camera Light Assembly (CLA)
Camera, Light, Pan/Tilt Assembly (CLPA)
Canadian Remote Power Control Module (CRPCM)
Canadian Remote Power Control Module (CRPCM)
Cargo Transport Container (CTC)
DDCU Cold Plate Assembly, (DDCU-CP)
DDCU External (DDCU-E)
Direct Current Switching Unit (DCSU)
Double Gimbal Control Moment Gyro (CMG)
Drive Lock Assembly (SARJ)
Drive Lock Assembly (TRRJ)
Electrical Assembly, CMG
Electrical Joint One Degree Pitch/Roll (EJOD P/R)
Electrical Joint One Degree Yaw (EJOD Y)
Electronic Control Unit (ECU)
Electronic Platform #1 (EP1)
Electronic Platform #2 (EP2)
Enhanced ORU Temperary Platform (EOTP)
ExternalVideo Switch Unit (EVSU)

Flex Hose Rotary Coupler Assembly (FHRC)
Heat Exchanger Assy, 4 kW Low Load
Heat Exchanger, High Load, 0-25 kW (HX)
High Pressure N_2 Tank (HPN)
High Pressure O_2 Tank (HPO)
Interface, Umbilical Assembly, MT/TUS
Linear Drive Unit (LDU)
Load Transfer Unit (LTU)
Main Bus Switching Unit (MBSU)
MBSU Cold Plate Assembly, (MBSU-CP)
MT/ Trailing Umbilical System Reel Assy (MT/TUS RA)
Nitrogen Refill Bottle (NRB)
Nitrogen Tank Assy (NTA)
ORU/Tools Changeout Mechanism (OTCM)
Pane Assembly, Debris (LAB)
PDGF, ORU Assembly, MBS (PDGF)
Plasma Contactor Unit Assy (PCU)
POA Latching End Effector (POA LEE)
Pump and Flow Control Subassembly (PFCS)
Pump Module Assembly (PM)
Radiator Assy-ORU, MDM Nadir
Radiator Beam Valve Module (RBVM)
Rate Gyro, Enclosure Assembly (RGEA)

Rotary Joint Motor Controller- TRRJ (RJMC-TRRJ)
Rotary Joint Motor Controller-SARJ (RJMC-SARJ)
RPC Module Type II (RPCM)
RPC Module Type III (RPCM)
RPC Module Type IV (RPCM)
RPC Module Type V (RPCM)
RPC Module Type VI (RPCM)
Sequential Shunt Unit (SSU)
Space-to-Ground Transmitter / Receiver/Controller (SGTRC)
SPDM Arm ASSY(SPDM-ARM)
SPDM Latching End Effector (SPDM LEE)
SSRMS Latching End Effector (SSRMS LEE)
Support Assy -S-Band Antenna (SASA)
TDRSS Transponder (XPDR)
Umbilical Mechanism Assembly MT (UMA)
Utility Rail Assembly- 2 Module External
Utility Rail Assembly- 6 Module, Split External
Utility Rail Assembly- 8 Module External
Utility Rail Assembly- 8 Module, Split External
Utility Rail Assy - 6 Module, Bus Input, External
Utility Transfer Assembly (UTA)
Video Distribution Unit (VDU)



- 94 payloads listed (includes ORUs and other engineering and science payloads)
- 93% of payloads reported mass and volume

