Human Mars Entry, Descent, and Landing Architecture Study: Phase 3 Summary

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OUTER MOLD LINE UPDATE

Background

- **Mid Lift-to-Drag (Mid L/D) vehicle being considered by NASA to land large payloads on the surface of Mars**

- **During Entry, Descent, and Landing Architecture Study (EDLAS) phase 3, Mid L/D conceptual design advanced significantly**
  - Updated outer mold line (OML) shape
  - Conducted packaging feasibility study
  - Completed preliminary vehicle structure design and mass sizing

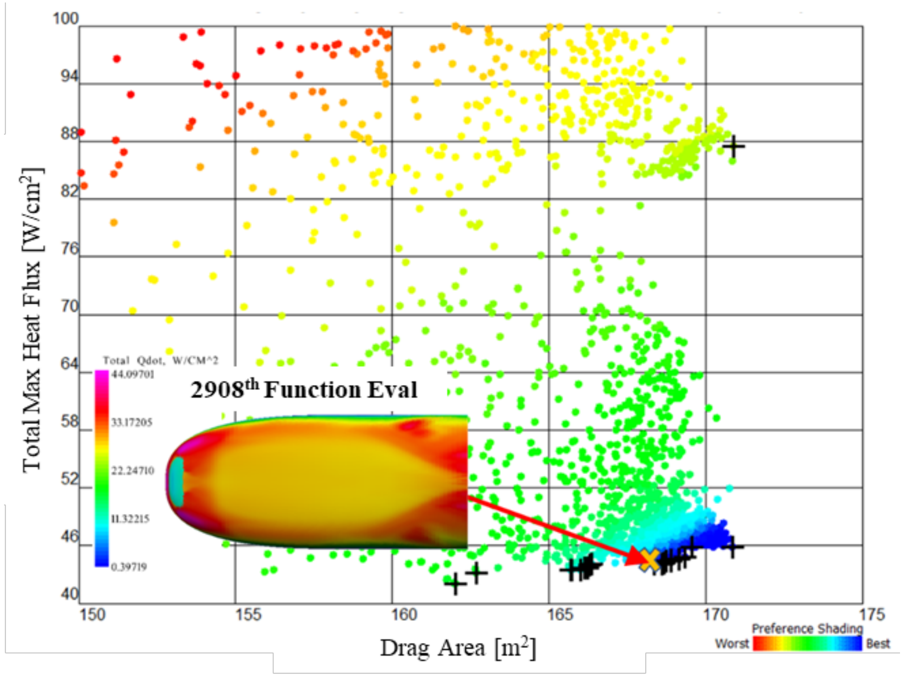
CobraMRV OML Update

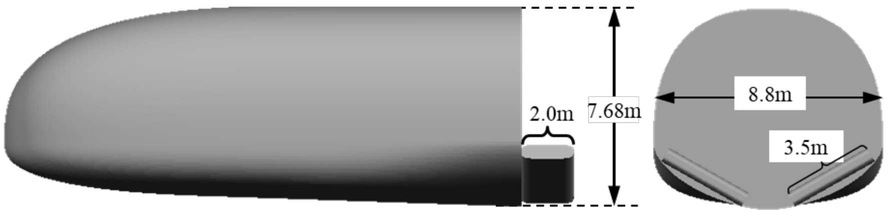
- **Co-Optimization Blunt-body Re-entry Analysis (COBRA) has been used by NASA for the past decade to arrive at a shape for the Mid L/D rigid vehicle (MRV)**
  - Goal to minimize surface heating, maximize drag area (C_dA)

- **Realistic body flap concept allowed integration of OML with body flap shape**

COBRA Optimization

- **Pareto front of multi-objective genetic algorithm (MOGA) shapes (left) used to down select CobraMRV2908 shape (right)**

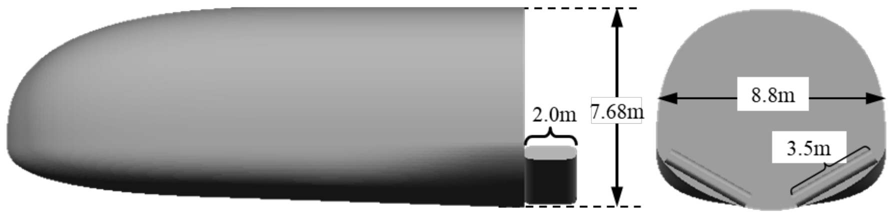




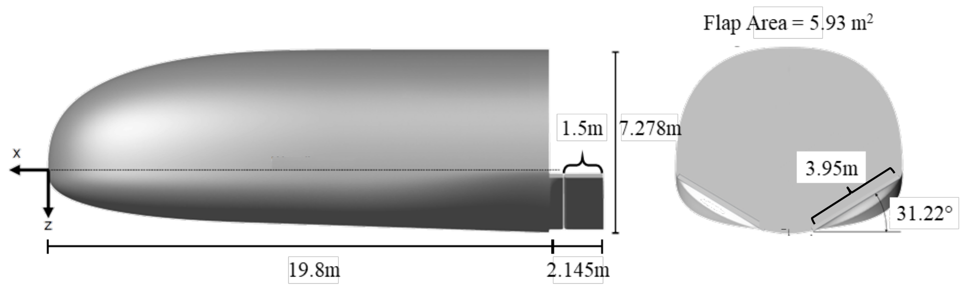
COBRA Optimization

- **2908 shape was modified to 2908b**
  - Allowed fit within SLS 10m shroud (Ø9.1 m inner volume)
  - Reduced high heating and flow separation on body flaps

