Systems Analysis and Structural Design of an Unpressurized Cargo Delivery Vehicle

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Systems Analysis and Structural Design of an Unpressurized Cargo Delivery Vehicle (UCDV)

- Historical background
- UCDV rationale and requirements
- Spacecraft configuration
- Orbital Replacement Units and Flight Support Equipment
- UCDV structure and configuration trade studies
- System performance estimates
- System concept of operations
- Concluding remarks

Columbia, the Vision for Space Exploration, NASA's Exploration Systems Analysis Study and the Constellation Program

STS-107 *Columbia* Disaster, February 2003



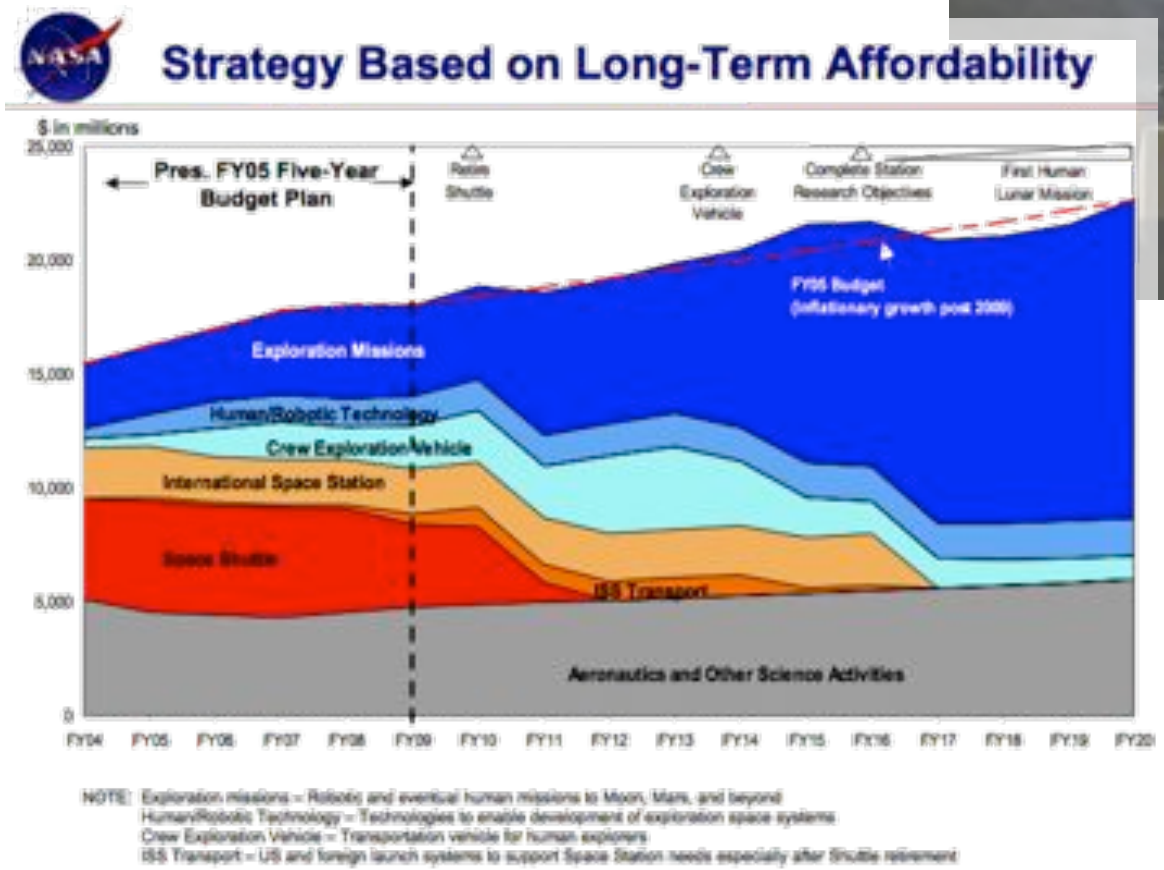




Constellation Program Born From Tragedy

The new "Vision for Space Exploration" announced in January 2004 by then-Pres. G.W. Bush. Constellation was the name given to NASA's implementation of the VSE.



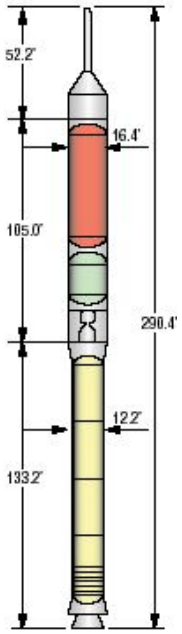


Key goals of the VSE

- Complete ISS by 2010, then retire Space Shuttle.
- Develop and test Crew Exploration Vehicle by 2008; 1st manned flight planned in 2014.
- Humans return to Moon by 2020.

Exploration Systems Analysis Study Final Report (NASA-TM-2005-214062, November 2005)

Crew Launch Vehicle 13.1



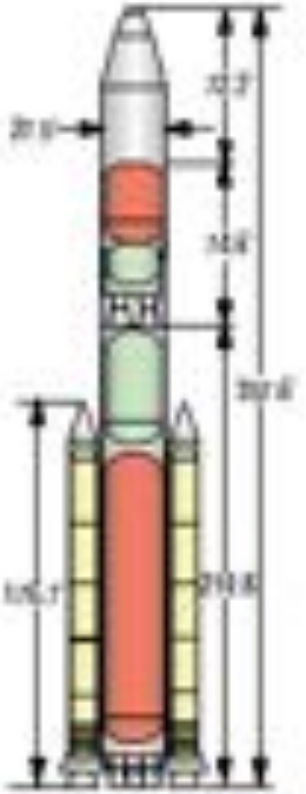
Shown to scale with CaLV

Vehicle Concept Characterization	
GLOW	1,795,205 lbf
Payload	5-m diameter CEV
Launch Escape System	9,300 lbm
Booster Stage (each)	
Propellants	PBAN
Useable Propellant	1,112,256 lbm
Stage prop	88.0 t
Burnout Mass	188,049 lbm
# Boosters / Type	1 / 4 Segment SRM
Booster Thrust (@ 0.7 secs)	3,139,195 lbf @ Vac
Booster Isp (@ 0.7 secs)	268.0 sec @ Vac
Second Stage	
Propellants	LOX/LH2
Useable Propellant	368,519 lbm
Propellant Offload	8.6 %
Stage prop	8.8882
Dry Mass	38,597 lbm
Burnout Mass	45,522 lbm
# Engines / Type	1 / SSME
Engine Thrust (100%)	409,449 lbf @ Vac
Engine Isp (100%)	452.1 sec @ Vac
Mission Power Level	104.5%

Delivery Orbit	30 x 160 nmi @ 28.5°
Delivery Orbit Payload	66,858 lbm 21.2 mT
Net Payload	53,908 lbm 24.5 mT
Vacuum Altitude	59.5 nmi
T/W @ Liftoff	1.38
Max Dynamic Pressure	575 psf
Max g's Ascent Burn	4.60 g
T/W Second Stage	1.03

Delivery Orbit	30 x 160 nmi @ 51.6°
Delivery Orbit Payload	56,009 lbm 25.4 mT
Net Payload	50,459 lbm 22.9 mT

Cargo Launch Vehicle 27.3



Vehicle Concept Characteristics	
GLOW	6,393,915 lbf
Payload Envelope L x D	59.4 ft x 24.5 ft
Shroud Jettison Mass	10,527 lbm
Booster Stage (each)	
Propellants	HTPB
Useable Propellant	1,424,886 lbm
Stage prop	0.8864
Burnout Mass	201,234 lbm
# Boosters / Type	2 / 5 Segment SRB
Booster Thrust (@ 0.7 sec)	5,600,123 lbf @ V
Booster Isp (@ 0.7 sec)	264.4 sec @ Vac
Lead Stage	
Propellants	LOX/LH2
Useable Propellant	2,274,388 lbm
Propellant Offload	0.0 %
Stage prop	0.8913
Dry Mass	184,961 lbm
Burnout Mass	215,258 lbm
# Engines / Type	5 / SSME Mk 2
Engine Thrust (100%)	525,181 lbf @ SL
Engine Isp (100%)	391.3 sec @ SL
Mission Power Level	104.5 %
Earth Departure Stage (ea)	
Propellants	LOX/LH2
Useable Propellant	49,884 lbm
Propellant Offload	0.0 %
Stage prop	0.8839
Dry Mass	42,645 lbm
Burnout Mass	49,648 lbm
# Engines / Type	2 / J-2S+
Engine Thrust (100%)	214,585 lbf @ Vac
Engine Isp (100%)	451.5 sec @ Vac
Mission Power Level	100.0 %

Delivery Orbit	30 x 62 nmi @ 28.5°
Del. Orbit Payload	326,896 lbm 148.3 mT
Net Payload	211,863 lbm 126.8 mT
CEV payload Optimized Tmax Propellant Offload at 0.0% of 80%	
Delivery Orbit	TLI @ ISS Rendezvous Burns
Gross Payload	420,193 lbm 68.6 mT
Net Payload	408,333 lbm 54.6 mT

Components of Program Constellation



ESAS Baseline Lunar Lander (LSAM)

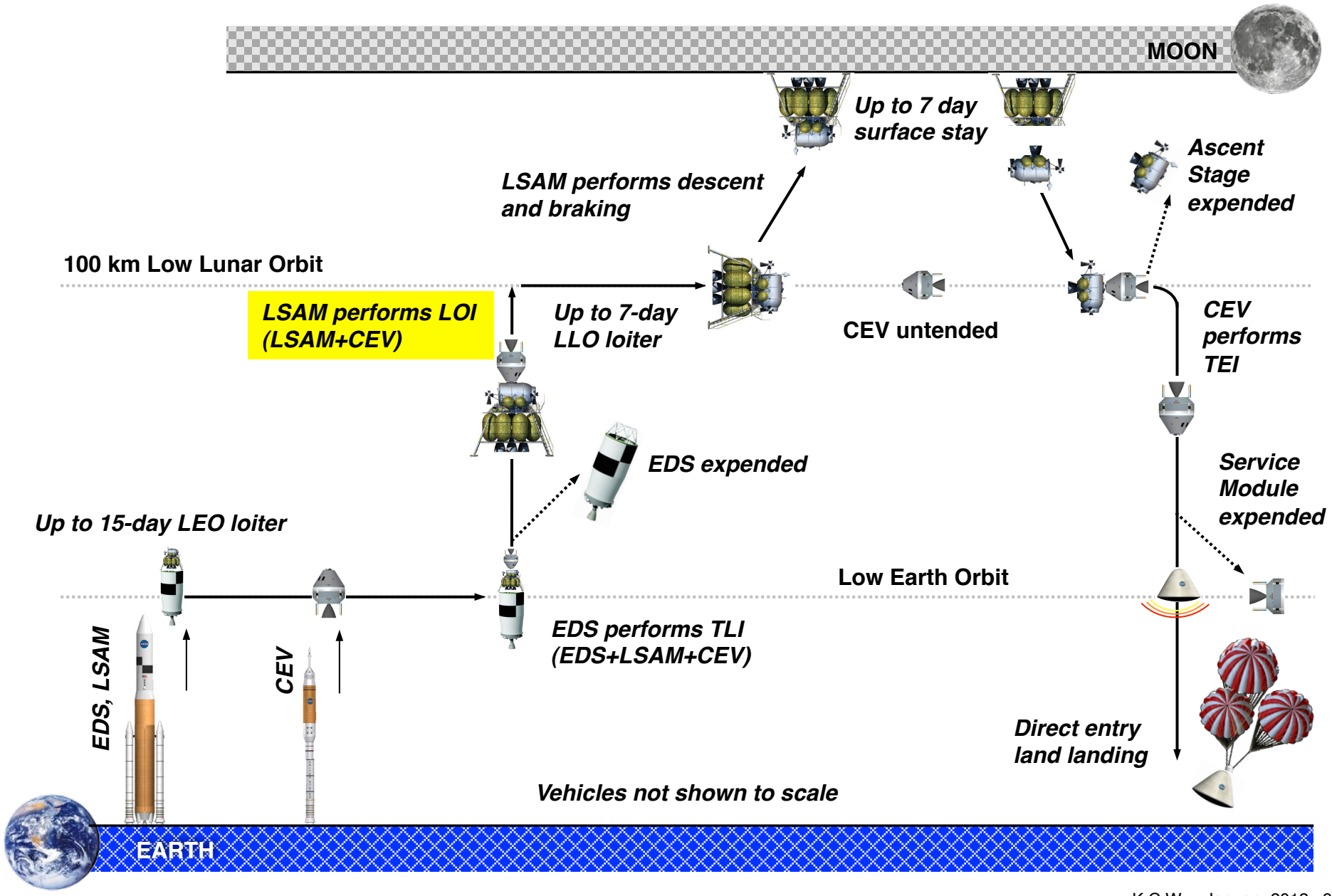
Crew Size (max)	4
Surface Duration (max)	7 days (Sortie missions) Up to 210 days (Outpost)
Landing site capability	Global
Stages	2
Overall height	9.7 m (31.8 ft)
Width at tanks	7.5 m (24.6 ft)
Width at footpads (diag.)	14.8 m (48.6 ft)
Crew module pressurized volume	31.8 m^3 (1123 ft^3)
Ascent Stage mass	10809 kg (23780 lbm)
Ascent Stage engines	1 – LOX/CH_4 (under study)
Ascent engine thrust	44.5 kN (10000 lbf)
Descent Stage mass	35055 kg (77120 lbm)
Descent Stage engines	4 – RL-10 derived LOX/H_2
Descent engine thrust	4x 66.7 kN (4x 15000 lbf)