Lunar Orbiting Payloads

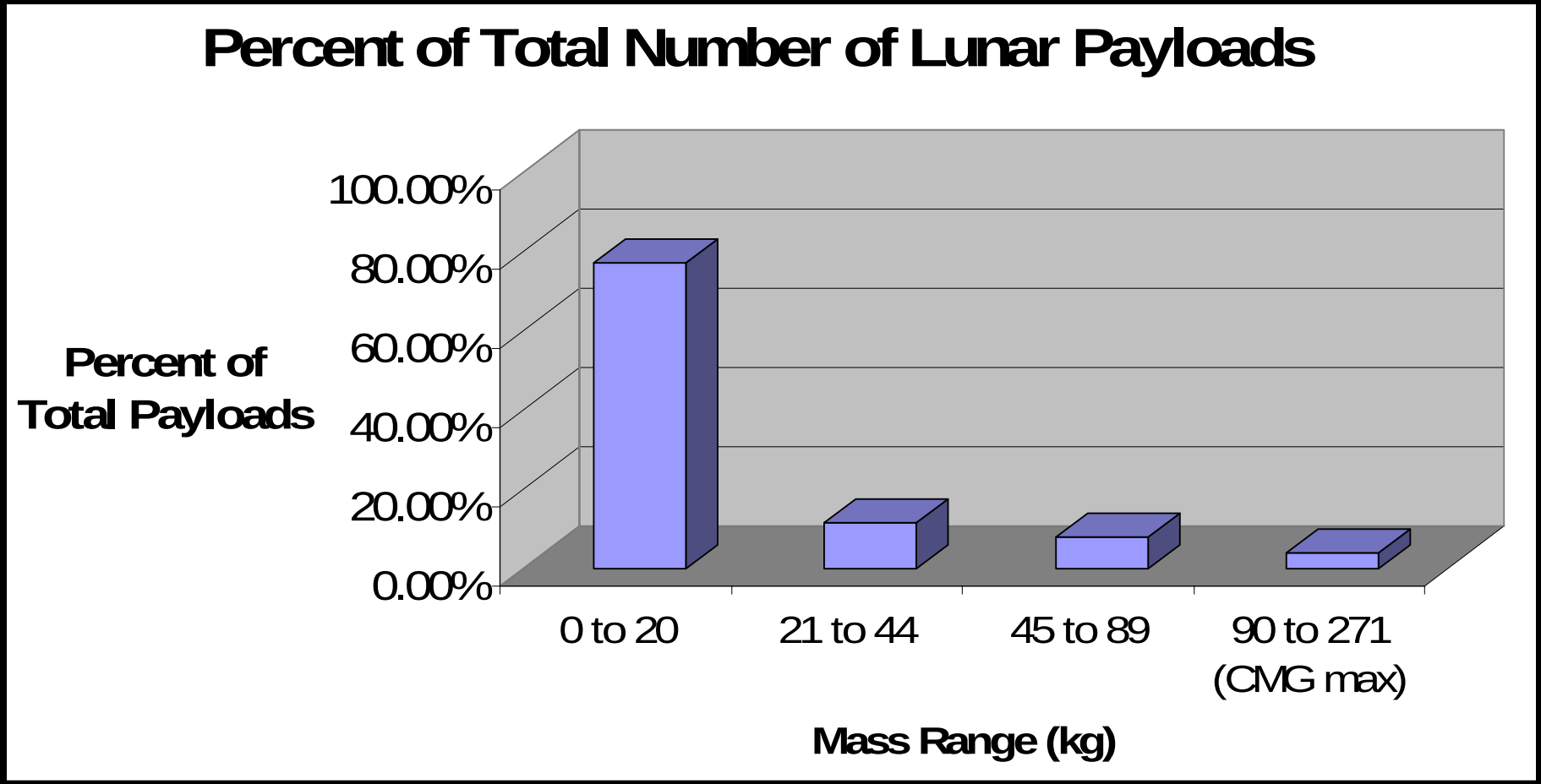
- Composed of a vast array of attached and ejected payloads for Constellation engineering development and science
- 43 payloads listed
- 51% of payloads reported mass
- 100% of currently listed payloads can be accommodated (considering mass only)

Terrain Mapping Camera (TMC)
Hyper Spectral Imager (HySI)
Lunar Laser Ranging Instrument (LLRI)
High Energy Gamma/X-ray Spectrometer (HEX)
Moon Mineralogy Mapper (M3)
Miniature Synthetic Aperture Radar (Mini-SAR)
Asteroid-Moon Micro-Imager Experiment (AMIE)
SMART-1 Infrared Spectrometer (SIR)
Compact Imaging X-ray Spectrometer (D-CIXS)
Clementine UV/Visible Camera
Clementine Near IR Camera
Clementine Long Wave IR Camera
Clementine Laser Image Detection and Ranging (LIDAR)
Clementine Charged Particle Telescope
Compact Reconnaissance Imaging Spectrometer for Mars (CRISM)
SELENE Terrain Camera
SELENE X-ray Fluorescence Spectrometer (XRS)
SELENE Spectral Profiler (SP)
SELENE Laser Altimeter
SELENE Lunar Radar Sounder
SELENE Alpha Particle Spectrometer
SELENE VRAD or Relay Subsatellites