2908

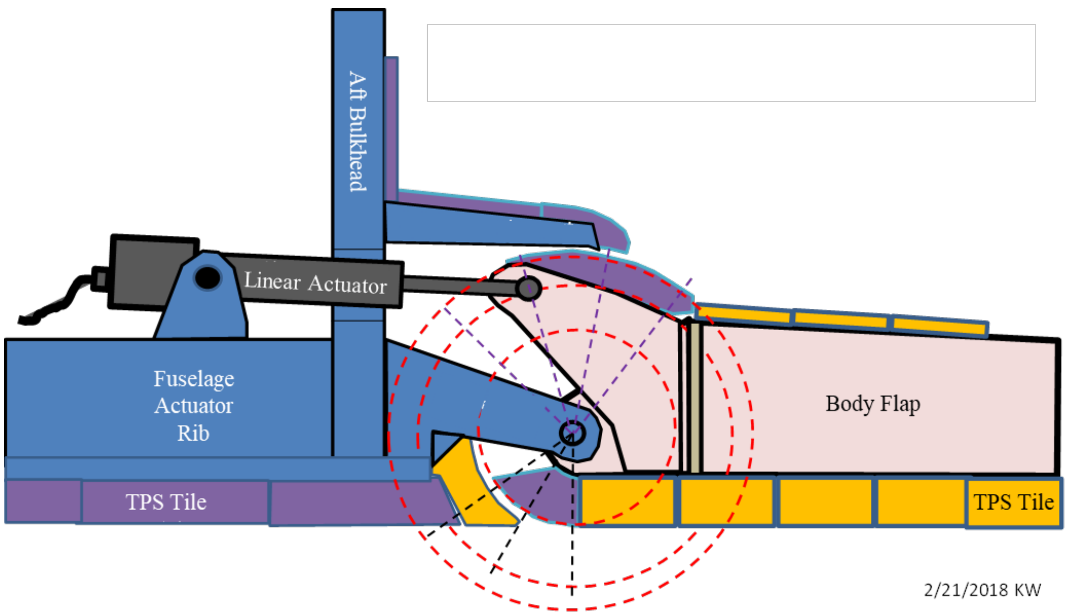


2908b



Body Flap Concept

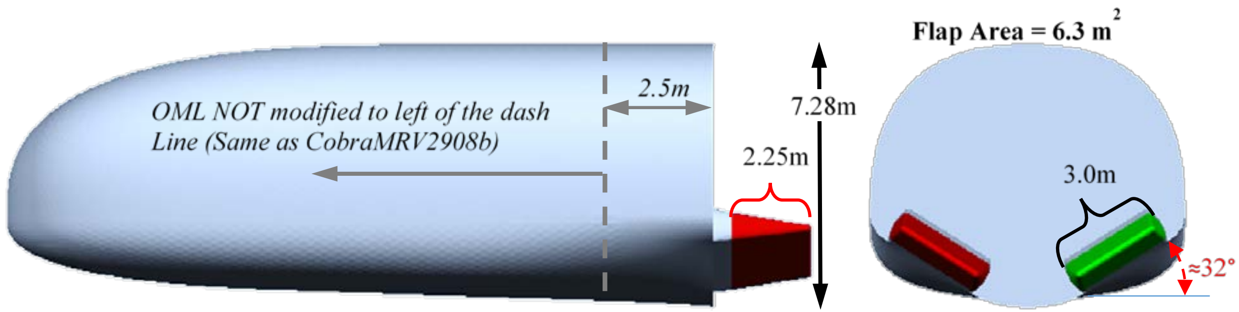
- **Conceptual design for body flap structure and actuators enabled more realistic modelling**
  - Below concept was based on Space Shuttle Orbiter design



COBRA Iteration

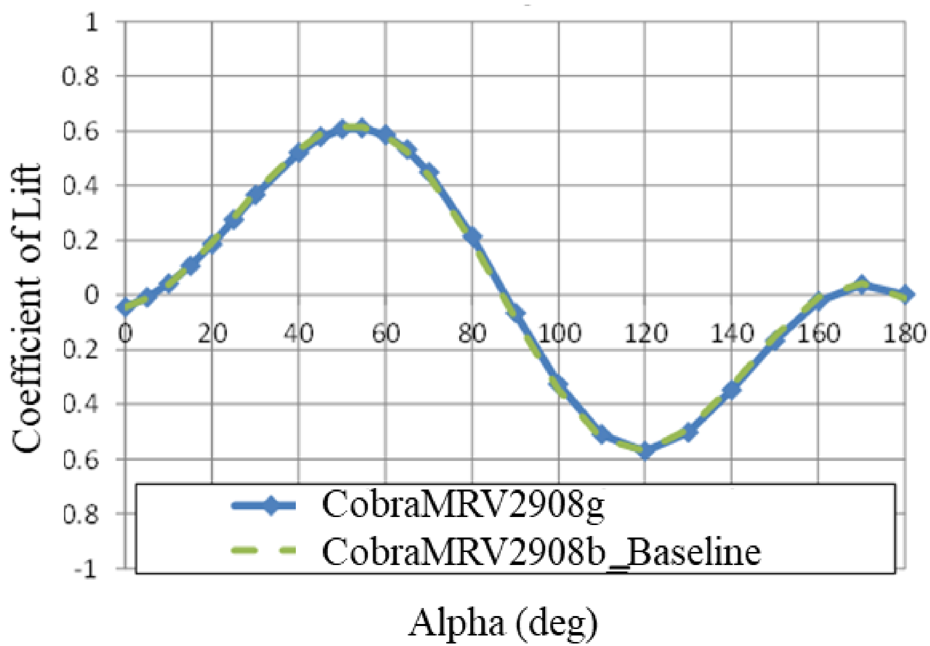
- **2908c → 2908d → 2908e → 2908f → 2908g**
  - Re-lofted aft 2.5 m of OML to smooth body flap transition
  - Changed to trapezoidal flaps
  - Increased cant angle and planform area of flaps
  - Increased aft body base corner radii to reduce heating

2908g



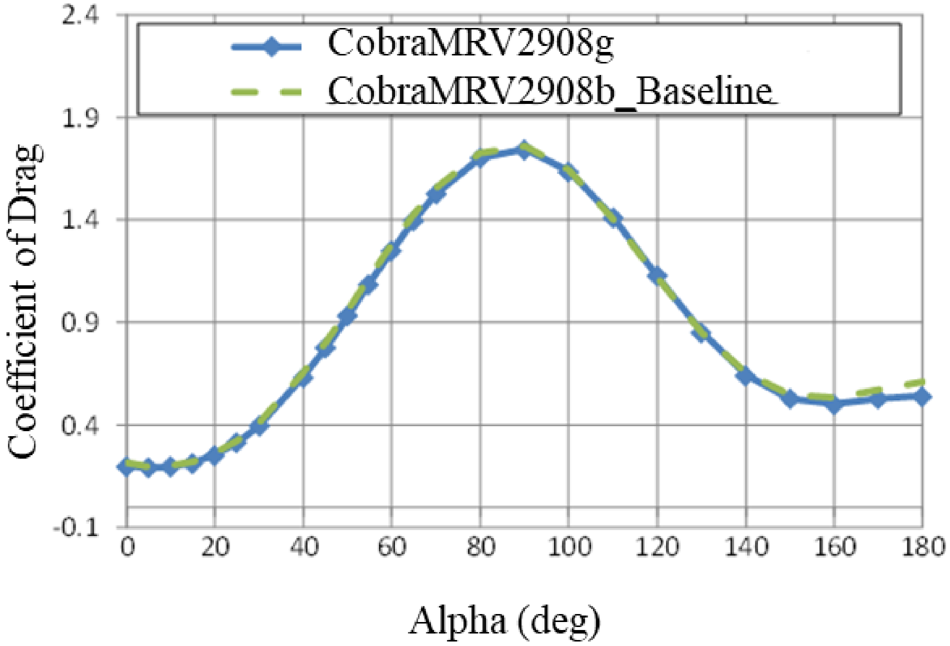
2908g Comparison

- **Used CBAERO Newtonian aerodynamic tool to compare 2908g to 2908b**
  - Similar Coefficient of Lift



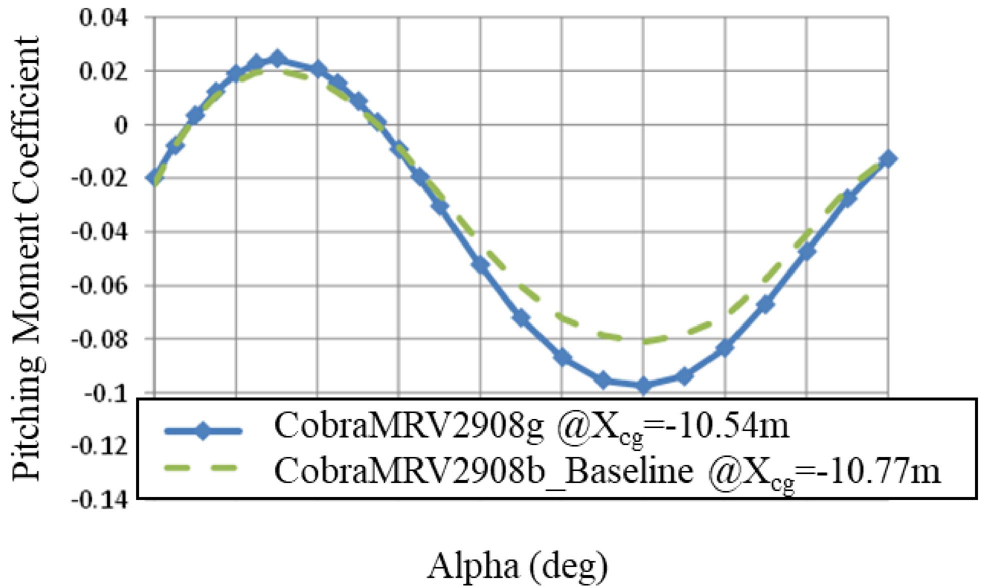
2908g Comparison

- **Used CBAERO Newtonian aerodynamic tool to compare 2908g to 2908b**
  - Similar Coefficient of Drag