Lunar Sortie Mission Concept of Operations

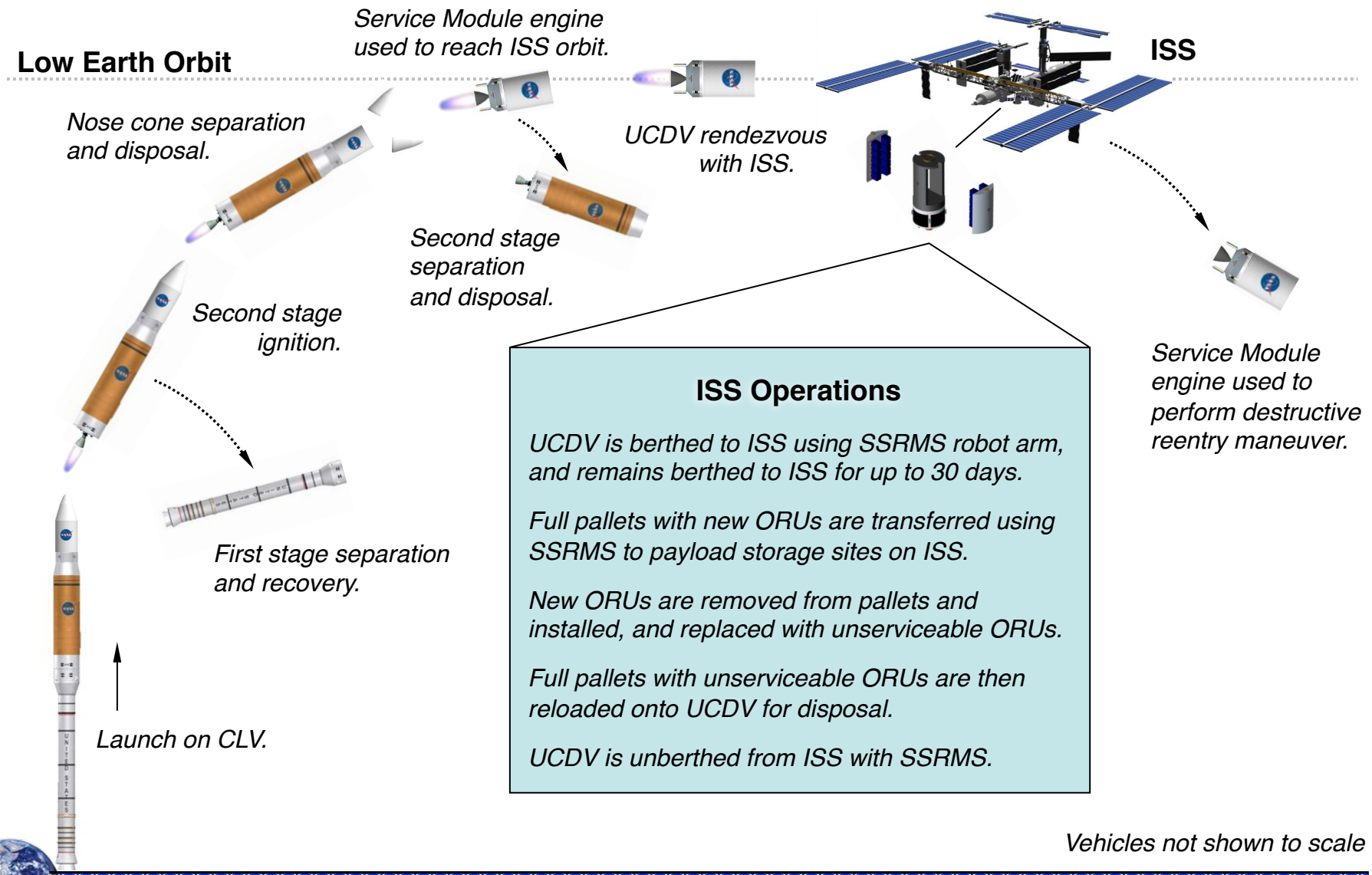


UCDV Rationale and Requirements

- Continuing support for the International Space Station is a key Agency commitment, requires ~ 10000 lbs/year external logistics.
- Restricted capability for unpressurized cargo resupply of the ISS after completion, and Space Shuttle retirement in 2010.
- H-II Transfer Vehicle (JAXA) cannot transport largest Orbital Replacement Units, while Automated Transfer Vehicle (ESA), Soyuz and Progress (Russia) carry no unpressurized cargo.

- Deliver at least 18 cargo units (each nominal 1 ORU and Flight Support Equipment) and 13200 lbs cargo mass to ISS.
- Maximum commonality with ESAS spacecraft, launch vehicles and existing ISS hardware (ORUs, FSE, other mechanisms).
- Maximum 30-day occupancy of ISS port.

ISS Resupply Mission Concept of Operations



ISS Operations

UCDV is berthed to ISS using SSRMS robot arm, and remains berthed to ISS for up to 30 days.

Full pallets with new ORUs are transferred using SSRMS to payload storage sites on ISS.

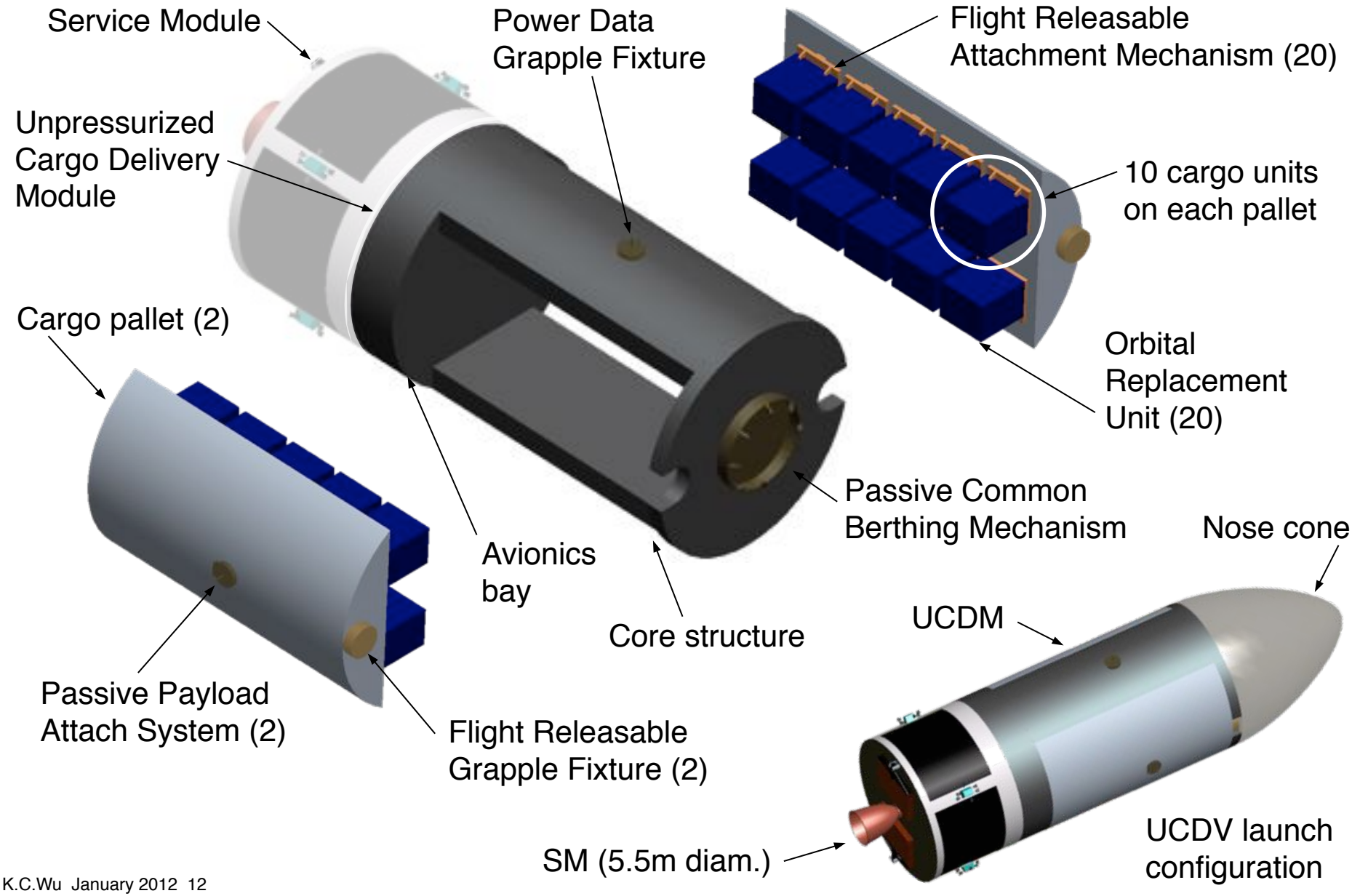
New ORUs are removed from pallets and installed, and replaced with unserviceable ORUs.

Full pallets with unserviceable ORUs are then reloaded onto UCDV for disposal.

UCDV is unberthed from ISS with SSRMS.

Vehicles not shown to scale

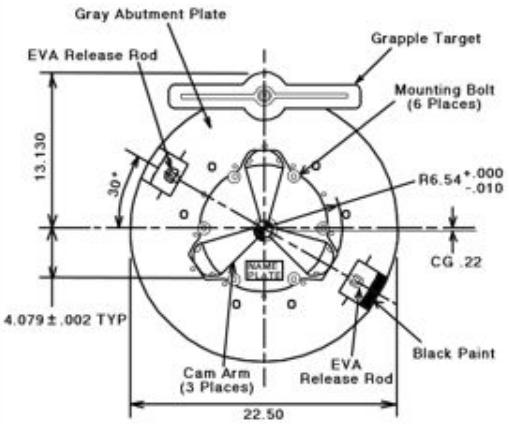
UCDV Expanded View with Components



UCDV/ISS Interface Mechanisms

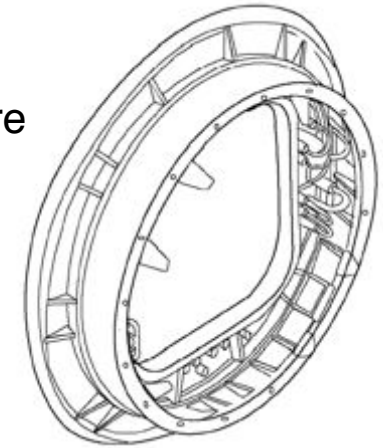
Flight Releasable Grapple Fixture

Grappled by SSRMS to extract pallet. Released when pallet on P3/S3 stowage site.



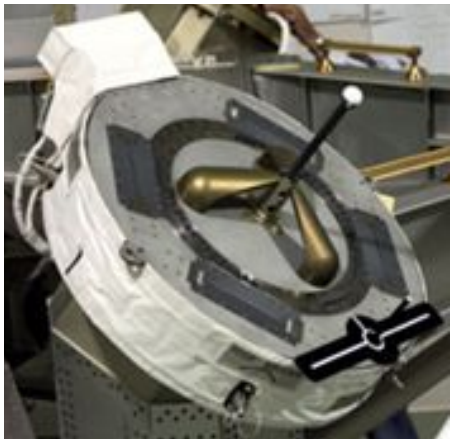
Passive Common Berthing Mechanism

Passive CBM on UCDV core structure connects to Active CBM on ISS node. Other interfaces (e.g., LIDS, APAS) are also available.



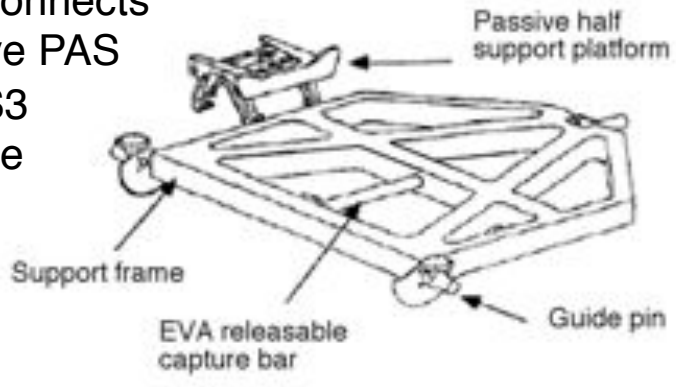
Power Data Grapple Fixture

Grappled by SSRMS to berth UCDV to ISS. Allows health monitoring of UCDV and payload.



Passive Payload Attach System

Passive PAS on pallet connects to Active PAS at P3/S3 stowage site.



Large Orbital Replacement Units

Pump Module Assembly

Mass = 848 lbs, volume = 71 ft^3.
3 spares on ISS.



Control Moment Gyroscope

Mass = 600 lbs, volume = 65 ft^3.
2 spares on ISS.