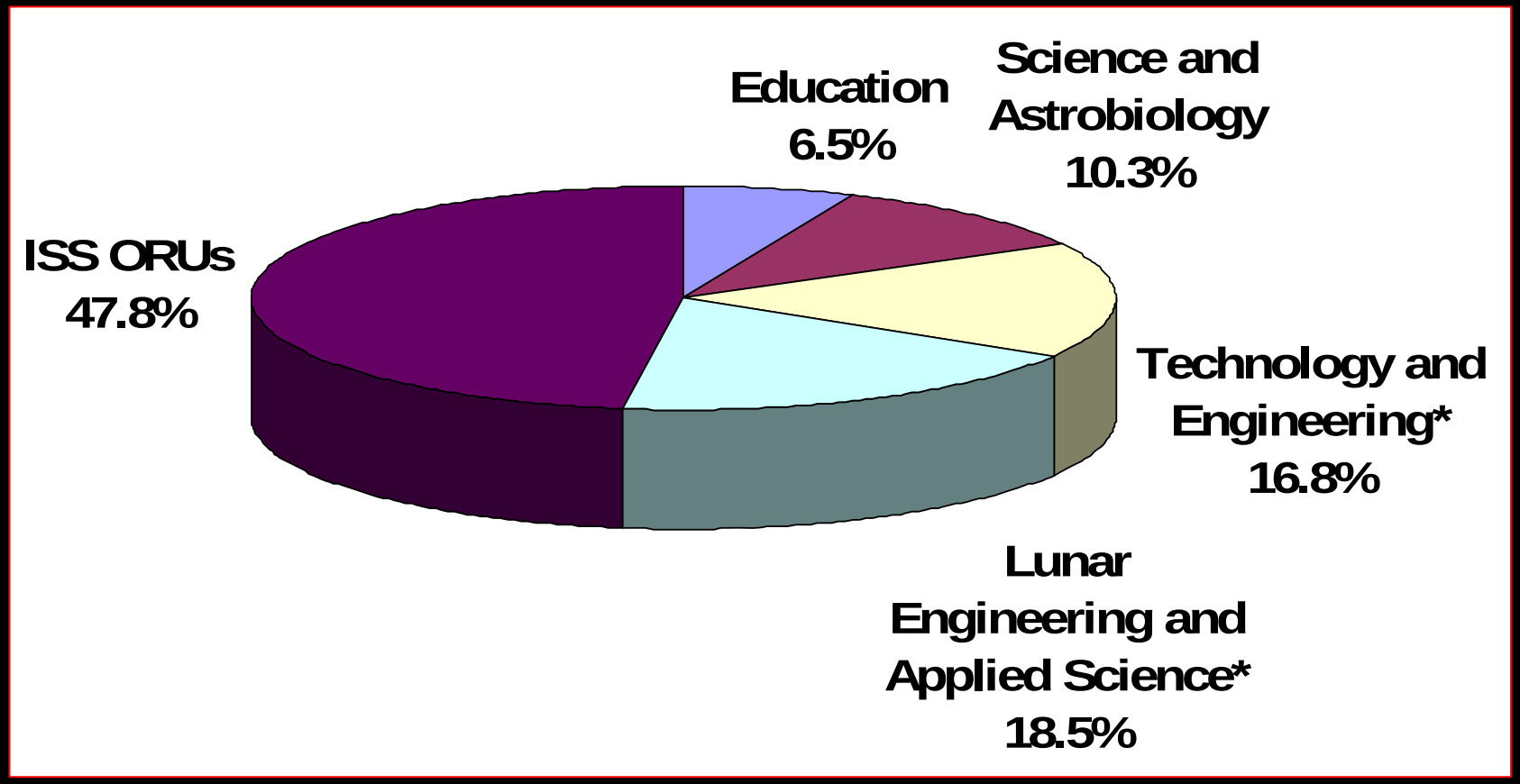
Micro- and/or Sub-Satellites (2)
Cosmic Ray Dosimeter
Astrobiology Measurements
Walking inspector
X-Ray Pulsar Navigation System
Advanced Optical Communication (Laser)
Materials Exposure
Large Area Deployment – Collector (LAD-C)
Plasma & Particle Environment Sensors
Autonomous Inspection and Maintenance Satellites
ISS AgCAM and HICO payloads and follow-on experiments
Multi-spectral system technologies
Cosmic Ray Detector
Lunar CEV warning event detector
Lunar Imaging Lidar for Terrain (LILT)
Lunar Hazards Mapping Camera (LHMC)
Lunar Penetrator
Ames SmallSat Communication Relay Orbiter
Low-Power Intelligent Reconfigurable Processing
Lunar Imaging Lidar for Terrain (LILT)
Transponder equipment (for NEOs) (1)