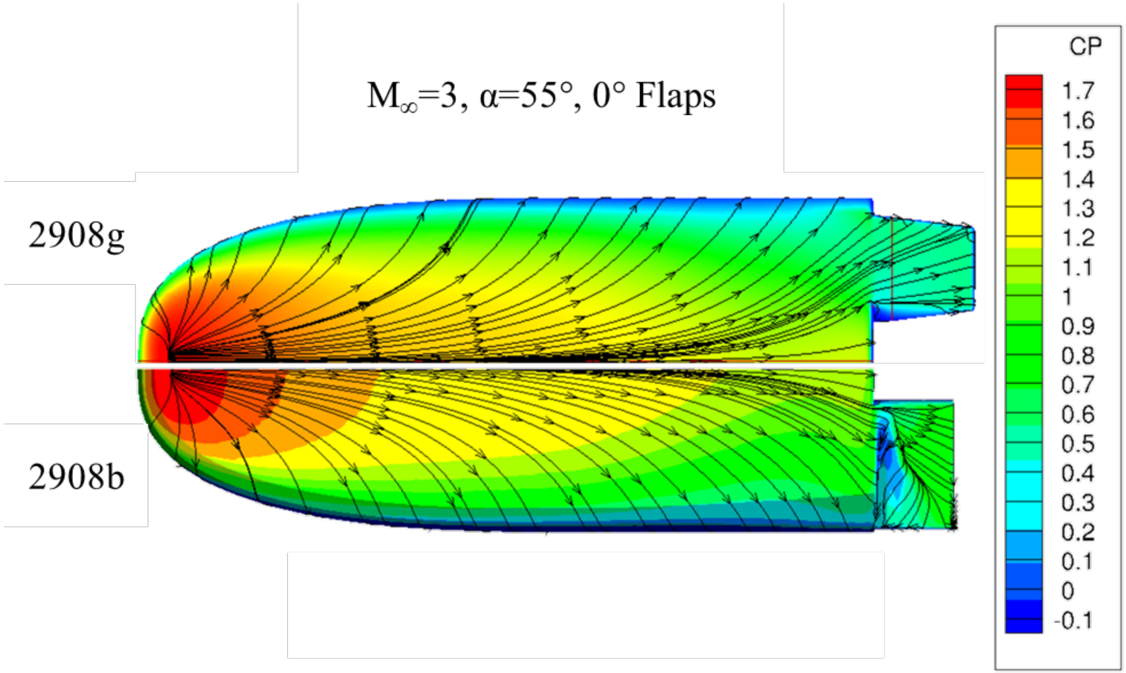
2908g Comparison

- **Used CBAERO Newtonian aerodynamic tool to compare 2908g to 2908b**
  - Improved pitching moment coefficient at high angles of attack



2908g Comparison

- **Used Kestrel computational fluid dynamics software to verify flow improvements**
  - Improved flow onto body flaps



Joseph Amar, Holly Newton, Zachery Wiens

MANIFEST PACKAGING

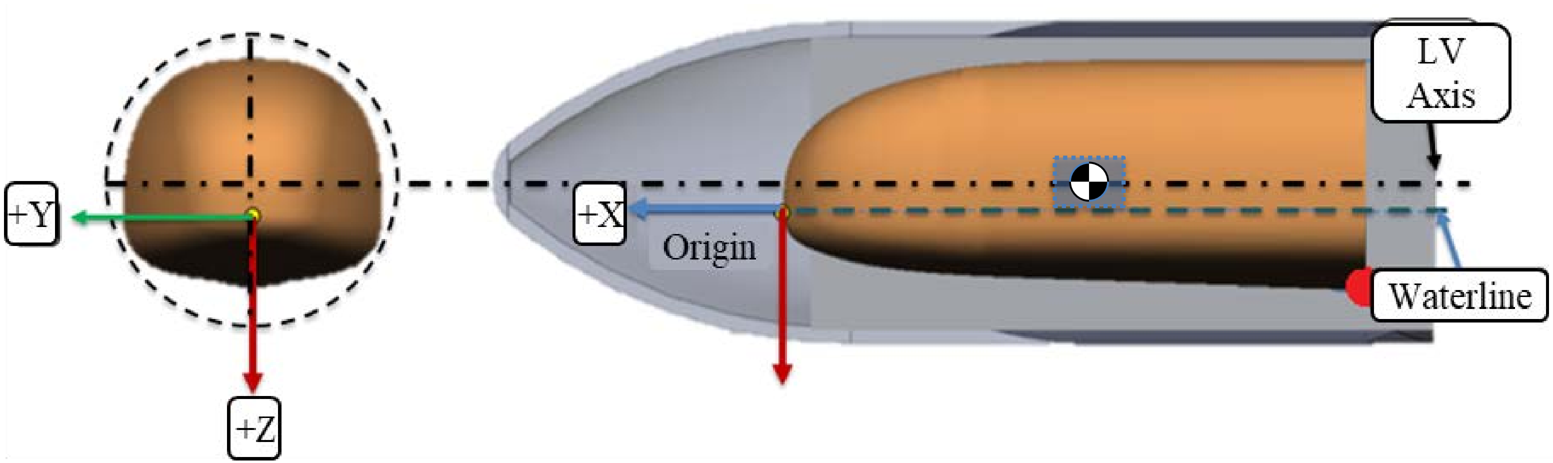
Assumptions

- **Assumed 22T Payload manifest for Crew Expedition 1 Mission**
  - Cargo-1, Cargo-2, Crew-1
  - Common items across manifest would be identically placed
- **Used the 2908G OML, manifest packaging for Cargo 2 for sizing**
  - Modeled frame to match OML form
- **Creo Parametric software used to conuct packaging and CG estimation**

CG Requirement

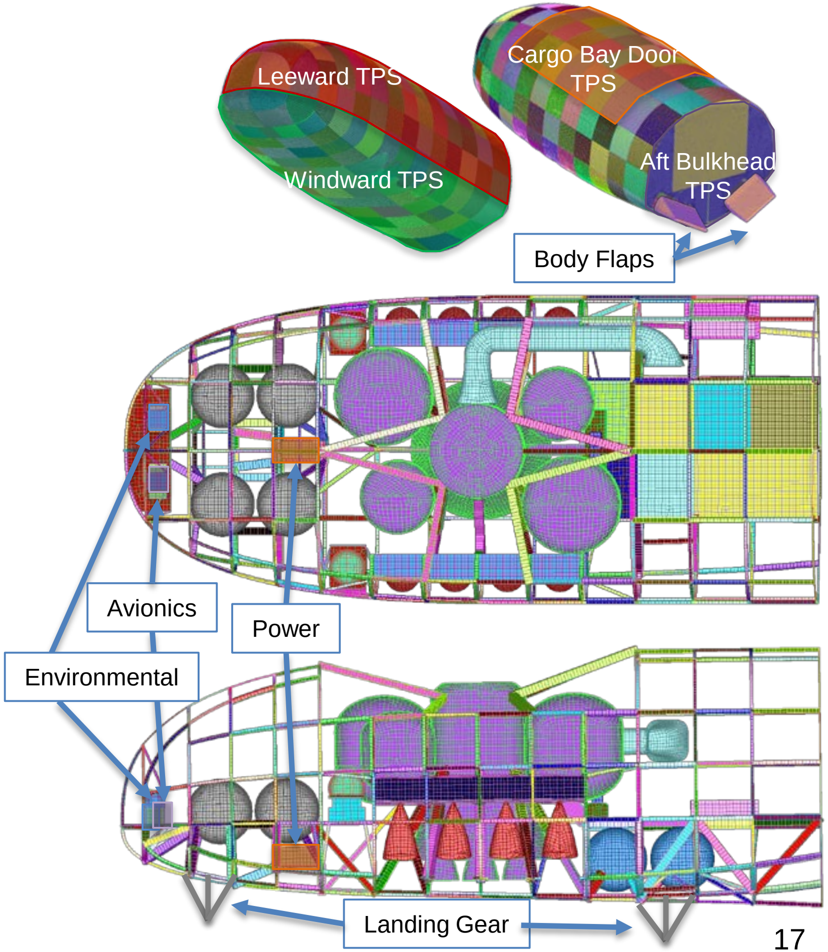
- **CG should be mid-body of MRV, along launch vehicle (LV) axis**