Radiator ORU

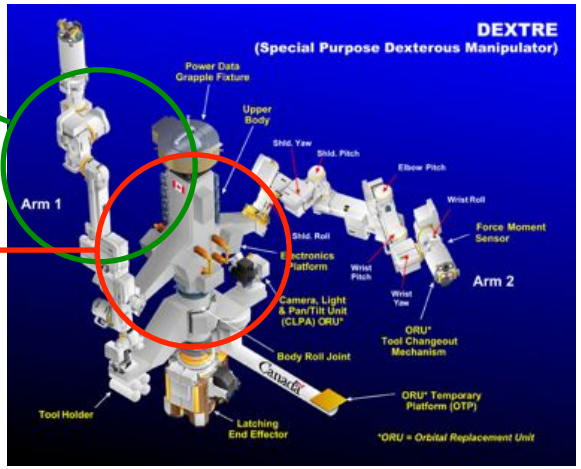
Mass = 2473 lbs, volume = 289 ft^3.

Radiators are the largest ORU.
1 spare on ISS.



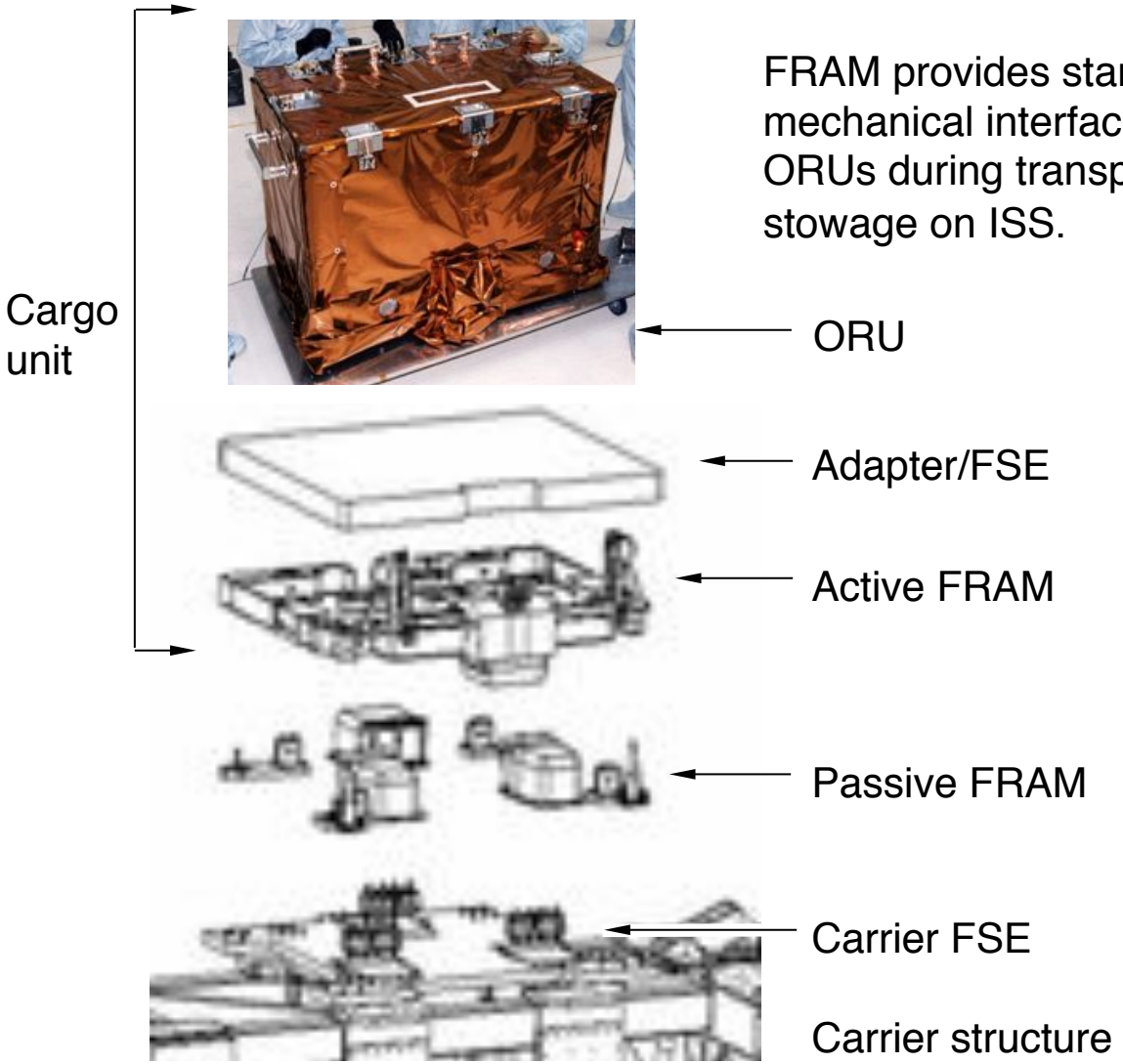
Special Purpose Dexterous Manipulator

Arm mass = 709 lbs, vol. = 51 ft^3.
UBS mass = 414 lbs, vol. = 122 ft^3.



ORU mass and volume data listed; FSE not included.

Flight Releasable Attachment Mechanism

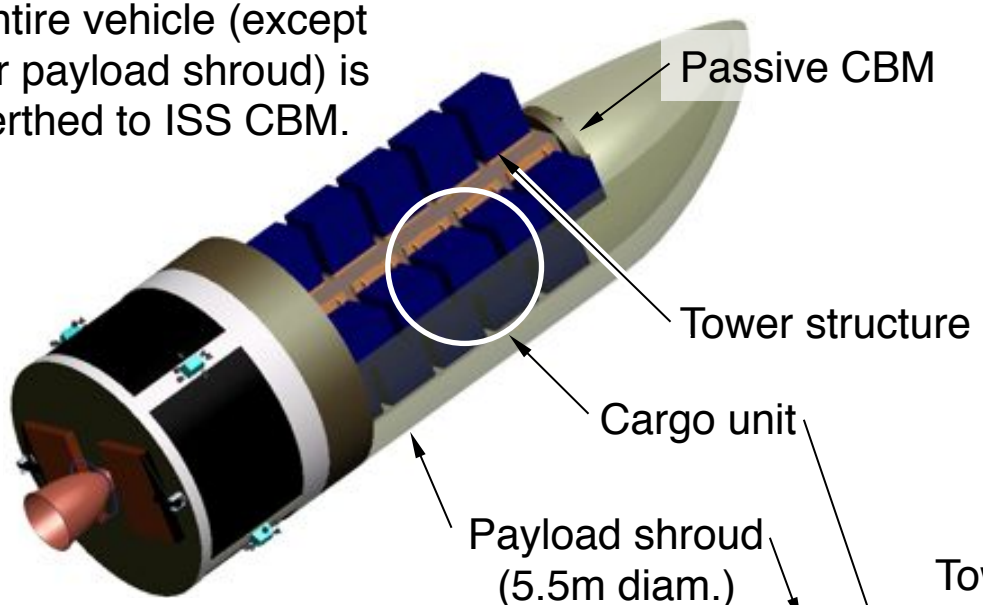


FRAM provides standard structural and mechanical interface for accommodation of ORUs during transport to, handling and stowage on ISS.

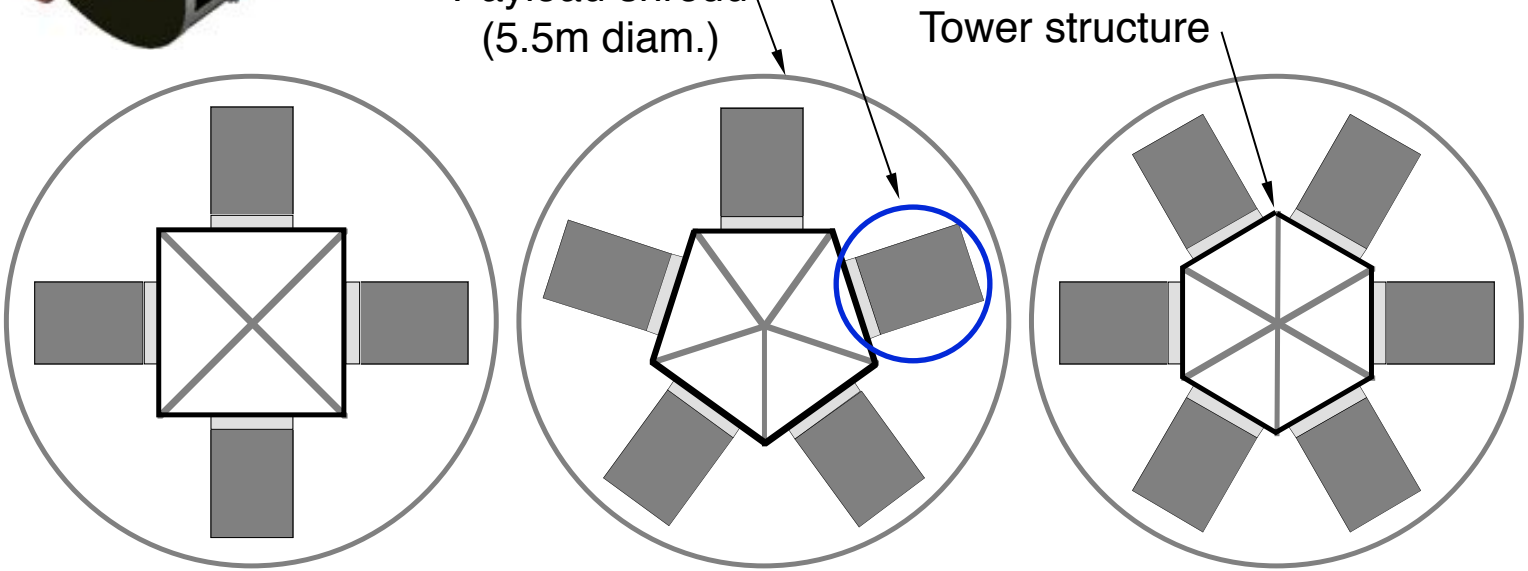
- A FRAM can either be removed manually by EVA astronauts, or with the Space Station Remote Manipulator System robot arm.
- A generic cargo unit (1 ORU+FSE) is 3 x 4 x 4 ft (48 ft^3) volume and 800 lbs mass.
- Combined mass of Active and Passive FRAMs ~150 lbs.

Early Concepts for UCDV Configuration

- Entire vehicle (except for payload shroud) is berthed to ISS CBM.



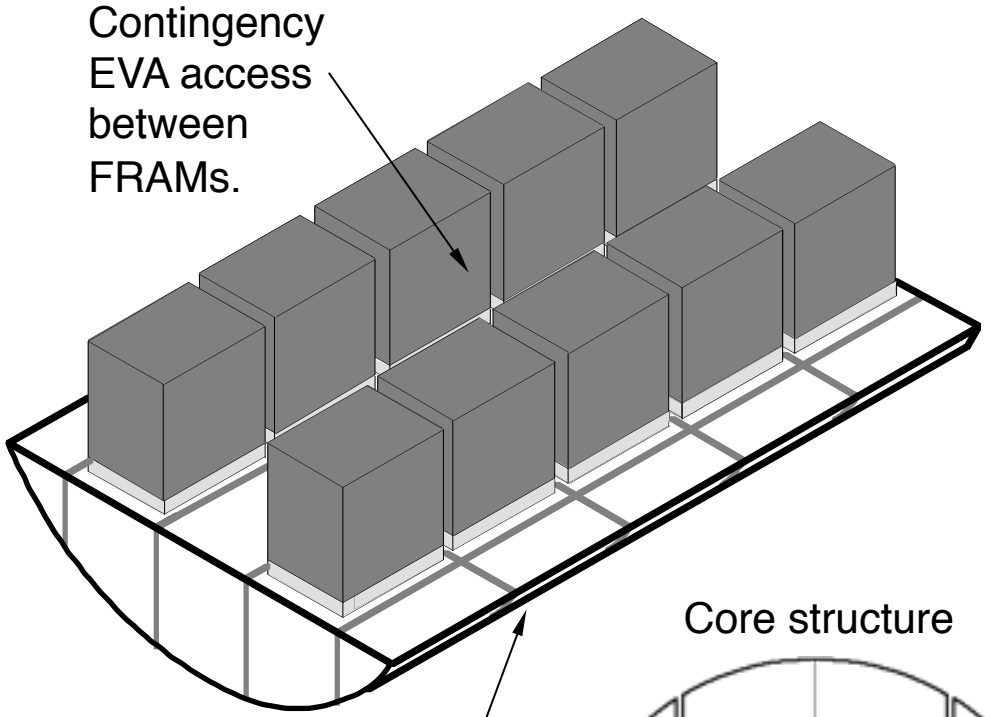
- Low bending stiffness and natural frequency, high CM and moment of inertia on ISS.
- Might need to occupy ISS CBM port for longer than maximum 30-day allowable stay time.
- Low packaging efficiencies. Also, difficult/impossible to stow oversized ORUs like radiators.