Lunar Surface and Return

- Modular-Extensible Power and Data-Telemetry System for Lunar Instruments
- Low-Power Intelligent Reconfigurable Processing
- High-Resolution Next Generation Solar Coronagraph (NGC)
- Janus
- Long duration exterior payloads (ORUs)
- Sample return (from Moon and Near Earth Objects)
- Cosmic Ray Dosimeter
- Astrobiology Measurements
- X-Ray Pulsar Navigation System
- Advanced Optical Communication (Laser)
- Materials Exposure
- Large Area Deployment – Collector (LAD-C)
- Plasma & Particle Environment Sensors
- Robonaut
- Autonomous Inspection and Maintenance Satellites
- Electromagnetic Propulsion Testing
- Cosmic Ray Detector
- Cosmic Event Early Warning Detectors/Imagers
- Lunar Surface Telescopes
- Equipment deployment technologies
- Construction techniques

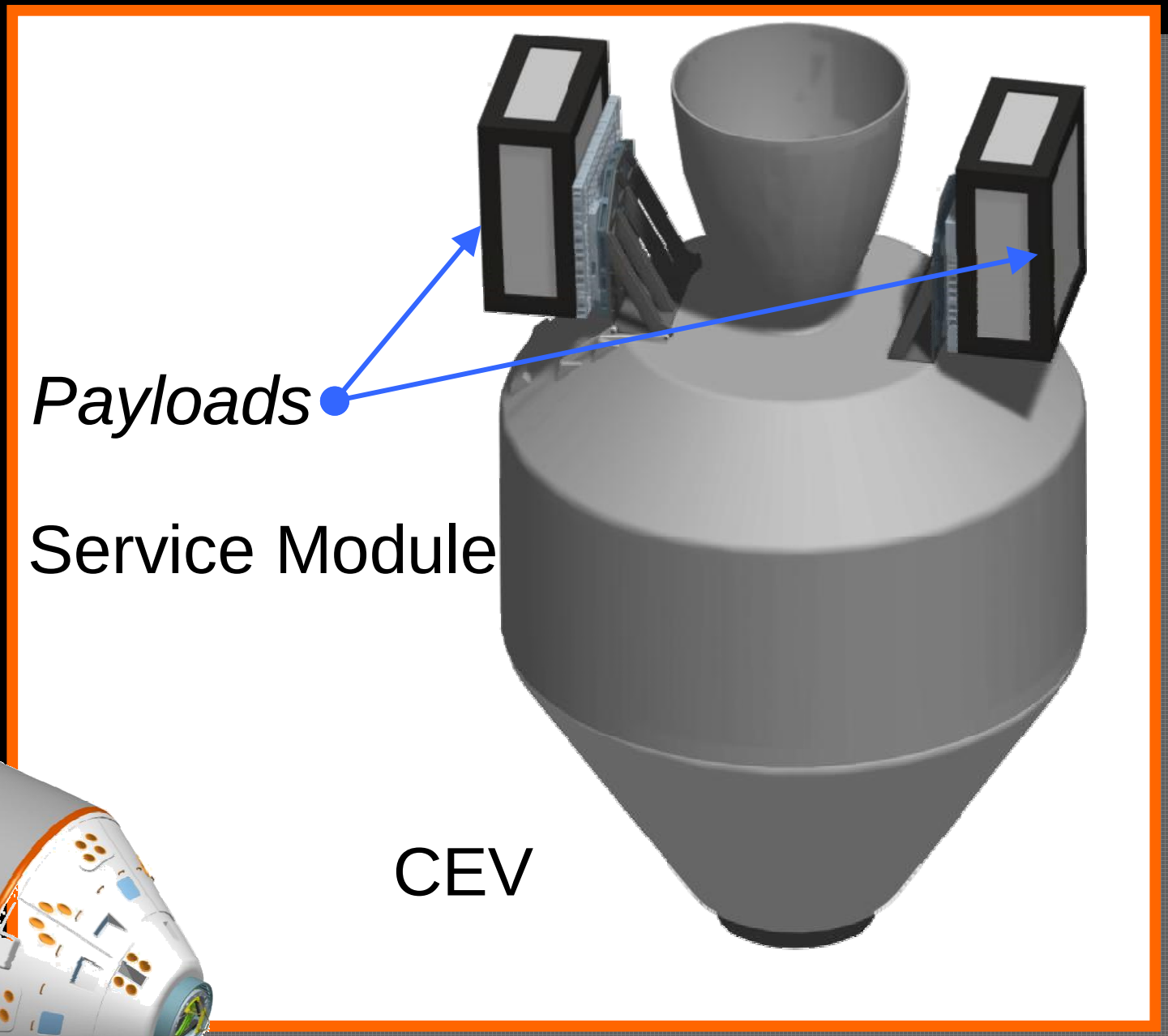

Percent of Total Number of Lunar Payloads