Axis	Minimum (m)	Maximum (m)
X	-10.747	-10.347
Y	-0.050	0.050
Z	-1.100	0.000



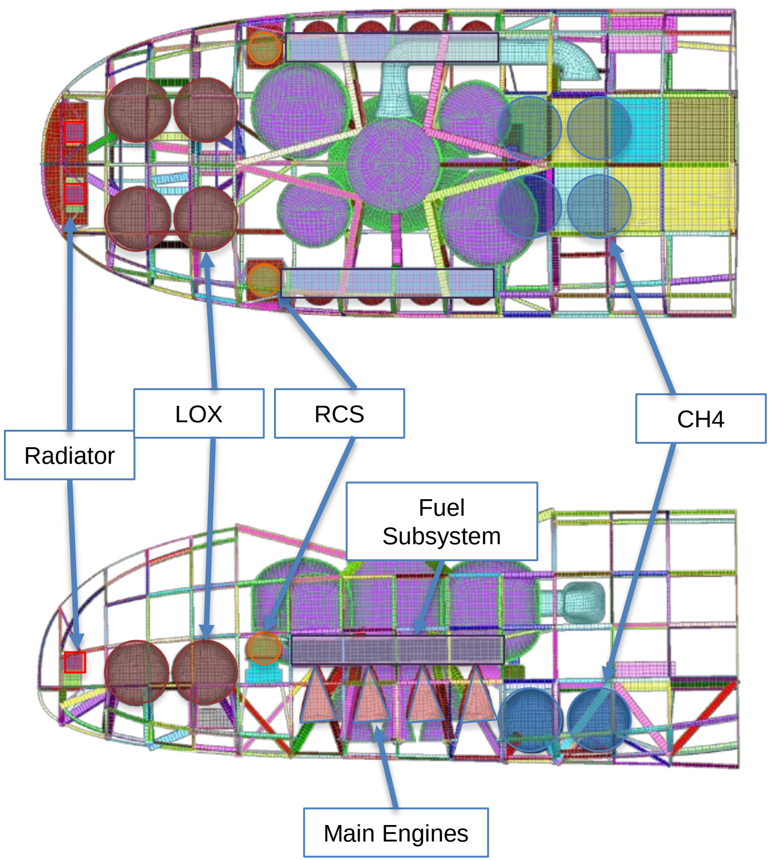
Expedition 1 Common Subsystems

Component	Qty.	Mass Each (kg)	Mass Total
Thermal Protection System (TPS)			**4624**
Windward	1	3590	3590.21
Aft Bulkhead	1	65	64.75
Aft Door	1	73	73.40
Leeward	1	653	653.13
Cargo Bay Doors	2	121	242.50
Acoustic Thermal Protection – Dist.			**635**
IML Blankets	1	459	458.80
IML Radiant Barrier - MLI	1	65	65.10
Lightning Protection	1	111	110.90
Power			**470.00**
Power Distribution	1	400	400.00
Power Cable (1 km) spool	1	70	70.00
Body Flaps	2	298	**595.40**
Landing Gear	3	388	**1164.60**
Avionics			**333.00**
Command and Data Handling	1	141	141.00
Communications and Tracking	1	76	76.00
Guidance, Navigation, & Control	1	116	116.00
Environmental Cabin			**212.50**
Active Cooling Loops	1	200	200.00
Heaters	1	13	12.50



Expedition 1 Common Subsystems

Component	Qty.	Mass Each (kg)	Mass Total
In-Space Radiator	**1**	**191**	**191**
Other – Dist.			**379**
Purge System	1	301	301
Umbilicals Interfaces	1	78	78
Methane + Tank	4	1080	**4322**
LOX + Tank	4	3274	**13095**
Fuel Subsystem	2	328	**656**
RCS Prop Distribution	2	205	**411**
RCS Cluster	2	506	**1013**
Main Engine	8	250	**2000**
Aft Ramp System			**469**
Strut	2	8	16
Hard stop	1	49	49
Hinges	1	22	22
Perimeter Seal	1	41	41
Ramp	1	175	175
Mechanism	1	166	166
Cargo Bay Doors Mech.			**360**
Power Drive Units	10	10	96
Rotary Actuators	8	6	46
Latches	22	8	168
Hinges	16	3	50