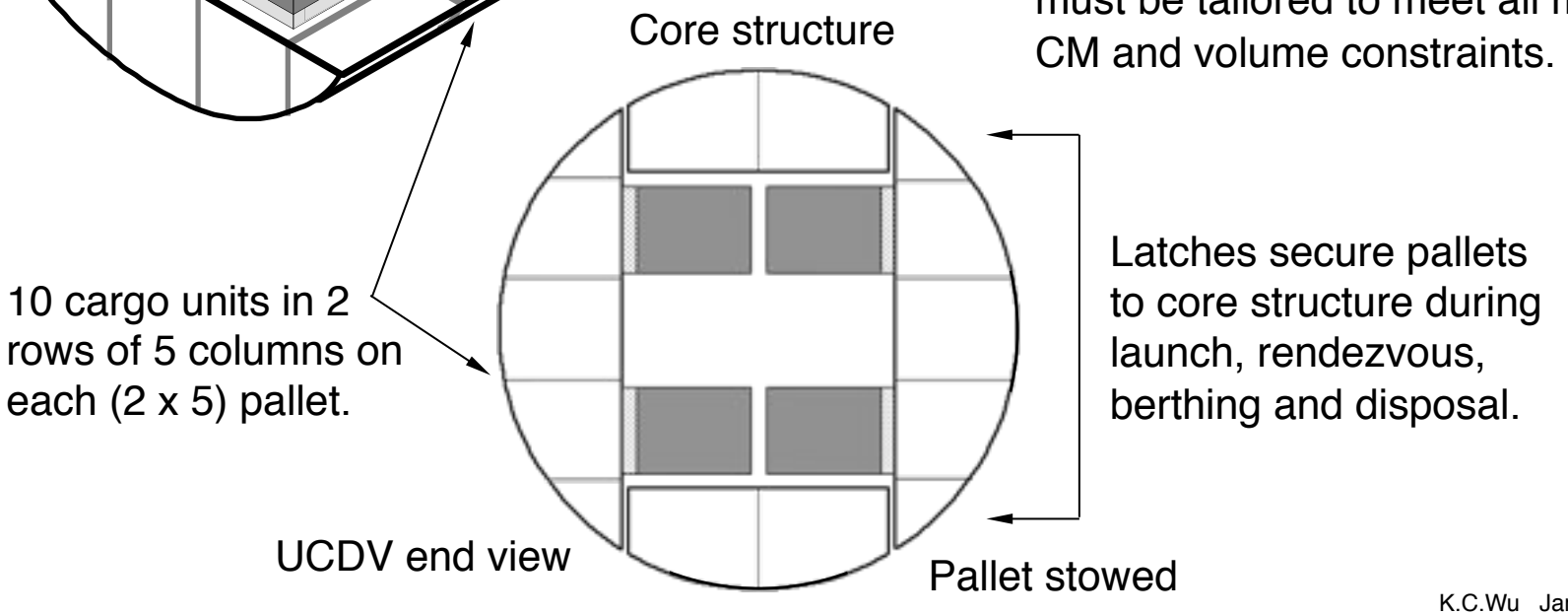
5 FRAMs long, 20 total. 4 FRAMs long, 20 total. 3 FRAMs long, 18 total.

UCDV end views

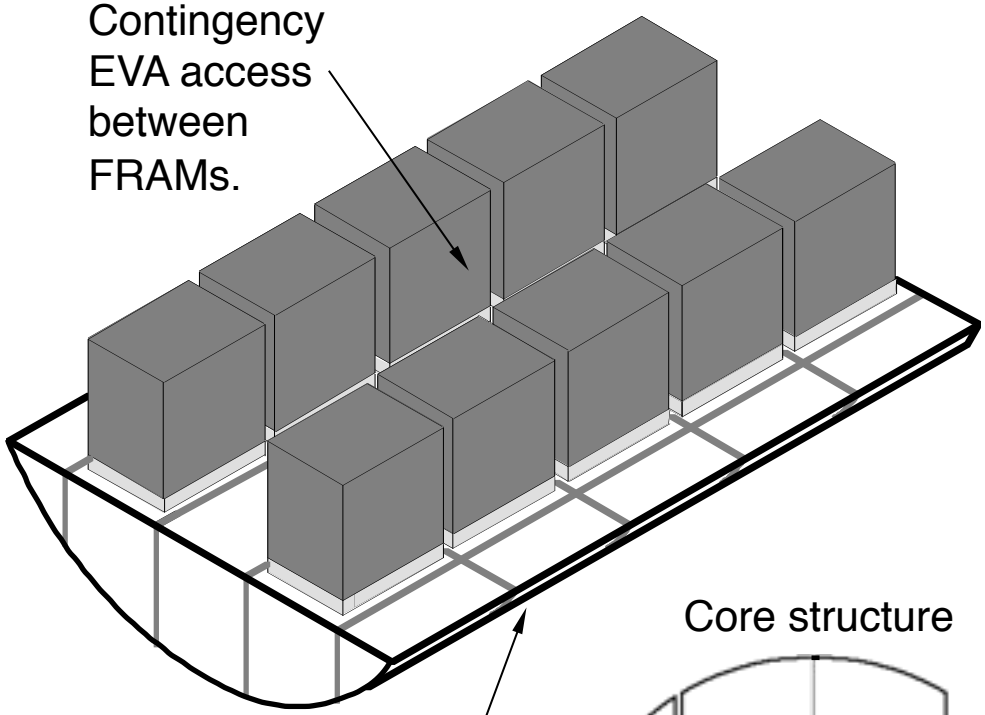
Removable Cargo Pallet Design Selected



- Vehicle OML expanded to full 5.5m SM diameter. No separate shroud.
- Design allows extraction of full pallets from UCDV for transport to ISS P3/S3 stowage locations.
- Improved pallet moment of inertia, natural frequency and CM (vs. tower designs) on ISS.
- Design readily accommodates the largest ORUs. The cargo manifest must be tailored to meet all mass, CM and volume constraints.



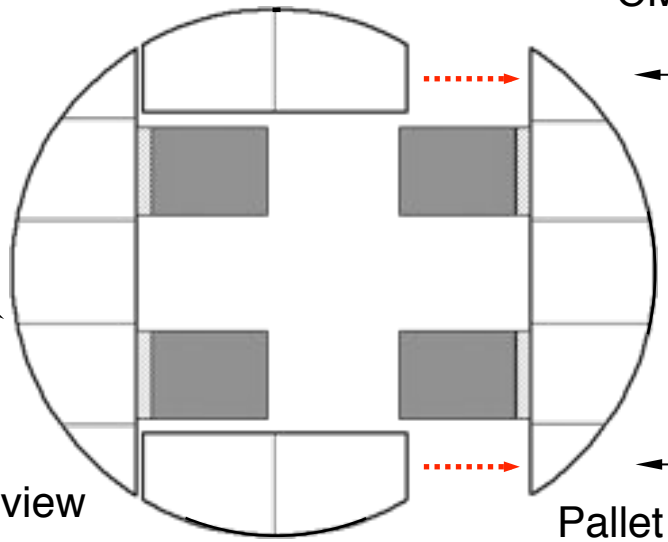
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- Improved pallet moment of inertia, natural frequency and CM (vs. tower designs) on ISS.
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Core structure

10 cargo units in 2 rows of 5 columns on each (2 x 5) pallet.



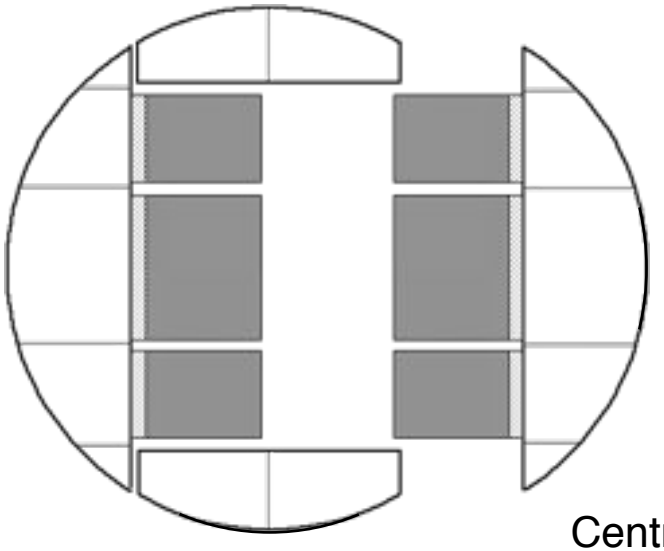
Latches are unlocked to remove loaded pallets. Must also be releasable during contingency EVA.

UCDV end view

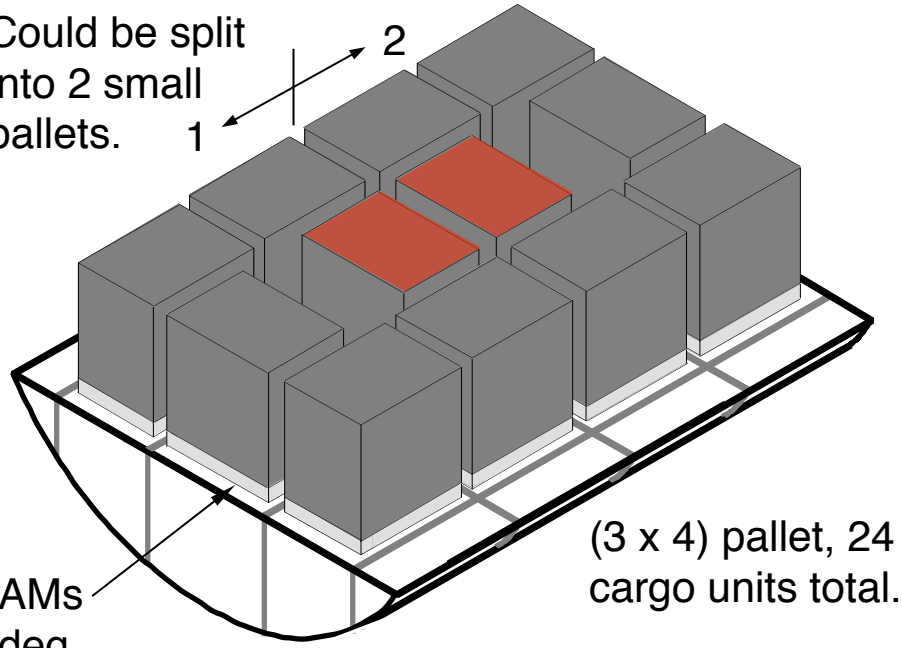
Pallet removed

Alternate Pallet Designs Also Proposed

UCDV end view

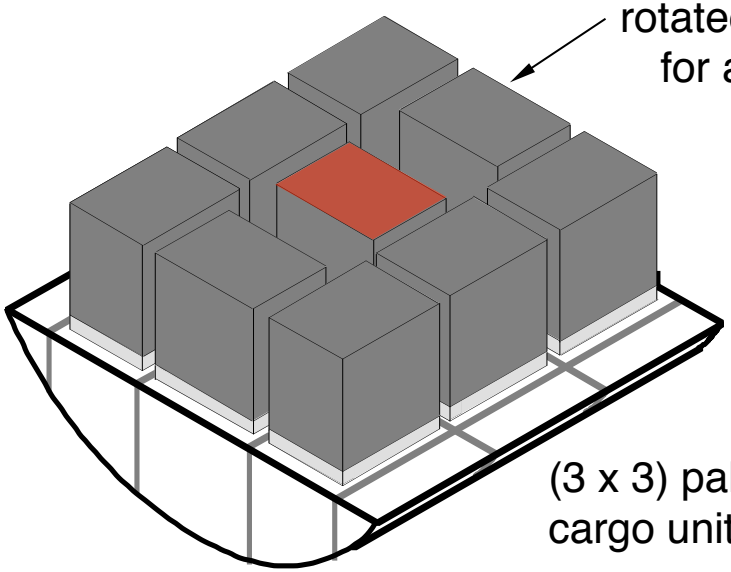


Could be split into 2 small pallets.



(3 x 4) pallet, 24 cargo units total.

Central FRAMs rotated 90 deg. for access.

