# Study of Orbiter-like Cargo Carrier on Crew Launch Vehicle

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## FEMCI Workshop 2006
### Goddard Space Flight Center, Greenbelt, Maryland

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# Content:

- **Study objective and requirements**
- **Vehicle size and two candidate designs**
- **Structural requirements, loads and interfaces**
- **Outline of analytical process**
- **Details of two designs and analytical weight prediction**
- **Non-optimal weight estimates**
- **Summary**

# Objective:

• **Design and determine primary structures analytical weight for an Orbiter-like Cargo Carrier concept that was examined during the early phase of the Crew Launch Vehicle (CLV ) program to fly attached on top of CLV**

 • **This vehicle is not part of the current program**

# Design Requirements:

• Cargo Carrier was envisioned to enable delivery
of all  International Space Station (ISS) elements
(15 ft dia., 48 ft length, 55,000 lb weight)
in Orbiter like payload accommodation environment

• No modifications of existing payload hardware
was required

# Size
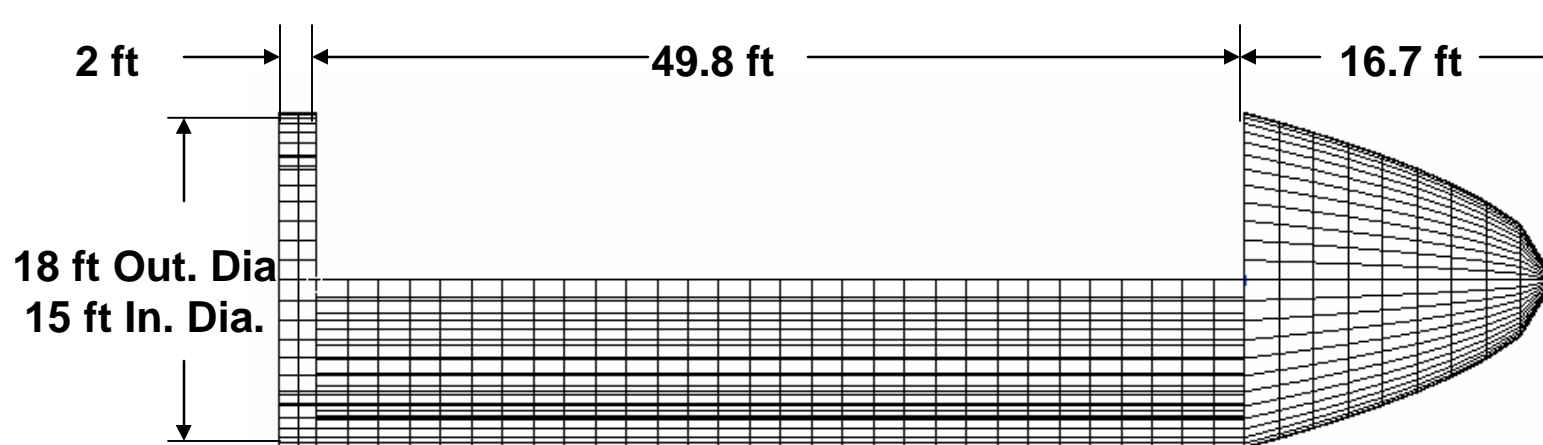
- **Inner diameter equaled Orbiter's inner diameter of 15 feet (4.57 meters)**

- **Outer diameter was 18 feet (5.49 meters)**

- **Length of Cargo Bay equaled the useful length of Orbiter Payload Bay when Orbiter was configured with ISS external airlock and Orbiter Docking Structure, 598 inch or 49.8 feet (15.2 meters).**
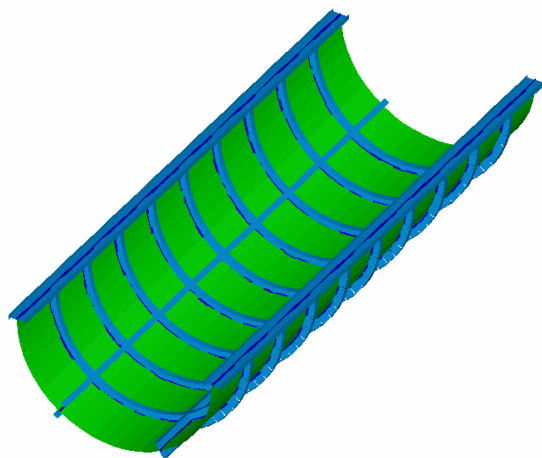


2 ft     49.8 ft     16.7 ft

18 ft Out. Dia
15 ft In. Dia.