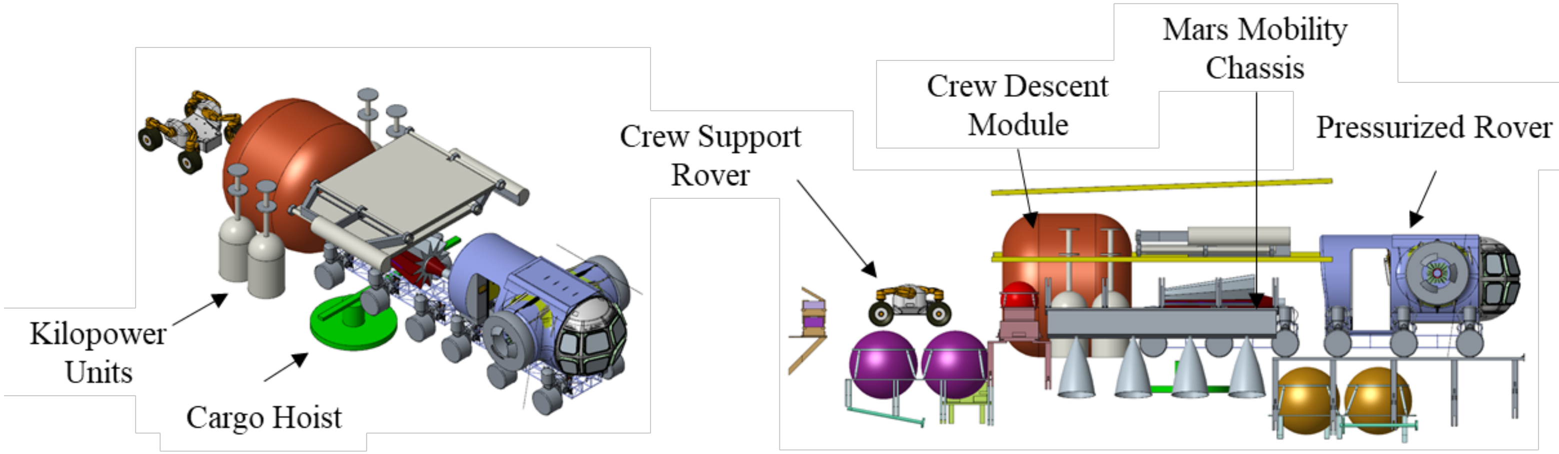
Expedition 1 Payload Manifest

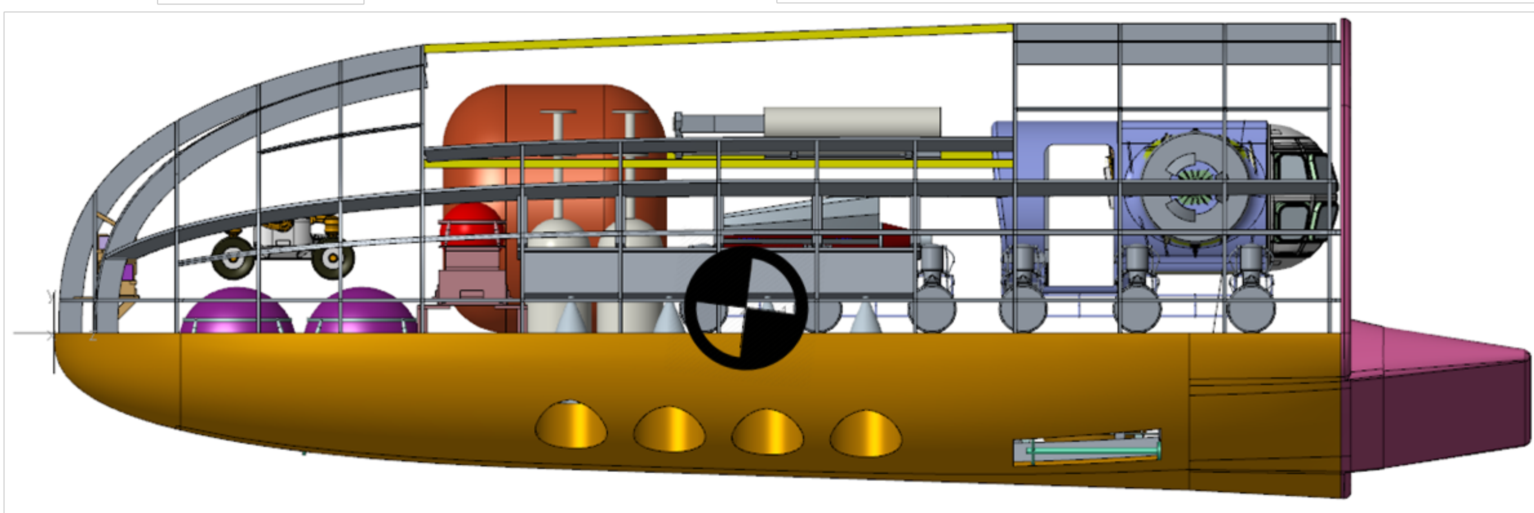
- **Cargo-1**

Manifested Item	Mass (kg)	Qty	Mass (kg)
Kilopower, 10 kW each	1544	5	7720
Power Management/Distribution	400	1	400
Power cable (1 km) spool	70	1	70
Crew Support Rover	1225	1	1225
Cargo Hoist	600	1	600
Crew Descent Module	3516	1	3516
Mars Mobility Chassis	2457	1	2457
Pressurized Rover	6021	1	6021
Total Payload Mass			22009

Cargo-1 Packaging

Zachery Wiens





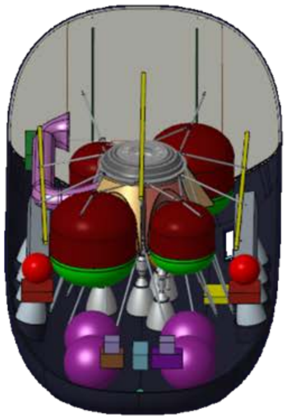
Expedition 1 Payload Manifest

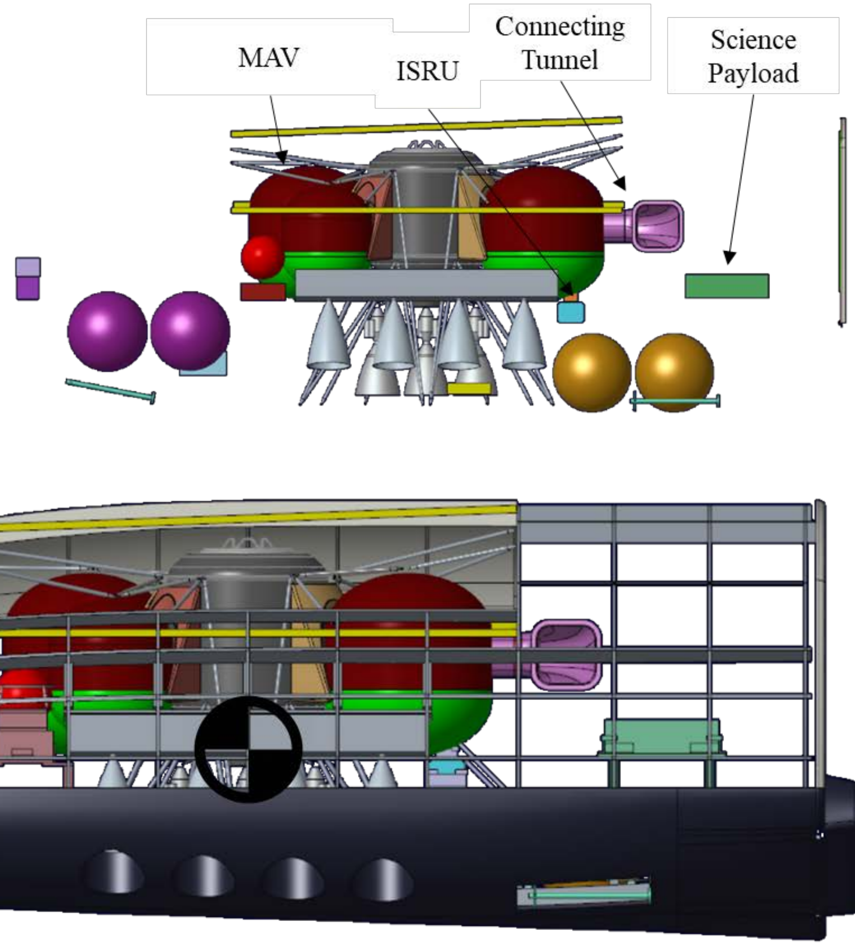
- **Cargo-2**

Manifested Item	Mass (kg)	Qty	Mass (kg)
Atmospheric Production Plant	1032	1	1032
Part of ISRU radiator mass	478	1	478
ISRU Deployment	130	1	130
Power Management/Distribution	400	1	400
Power cable (1 km) spool	70	1	70
Connecting Tunnel	237	1	237
Allocated Science Payload	1000	0.2	200
MAV (5 sol, wet)	18868	1	18868
Part of MAV Radiator	212	1	212
MPS Tank Cryocoolers/BAC charged to MAV	141	1	141
MDM-to-MAV Adapter	200	1	200
Total Payload Mass			21968