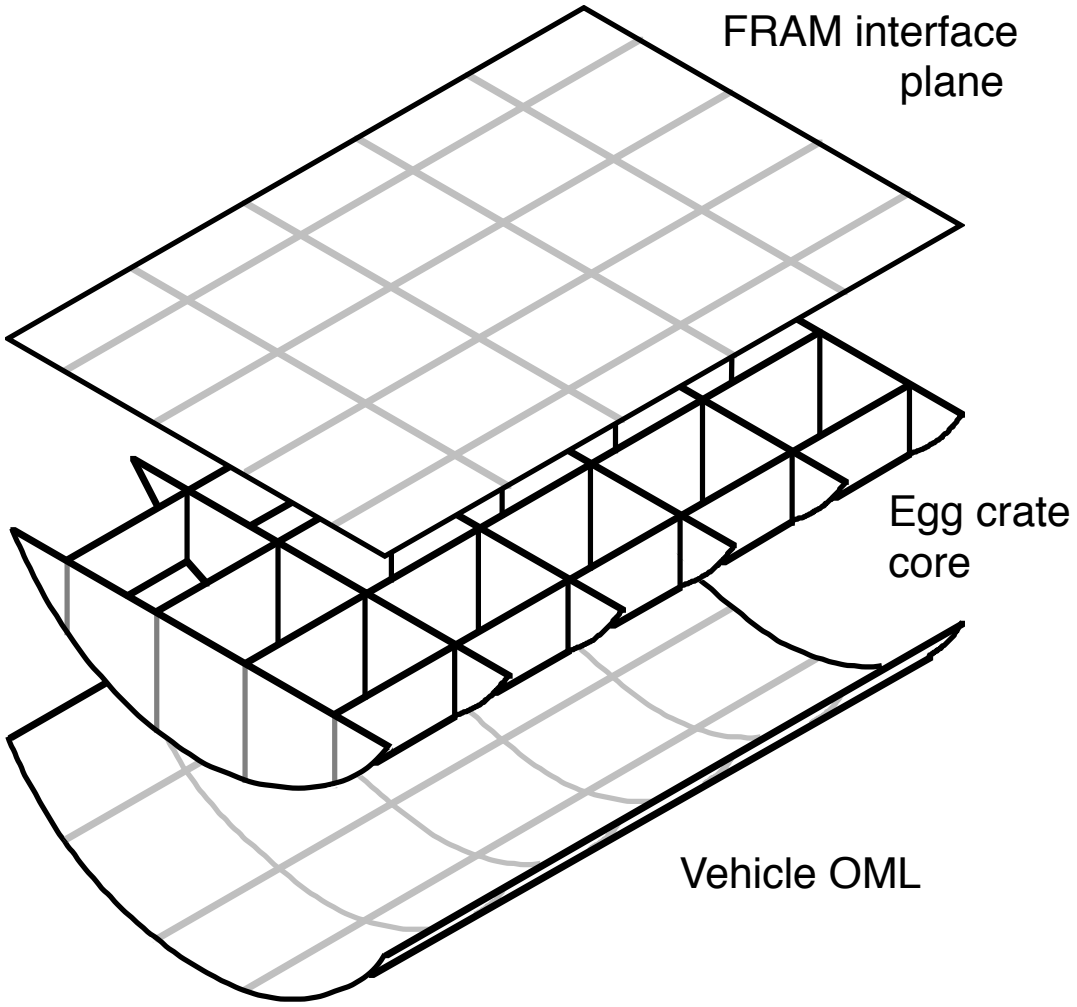


(3 x 3) pallet, 18 cargo units total.

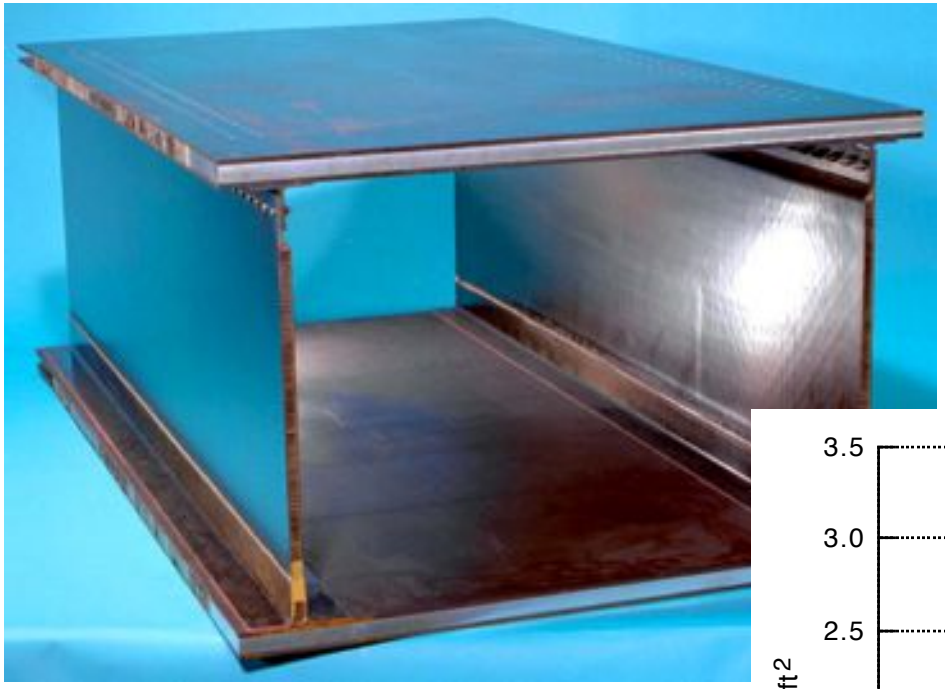
- EVA access requirement revisited. FRAMs could be added in central aisle.
- Allows much more efficient packaging of ORUs. Lower stowed pallet mass and moment of inertia on ISS.
- Between 20-40 percent lower mass than baseline (2 x 5) design.
- Restricted access to center ORUs, and reduced core structure depth.

Expanded View of (2 x 5) Cargo Pallet

- Graphite-epoxy honeycomb sandwich structure selected as a baseline concept.
- Reduced overall part count and manufacturing complexity.
- Local reinforcements for FRAM and edge latch attachments will require additional analyses and detailed design.
- Uniform axial running loads ~300 lb/in. at UCDM/SM interface plane.
- Structure areal density of 2 lb/ft^2 is based on HSR wing box experience.

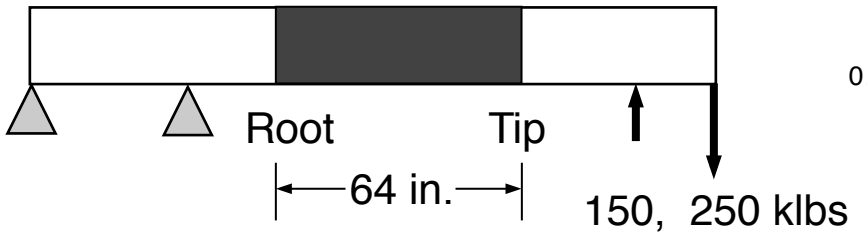


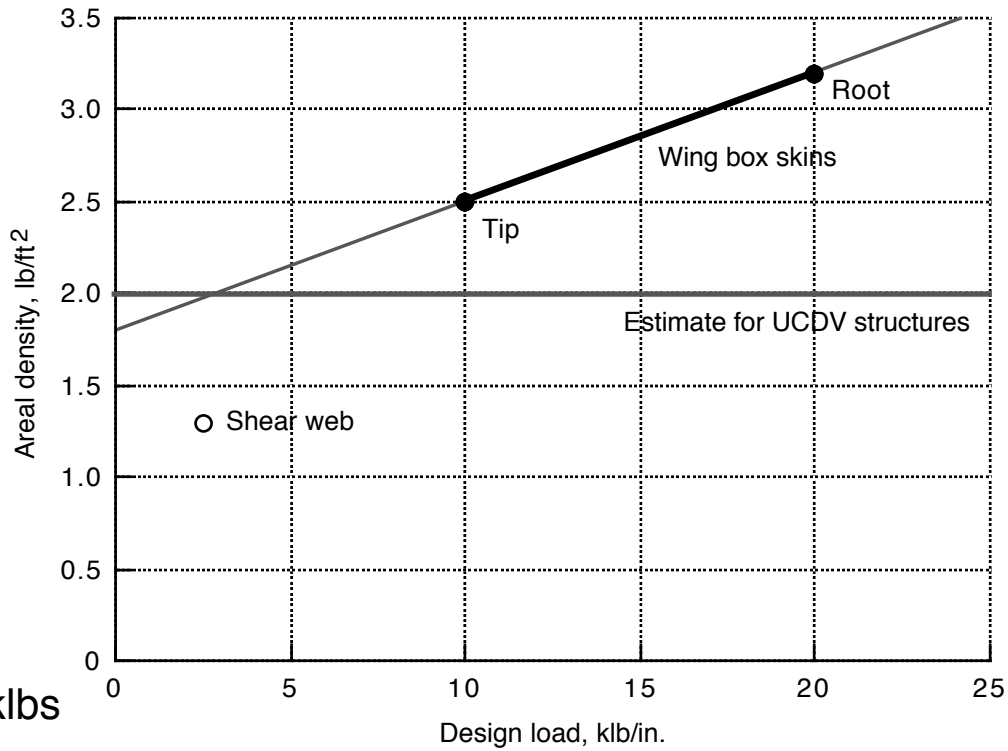
Graphite/BMI Honeycomb Sandwich Wing Box



Wing surfaces and shear webs are IM7/5260 graphite/toughened bismaleimide composite face sheets (12 to 28 plies) over titanium honeycomb cores (0.5 to 1.0 inch thickness).

Wing box built by NG and loaded to failure in 4-point bending at LaRC.





UCDV System Mass Estimates

1.0 Structure	Quantity	4995	kg	11010	lb
Pallet structure (1250 kg each)	2	2500		5512	
Core structure	1	1250		2756	
Passive PAS (115 kg each)	2	230		506	
Passive FRAM (15 kg each)	20	300		660	
FRGF (2) & PDGF (1)	3	38		84	
Passive CBM	1	177		390	
Avionics bay	1	500		1102	
2.0 Protection		**100**	**kg**	**220**	**lb**
Insulation		100		220	
3.0 Propulsion		**0**		**0**	
4.0 Power		**290**	**kg**	**638**	**lb**
Cabling		290		638	
5.0 Control		**0**		**0**	
6.0 Avionics		**623**	**kg**	**1373**	**lb**
Command, control & data handling		156		344	
Guidance, navigation & control		112		247	
Communications		128		282	
Instrumentation & cabling		227		500	
7.0 Environment		**0**		**0**	
8.0 Other		**0**		**0**	
9.0 Growth Margin		**1202**	**kg**	**2648**	**lb**
20 percent		1202		2648	
10.0 Non-Cargo		**0**		**0**	
11.0 Cargo		**7260**	**kg**	**16000**	**lb**
Cargo unit (363 kg each) includes ORU & Active FRAM	20	7260		16000	
12.0 Non-Propellant		**0**		**0**	
13.0 Propellant		**0**		**0**	
UCDM Gross Mass		**14470**	**kg**	**31889**	**lb**
SM Gross Mass		**6912**	**kg**	**15241**	**lb**
Nose Cone Mass and performance impact		**1000**	**kg**	**2205**	**lb**
Total UCDV Mass		**22382**	**kg**	**49335**	**lb**
CLV Performance to 30 x 160 nmi, 51.6 deg. orbit		**22900**	**kg**	**50480**	**lb**

- Mass of (5 x 2) pallets and core structure = 8268 lbs.
- Mass of additional mechanisms = 1640 lbs.
- 20 percent growth margin on dry mass required in ESAS ground rules.
- 20 generic cargo units (800 lbs ea.) payload assumed. Detailed cargo manifests were not prepared.
- Estimate 1145 lbs below CLV performance. Treat as additional growth margin (+9 percent) or payload.
- UCDM, cargo, SM and nose cone => complete UCDV.

Comparison of UCDM with ESP-2 Payload



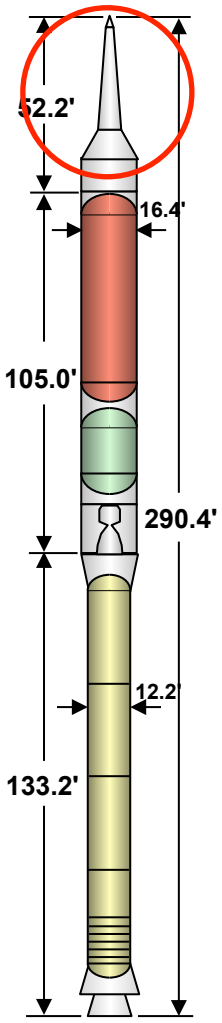
ESP-2 Cargo Carrier

- Unpressurized pallet flown to the ISS on STS-114 (July 2005).
- Dry mass of 5900 lbs, with 8 FRAM capacity.
- Normalized ESP-2 system mass of 738 lbs per FRAM.

- Predicted UCDM dry mass is (31889 - 16000 cargo) lbs, or 15889 lbs.
- Normalized UCDM mass is 15889 lbs/20 FRAMs, or 794 lbs per FRAM.
- (794 - 738)/738 x 100 percent = 7.6 percent. UCDM is ~ 8 percent heavier when compared with the ESP-2 flight hardware.
- Good correlation gives added confidence in mass estimates.