Percent of Total Payloads
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
0 to 20
21 to 44
45 to 89
90 to 271 (CMG max)
Mass Range (kg)

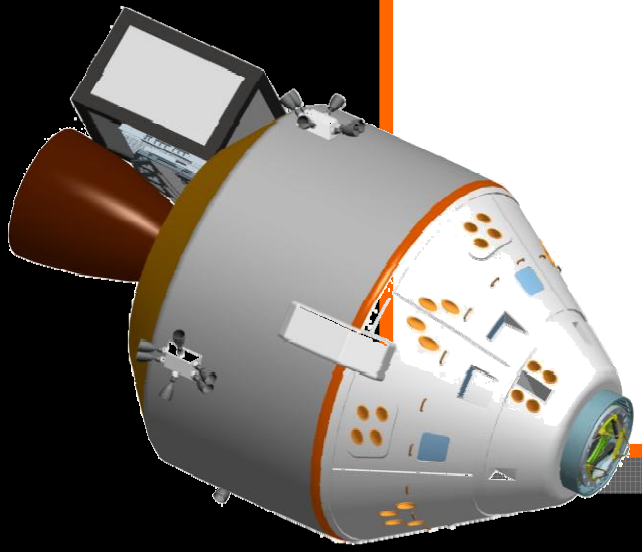
User Demographics



GSFC Approach to Concepts, Cost, Risk

- Worked with NASA Glenn Research Center to establish existing CEV/SM capabilities & available interfaces (e.g., mass, power, volume, data, etc.)
- Conducted accelerated concept design studies via Integrated Mission Design Center - focused on first order trends only
- Selected bounding cases for evaluation based on GSFC use case analysis
- Applied knowledge gained during study to guide:
  - Interface evaluation
  - functional flow
  - operations concepts
  - requirements development
  - cost


Payloads
Service Module
CEV



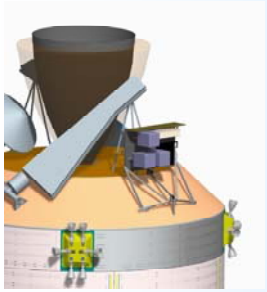
Preliminary Results for External Carrier Cases Evaluated (12 Nov 06)