Cargo-2 Packaging

Holly Newton





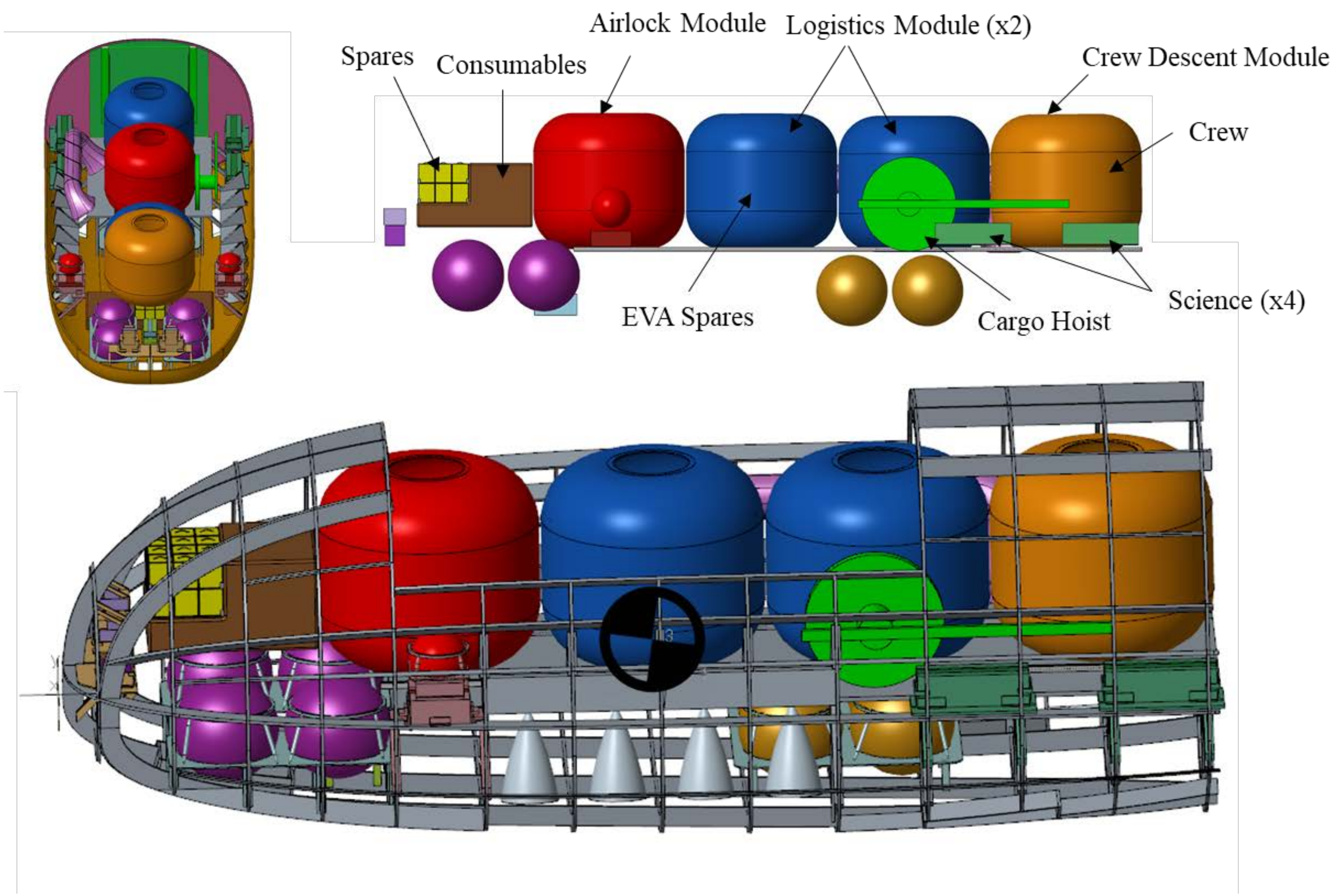
Expedition 1 Payload Manifest

- **Crew-1**

Manifested Item	Mass (kg)	Qty	Mass (kg)
Crew (each)	100	4	400
Power Management/Distribution	400	1	400
Power cable (1 km) spool	70	1	70
Cargo Hoist	600	1	600
Logistics Module (Dual Hatch 3500 kg capacity)	2600	2	5200
Crew Descent Module	3516	1	3516
Airlock Module	3500	1	3500
Connecting Tunnel	237	1	237
Consumables (4.02 kg/person/sol + 97.57)	4.02	163	2719
Spares and Other Logistics (2.946 kg/sol + 2112.9 kg)	2.946	163	2593
Maintenance Equipment	70	1	70
EVA Suit + Primary Life Support System	693	1	693
Launch-Entry Assembly Suits	104	1	104
Spares (1.73 kg/sol/crew + 796.8)	4 crew	163	1079
Allocated Science Payload	1000	0.8	800
		21981	

Crew-1 Packaging

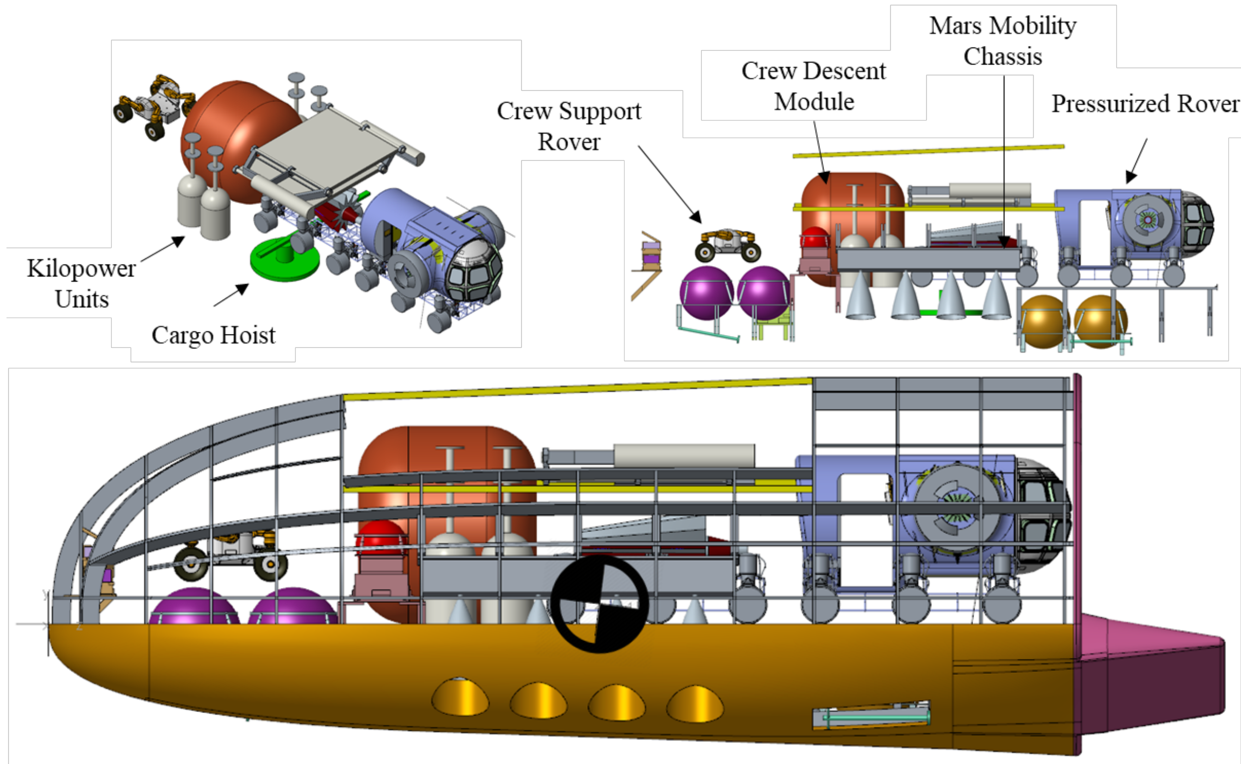
Joseph Amar



CG Cargo 1

Zachery Wiens

- **Calculated CG with all Cargo-1 items:**
  - X: 10.557 m
  - Y: -0.0139 m
  - Z: 0.393 m



CG Estimations

- **All configurations meet CG requirements**

Manifest	X_{CG} (m)	Y_{CG} (m)	Z_{CG} (m)
Cargo-1	-10.557	-0.014	-0.393
Cargo-2	-10.446	0.001	-1.009
Crew-1	-10.380	-0.006	-0.013