Crew Launch Vehicle (ESAS LV 13.1)

Replace with UCDV



Vehicle Concept Characteristics

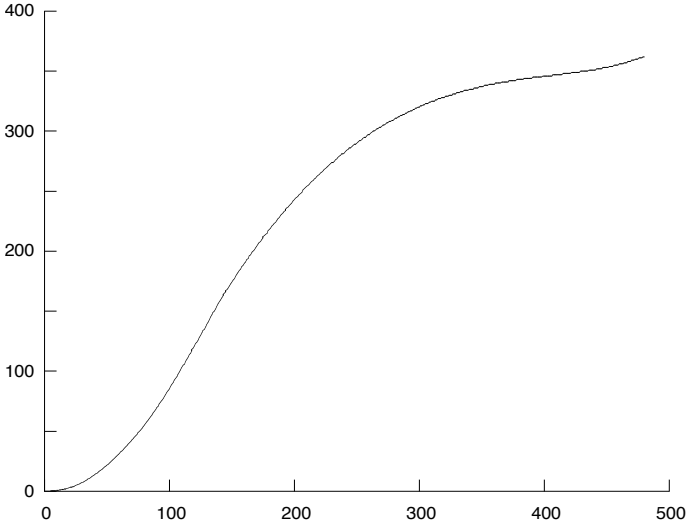
GLOW	**1775385 lbf**
Payload	5 m diameter CEV
Launch Abort System	9300 lbm
Booster Stage	
Propellants	PBAN
Useable Propellant	1112256 lbm
Stage pmf	0.8604
Burnout Mass	180399 lbm
# Boosters/Type	1 @ 4 Segment SRM
Booster Thrust (@ 0.7 secs)	3139106 lbf
Booster Isp (@ 0.7 secs)	268.8 s
Second Stage	
Propellants	LO2/LH2
Useable Propellant	360519 lbm
Propellant Offload	0.0 %
Stage pmf	0.8882
Dry Mass	38597 lbm
Burnout Mass	45022 lbm
# Engines/Type	1 @ SSME
Engine Thrust (100%)	469449 lbf @ Vac
Engine Isp (100%)	452.1 s @ Vac
Mission Power Level	104.5 %
Delivery Orbit	30 x 160 nmi @ 28.5 deg.
Delivery Orbit Payload	59898 lbm 27.2 MT
Net Payload	53908 lbm 24.5 MT
Insertion Altitude	59.5 nmi
T/W @ Liftoff	1.38
Max Dynamic Pressure	576 psf
Max g's Ascent Burn	4.00 g
T/W Second Stage	1.03
Delivery Orbit	30 x 160 nmi @ 51.6 deg.
Delivery Orbit Payload	56089 lbm 25.4 MT
Net Payload	50480 lbm 22.9 MT



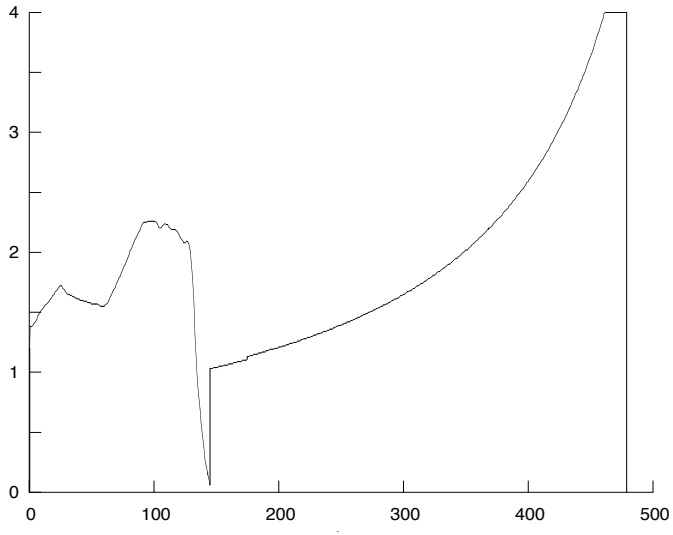
CLV Ascent Performance

(30 x 160 nmi orbit @ 28.5 deg.)

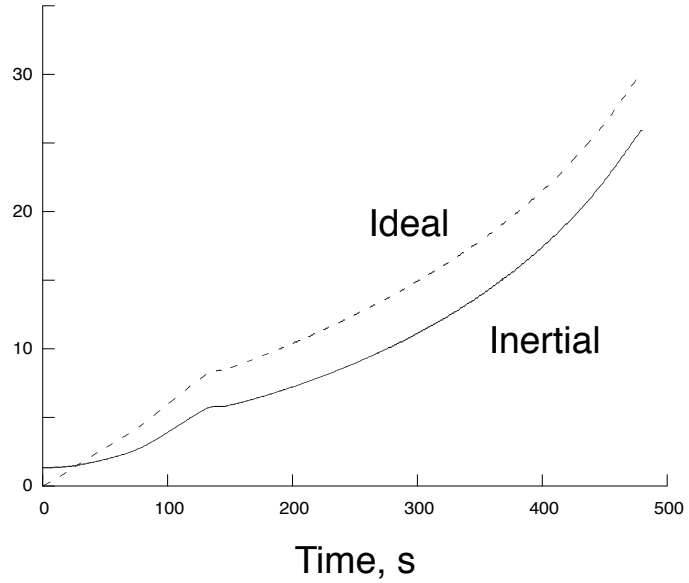
Altitude, kft



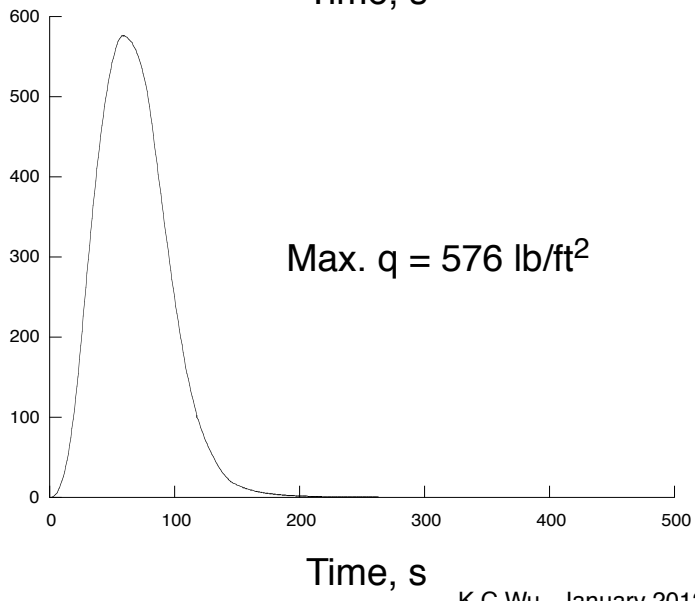
Axial acceleration, g



Velocity, kft/s

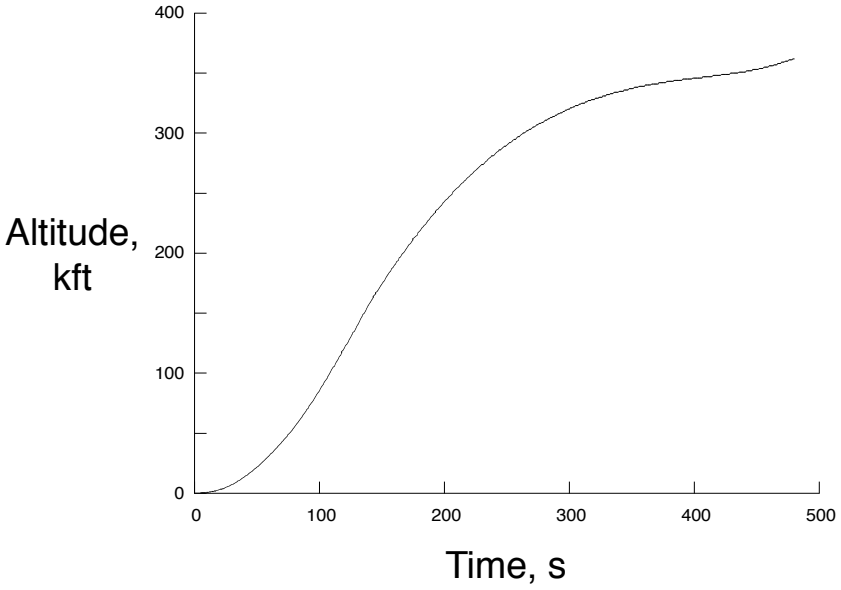


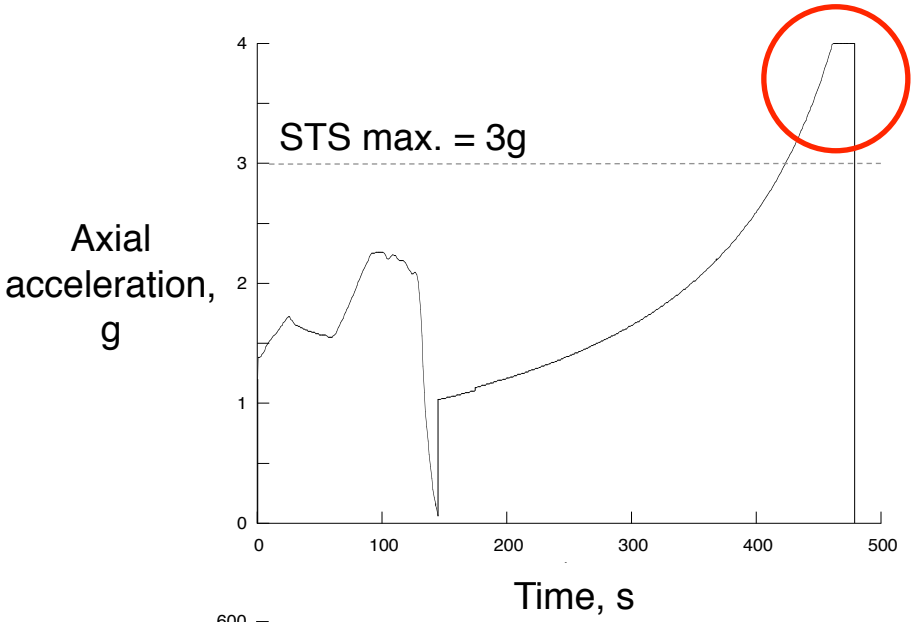
Dynamic pressure, lb/ft^2

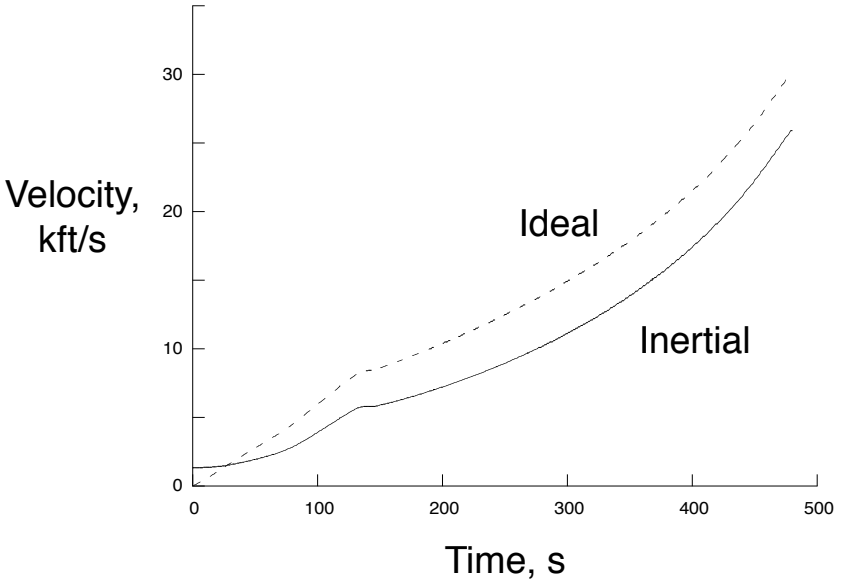


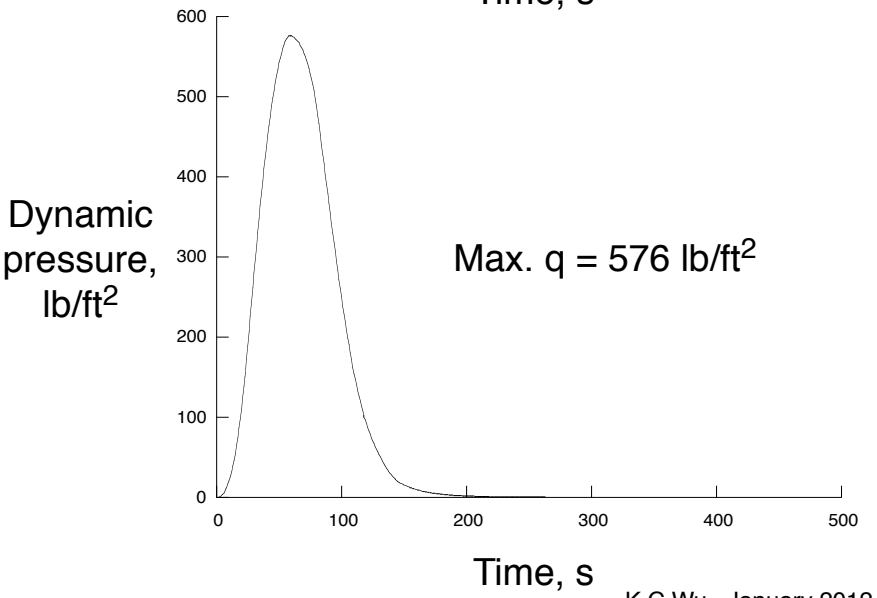
CLV Ascent Performance

(30 x 160 nmi orbit @ 28.5 deg.)