Case No.	Payload/ Mission Type	Payload Mass [1]	Payload Power [2] (W Avg)	Payload Volume [3] (m^3)	# Pay-loads	Ejectable Payloads [4]	# Axes Articu-lation	Releasable Carrier [5]	Total Mass (kg) [6]	Total Power Req'd [7] (W Avg)	Total Volume Req'd [8] (m^3)
	Exploratory Trade Study Cases for External Carriage (Mass & Power Shown Exclude Contingency) - Payload Mass: Cases 1a & 1b bounded by CMG mass, Case 2a bounded by modest use case - Payload Power: Case 1a uses 100% duty cycle on CEV downlink (+400W), Case 2b used 50% (+200W) - Articulation/Ejection/# Payloads: Selection was somewhat arbitrary & for instructional purposes -- Deleting/reducing these options typically will reduce total mass & volume - Case 1b Total Volume: To stay within 3.6 m^3, payload volume must drop; articulation h/w requires 0.4 m^3 - Payload Densities assumed may be disproportionately high; should an analysis is follow on analysis								**Preliminary Results (Includes Contingency on Mass/ Power)**		
1a	Science/ Engr at ISS	460	400	1.4 (~50 cu ft)	1						
1b	Science/ Engr at ISS	460	400	~2.2 (78 cu ft)	10						
2a	Science/ Engr at LLO	20	50	0.054 (1.9 cu ft)	3						
2b	Science/ Engr at LLO	60	120	0.097 (3.4 cu ft)	3						
3	Cargo/ CMG to ISS	600[11]	100[12]	3.3	1						

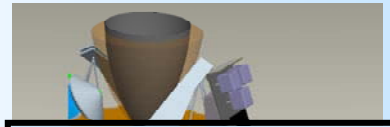
GSFC Unpressurized Carrier Study ISS Cases 1a & 1b

Configuration 1a

GSFC Unpressurized Carrier Study Lunar Cases 2a & 2b

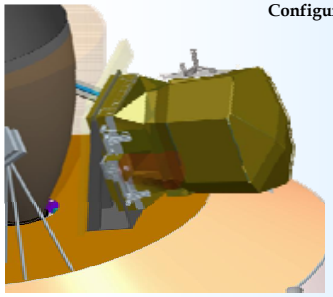


Configuration 2a



GSFC Unpressurized Carrier Study ISS Case 3 (CMG Cargo)

Configuration 3



Notes:

1) **SPDM shown fitting is not required**

2) **Small encroachment into 5.1 cm (2.0 in) shroud envelope clearance; will increase with 7.6 cm (3.0 in) required clearance. Structural optimization may help mitigate.**

Requirements

- **Proposed requirements for inclusion in CARD/SRD**
  - The CEV shall deliver unpressurized cargo from the Earth surface to the ISS with each ISS crew and pressurized cargo mission.
  - **Rationale:** This unpressurized cargo requirement is based on ESAS (NASA-TM-2005-214062)
  - The CEV shall deliver at least 590 kg (1,300 lbm) of unpressurized Cargo from the Earth to the ISS with each ISS crew and pressurized cargo mission.
  - **Rationale**: The cargo capability is possible for ISS missions only due to propellant offloading of the Service Module. An unpressurized cargo capability is required to enable transport of ORUs to ISS post-Shuttle retirement. This requirement applies to each ISS mission (Crew Transport and Pressurized Cargo). The structure to accommodate this cargo is anticipated to be minimized to prevent mass penalties to lunar missions
  - The CEV shall deliver a volume of 125 ft3 of unpressurized cargo to the ISS with each ISS Crew and pressurized cargo mission.
  - **Rationale**: The cargo capability is possible for ISS missions only due to propellant offloading of the Service Module. An unpressurized cargo capability is required to enable transport of ORUs to ISS post-Shuttle retirement. This requirement applies to each ISS mission (Crew Transport and Pressurized Cargo). The structure to accommodate this cargo is anticipated to be minimized to prevent mass penalties to lunar missions

Conclusions and Follow-On

- Feasibility = positive
- Upmass issue
- More mature design options and accommodations data required
- Continue to devise and refine concept of operation
- Discussions underway to accommodate the need/desire
- Further study is expected, in whatever capacity, after requirements mature
- Proponents
  - NASA Administrator supports having a CEV “trunk”, capability equal to if not exceeding Apollo capability
  - March 2007 NAC Workshop Science Working Groups
  - International Space Station program
  - Other government institutions, e.g. Department of Defense

Discussion Points

- Will enable and advance Lunar science and outpost design and development?
- Learning from the Past
  - Hitchhiker program began as ballast but became missions of opportunity and quick turnaround method to fly “last minute” and contingency payloads
  - The need for an infrastructure to accommodate the vehicular transportation and implementation of Lunar science and outpost payloads to, from, on, and about the Moon
- Derivation of priority and ranking scheme considering factors such as technical readiness, market, mass, etc.