Damien Calderon

STRUCTURAL SIZING AND OPTIMIZATION

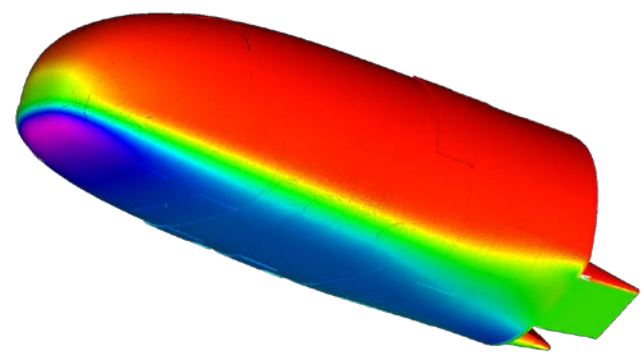
Initial Assumptions

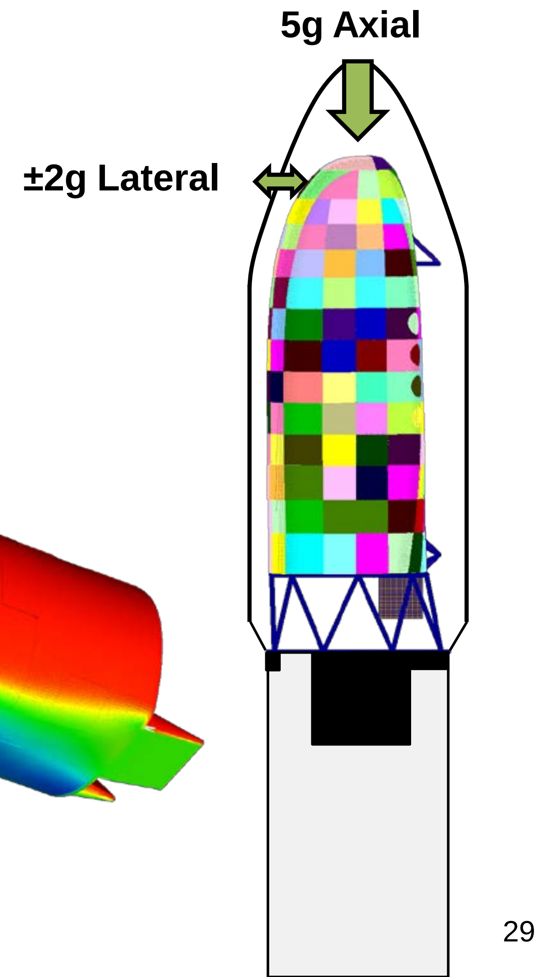
- **Used the 2908G OML, manifest packaging for Cargo 2 for sizing**
  - Modeled frame to match OML form
  - Modified substructure to support cargo packaging, dynamic constraints
- **MSC Nastran used as a linear solver (SOL 101)**
- **Collier Research Hypersizer used for sizing optimization**
- **All sized structure assumes Aluminum 2024 construction**

Load Cases

Four load cases envelope the design:

1. **Earth Launch/Ascent**
   - +5g Axial, +/-2g Lateral
   - 0-0.5 psig Vent Pressure
2. **Mars Entry**
   - Peak Dynamic Pressure
3. **Mars Propulsive Descent**
   - 800 kN
4. **Mars Landing**
   - 3g

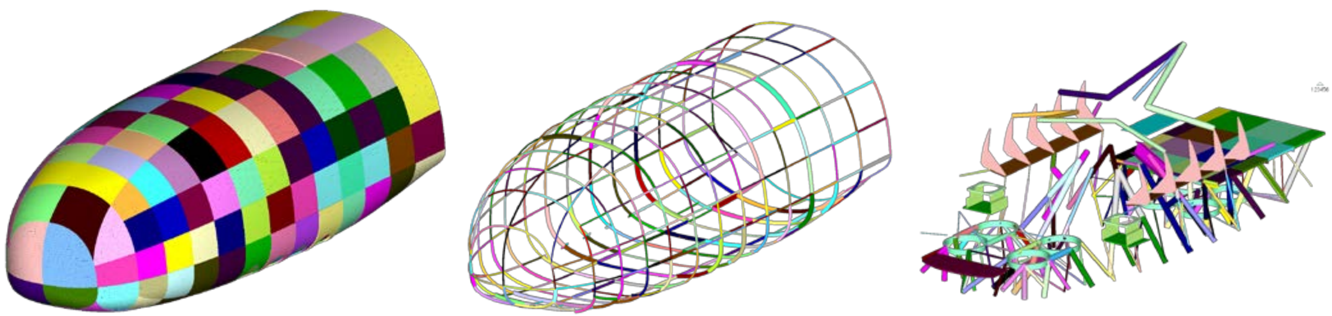




Structural Architecture

- **Skin, Airframe (Ring, Longeron), Substructure**

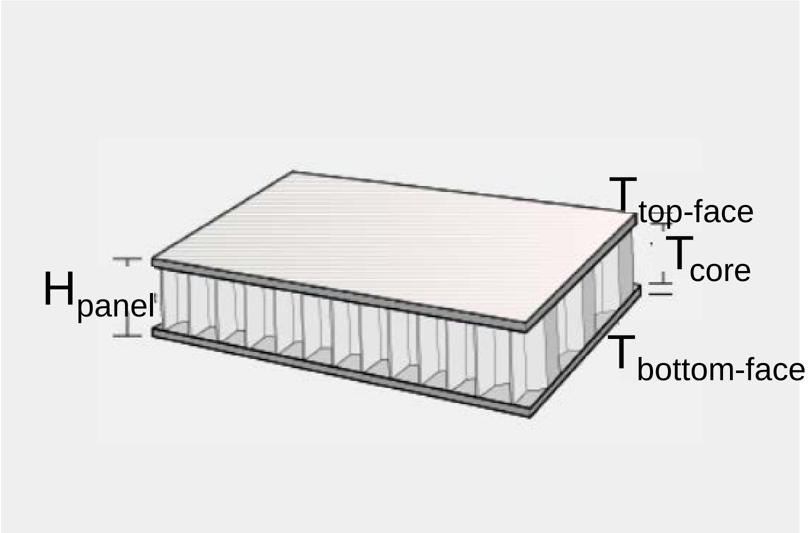
- **Components modeled as discrete members, sized independently to allow for optimum mass**



OML Skin **Airframe** **Substructure**

Honeycomb Sandwich Panels

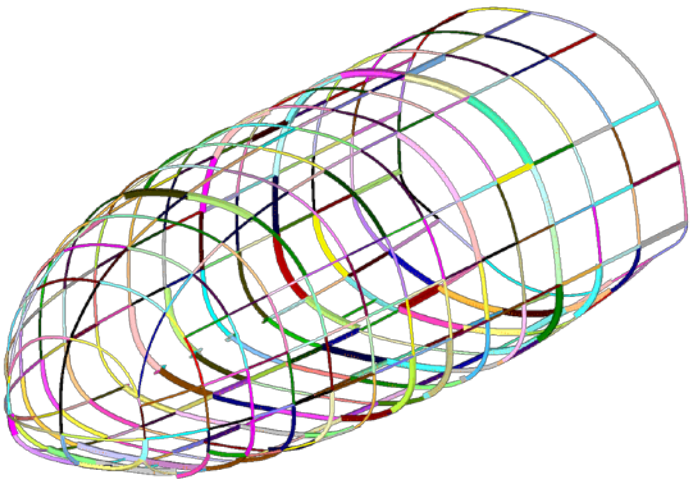
OML Skin and Cargo Doors

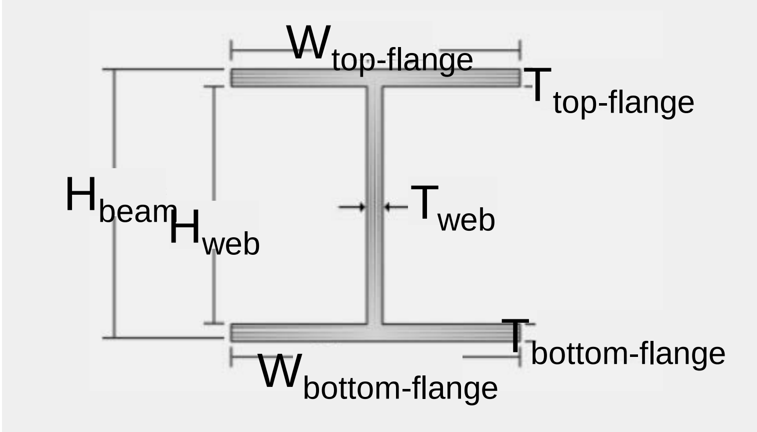


Dimension	Min (mm)	Max (mm)
T_{bottom}	0.3	3.0
T_{core}	20.0	100.0
T_{top}	0.3	3.0