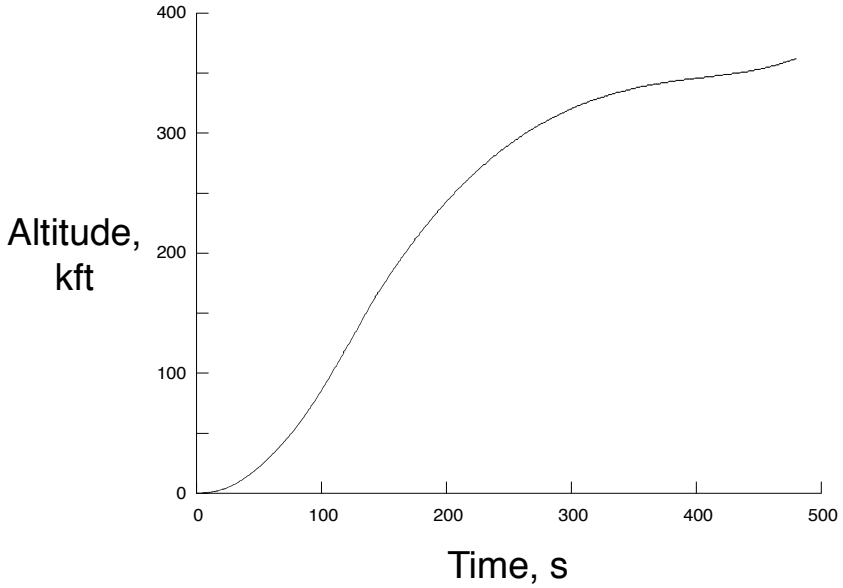


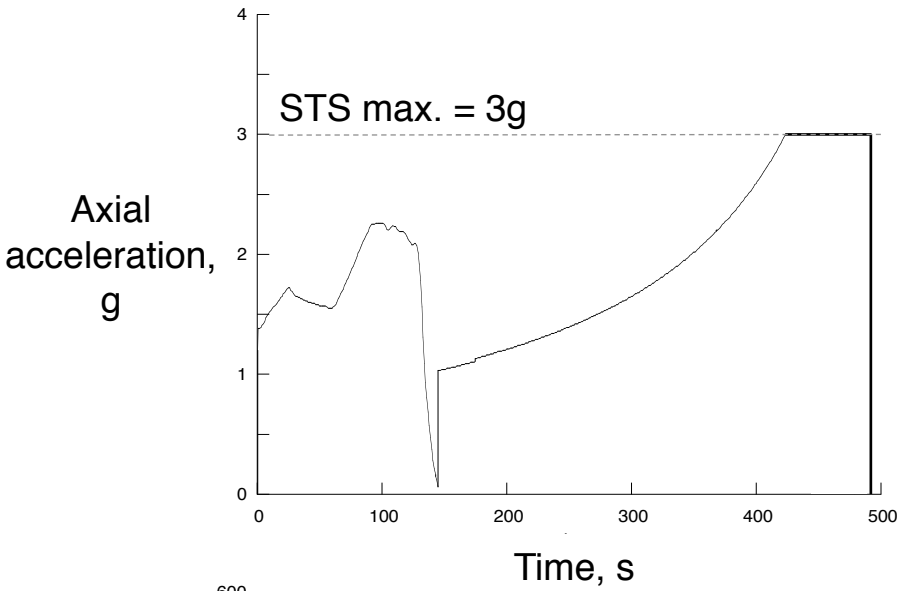


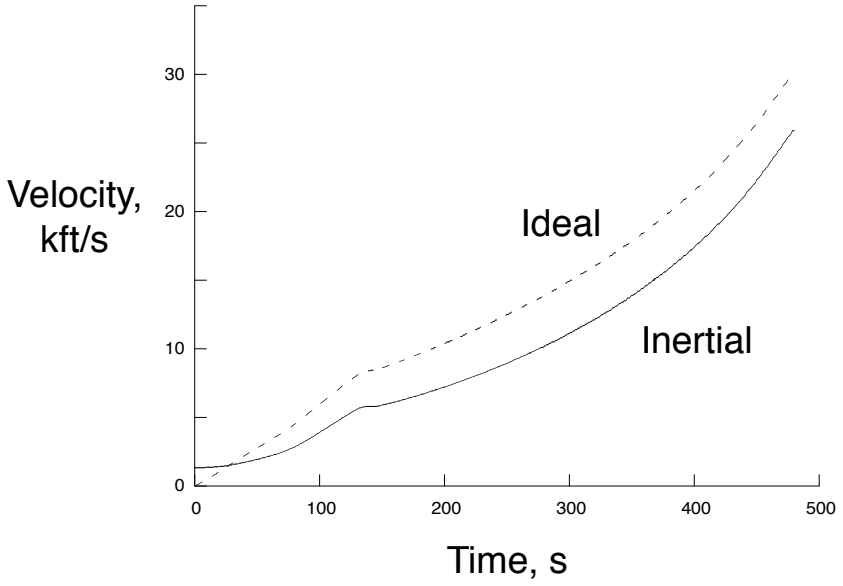


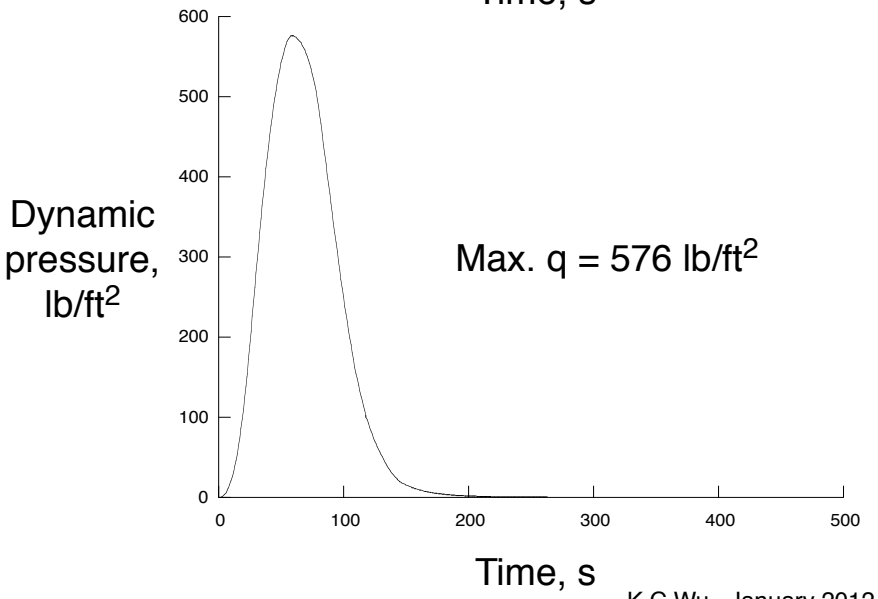
CLV Ascent Performance

(30 x 160 nmi orbit @ 28.5 deg.)

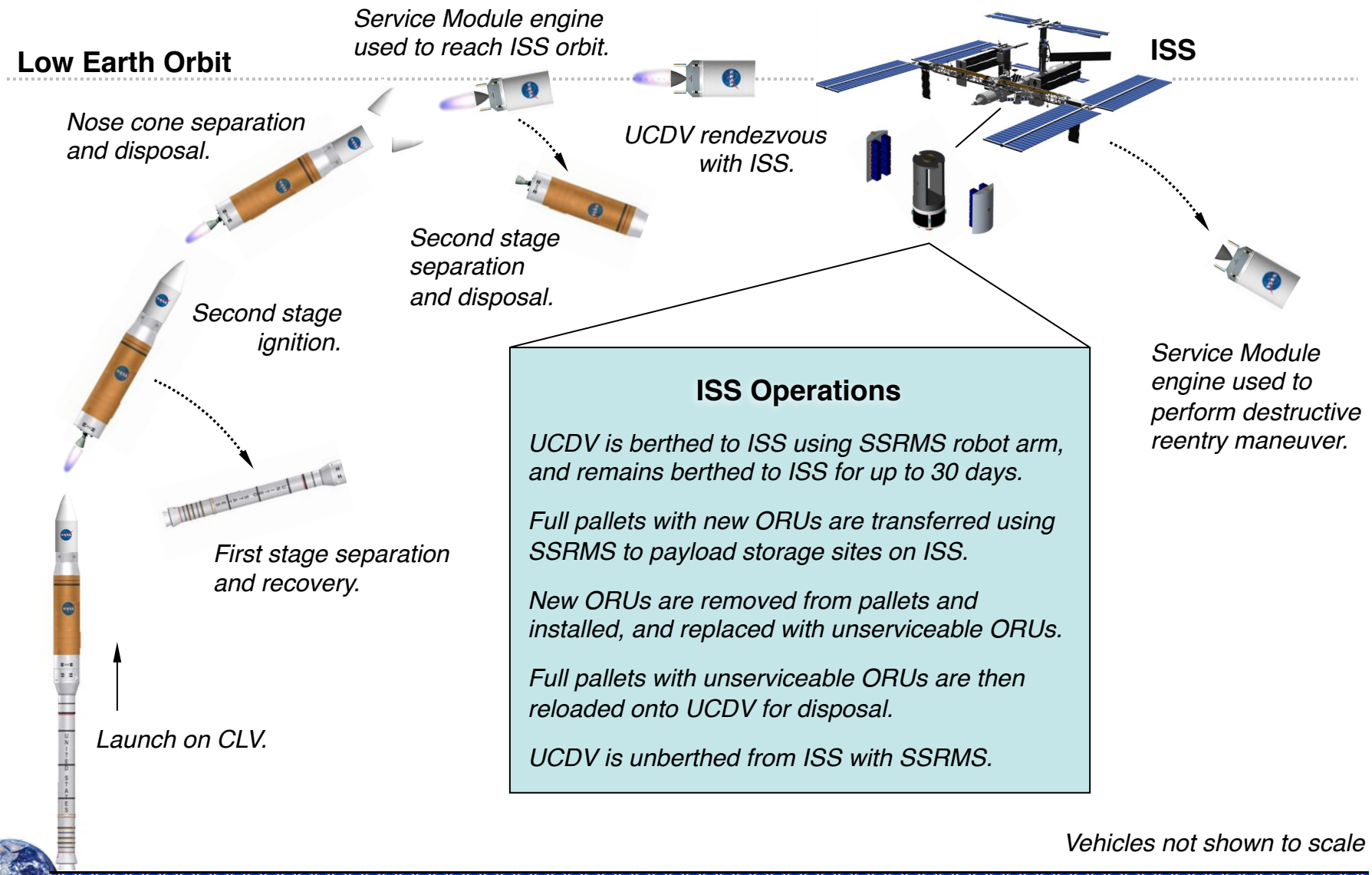








ISS Resupply Mission Concept of Operations



ISS Operations

UCDV is berthed to ISS using SSRMS robot arm, and remains berthed to ISS for up to 30 days.

Full pallets with new ORUs are transferred using SSRMS to payload storage sites on ISS.

New ORUs are removed from pallets and installed, and replaced with unserviceable ORUs.

Full pallets with unserviceable ORUs are then reloaded onto UCDV for disposal.

UCDV is unberthed from ISS with SSRMS.

Vehicles not shown to scale

UCDV Launched on CLV



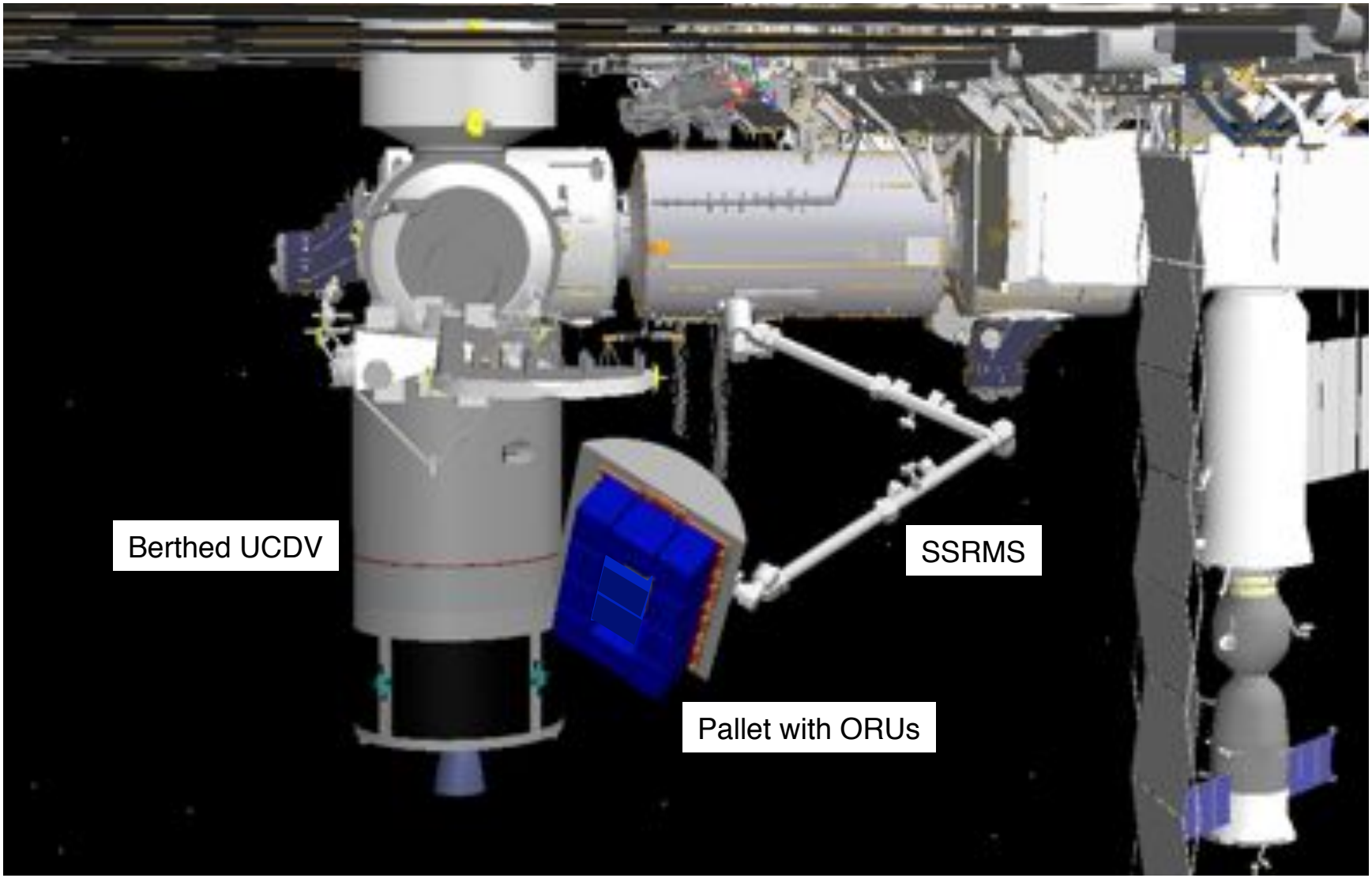
First Stage Burnout and Upper Stage Separation



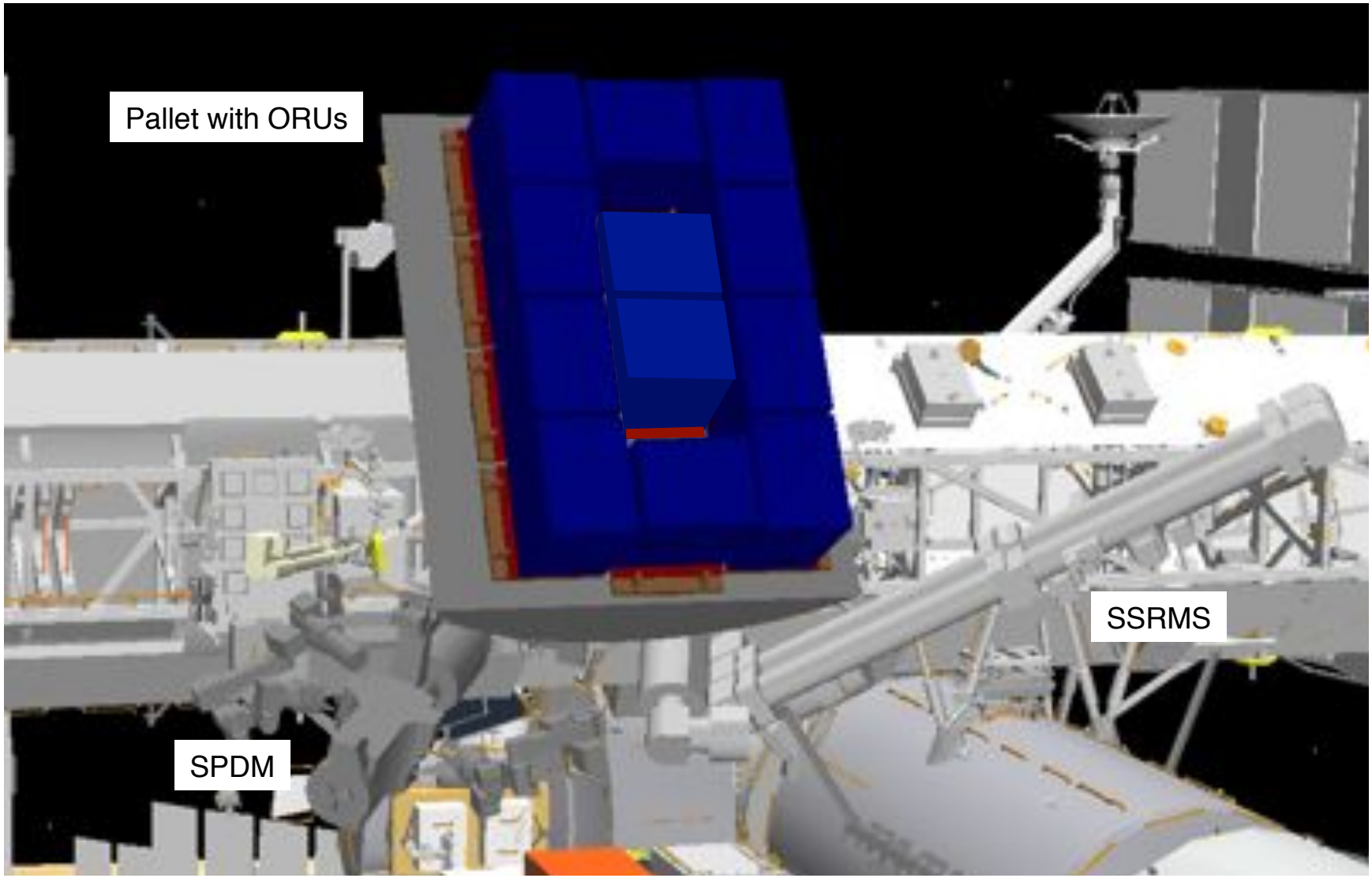
UCDV Rendezvous with ISS



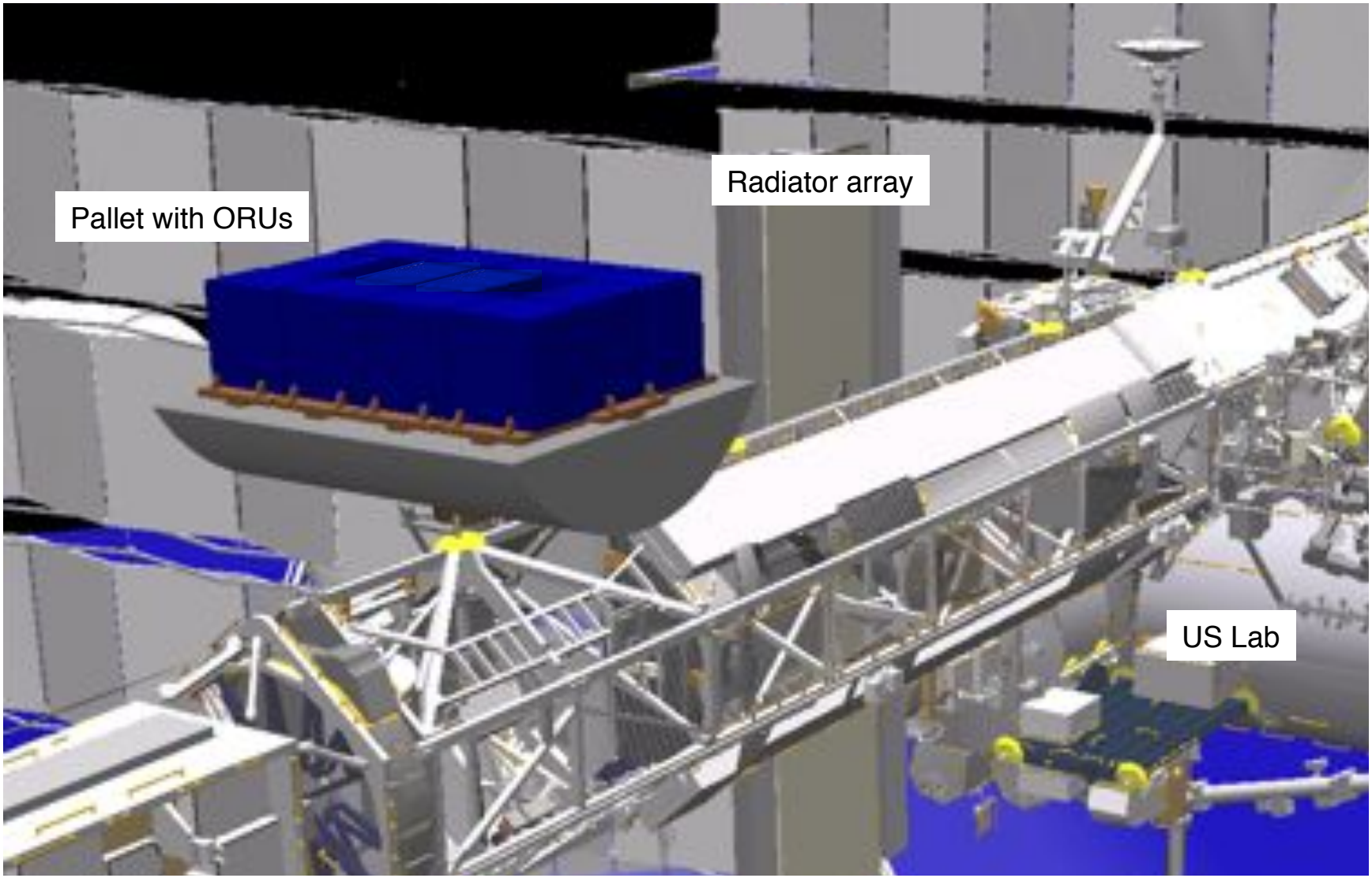
Cargo Pallet Removed from Berthed UCDV



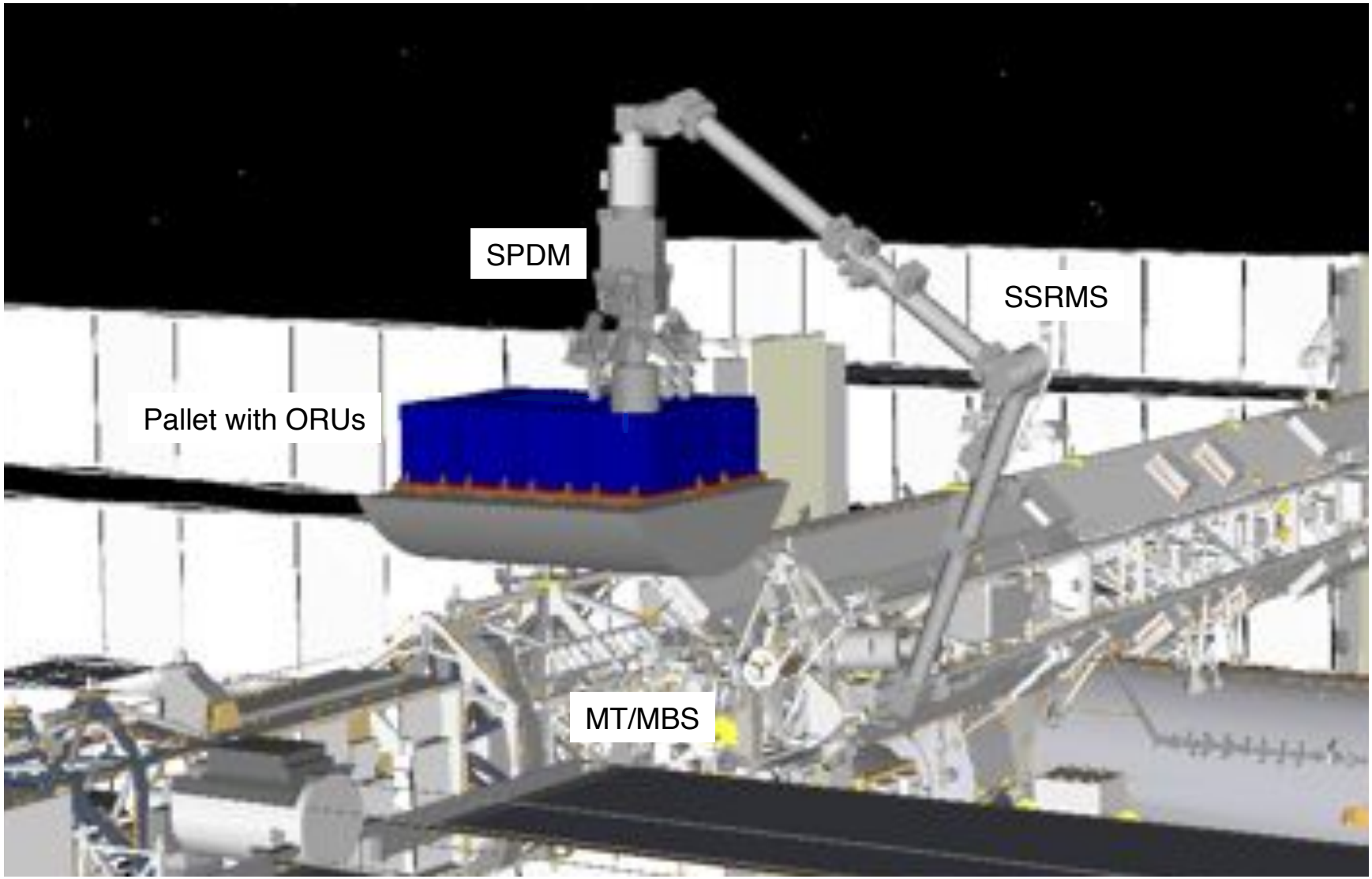
Cargo Pallet Moved Using MT/MBS



Cargo Pallet Stowed on ISS S3 Payload Site



ORU Removed from Cargo Pallet Using SPDM



Concluding Remarks

- Conceptual design of a UCDV performed by a team from NASA Langley in support of ESAS, and later refined.
- The baseline UCDV delivers 20 cargo units with 16000 lbs of logistics to ISS, and is scalable to meet changing needs.
- The UCDV satisfies all identified mission requirements using the ESAS LV 13.1 performance estimates, and also appears to be compatible with current Ares I CLV performance.
- Instead of pursuing in-house development, NASA started the Commercial Orbital Transportation Services program to provide both ISS crew transfer and cargo resupply functions.
- Phase 1 Space Act Agreement funding awarded in August 2006 to demonstrate and develop these capabilities.
- This UCDV design was presented to COTS competitors, and is also available as a fallback option for ISS resupply.

Questions?