Beam Components

Longerons and Ring Frame

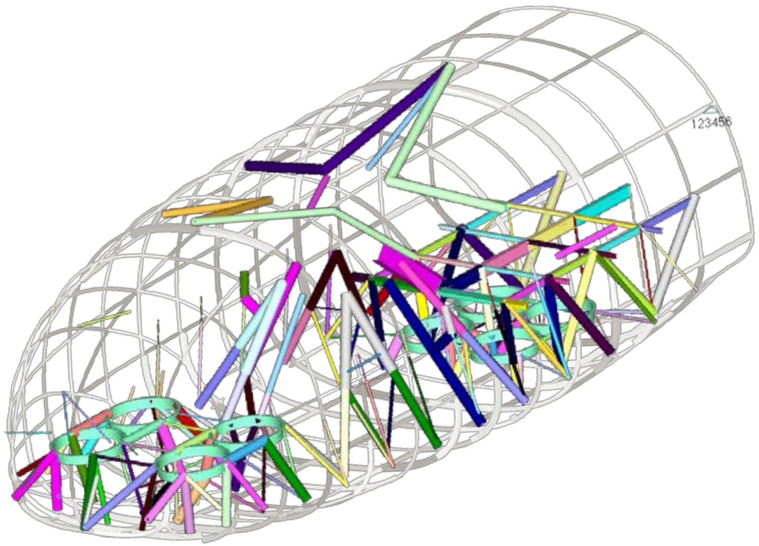


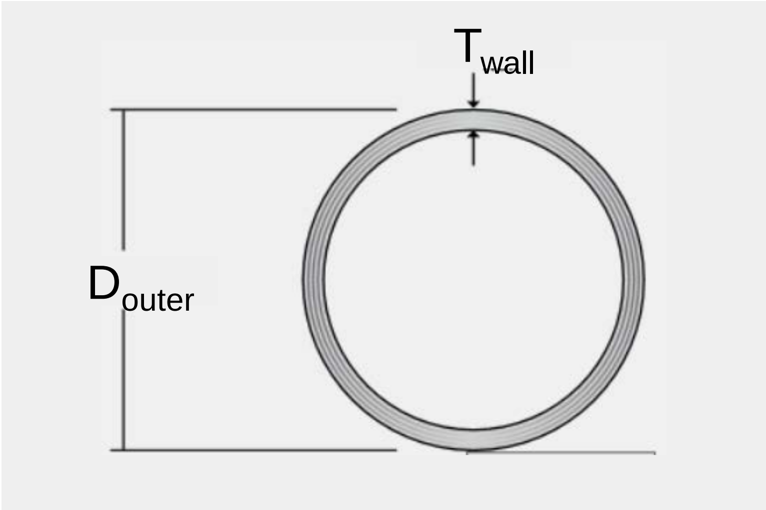


Dimension	Min (mm)	Max (mm)
T_{top}	2.0	20.0
T_{web}	2.0	20.0
T_{bottom}	2.0	20.0
W_{top}	30.0	200.0
W_{bottom}	30.0	200.0
H_{beam}	30.0	200.0

Beam Components

Cargo Support Struts

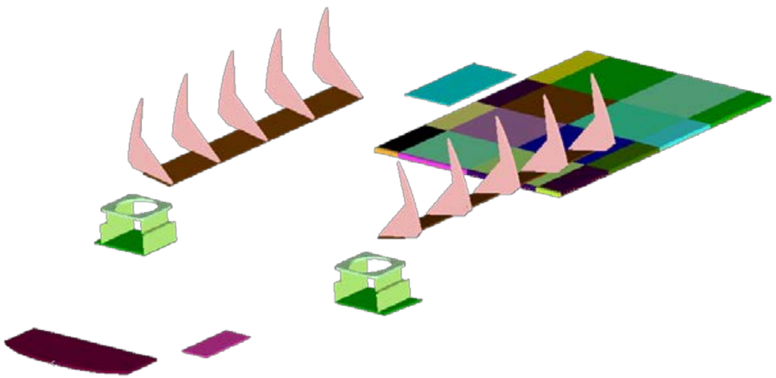


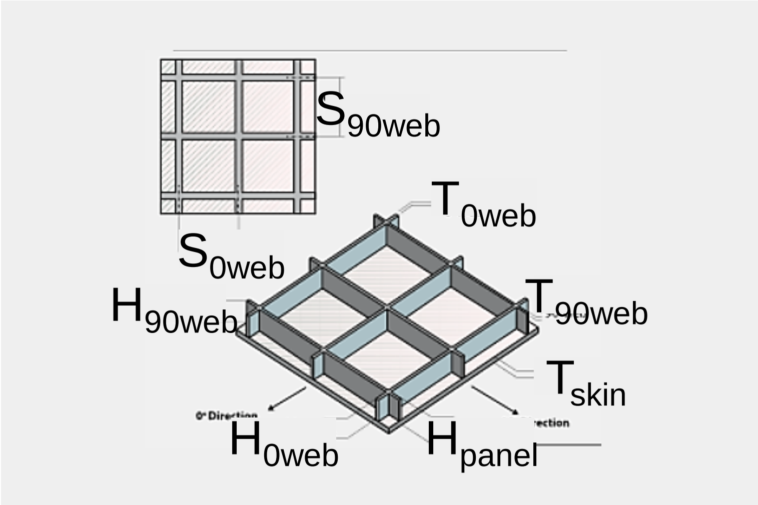


Dimension	Min (mm)	Max (mm)
D_{outer}	1.0	15.0
T_{wall}	30.0	250.0

Grid Stiffened Panels

Substructure





Dimension	Min (mm)	Max (mm)
T_{skin}	1.0	10.0
T_{0web}	2.0	20.0
T_{90web}	2.0	20.0
H_{0web}	20.0	100.0
H_{90web}	20.0	100.0
S_{0web}	50.0	800.0
S_{90web}	50.0	800.0

Basic Mass Results

Baseline predicted structural mass: 10281 kg

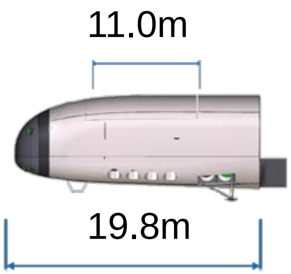
Assembly	Basic Mass (kg)	20% MGA (kg)	Predicted Mass (kg)
Skin	4111	822	4933
Frame	1483	297	1780
Substructure	2973	595	3568
Total Structural Mass	*8567*	*1714*	*10281*

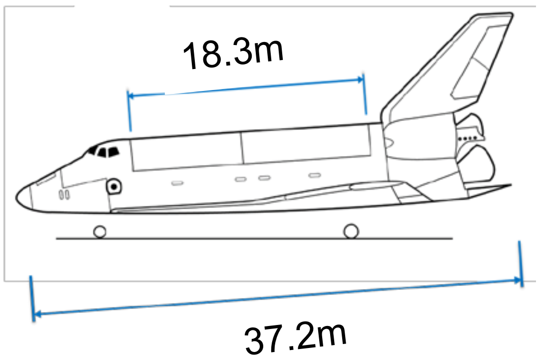
BACKUP

Cargo Bay Doors (CBD)

Theodore Christian/JSC

- Orbiter payload bay door (PLBD) system actuator was 0.66 t (1446.2 lbm)
- Assume system mass scales with area PLBD:CBD ~ 1.83:1
- Estimated mass of CobraMRV CBD mechanisms and associated structure is 0.36 t (793.7 lbm)





Predicted CobraMRV

Major Components	
Power Drive Units	10
Rotary Actuators	8
Latches	22
Hinges	16

Total number of parts: 56

Aft Door/Ramp

Amy Quartaro/JSC

- **Assumptions**
  - Single Use Deployment
  - Vent Pressure of 0.5psi

- **Design Background – C130 Hercules cargo ramp**
  - Frangible nuts to secure door, blown upon deployment
  - Pin/Hammer system to encourage door deployment
  - Struts, hard stop to control drop of door
  - Pin system to release support ramp

Aft Door/Ramp (cont)

Amy Quartaro/JSC

- **Estimated door/ramp mass ~177 kg (389 lbs)**
- **Estimated mechanisms and seal mass ~209 kg (460 lbs)**