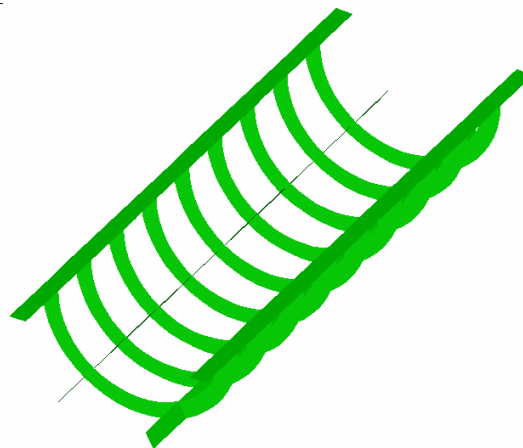**Zoran N. Martinovic/NASA LaRC/VAB October 2006**

# Design

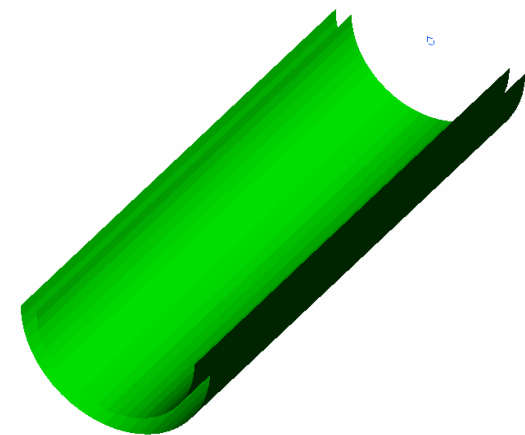## Two designs were considered and sized

- **Open Wall Design** that consisted of stiffened skin with stringers, longerons and frames.

- **Closed Wall Design** that had outer stiffened skin closed with inner skin that resists torque loads.



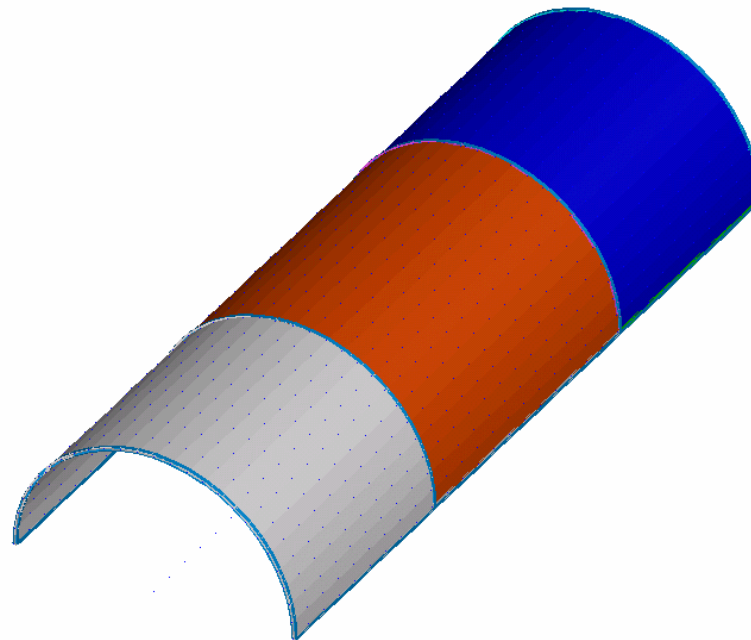**Open Wall Design**          **Closed Wall Design**

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# Design (cont.)

**Cargo Bay doors were designed and sized
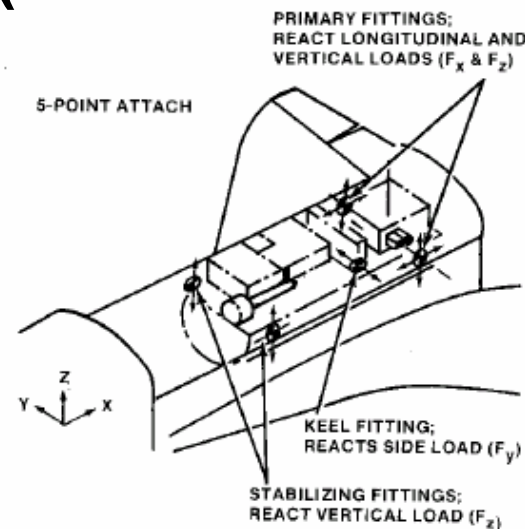and there influence factored in the Closed
Wall Design sizing of Cargo Carrier**

# Structural Requirements

- Payload attachments were like in Orbiter and statically determinate *
- Load Factors: axial 4g, lateral 1g (1.41 g lateral combined).
- Safety Factor (Ultimate Load/Limit Load) equal to 1.5



* **Space Shuttle System Payload Accommodations, NSTS 07700 Vol. XIV**
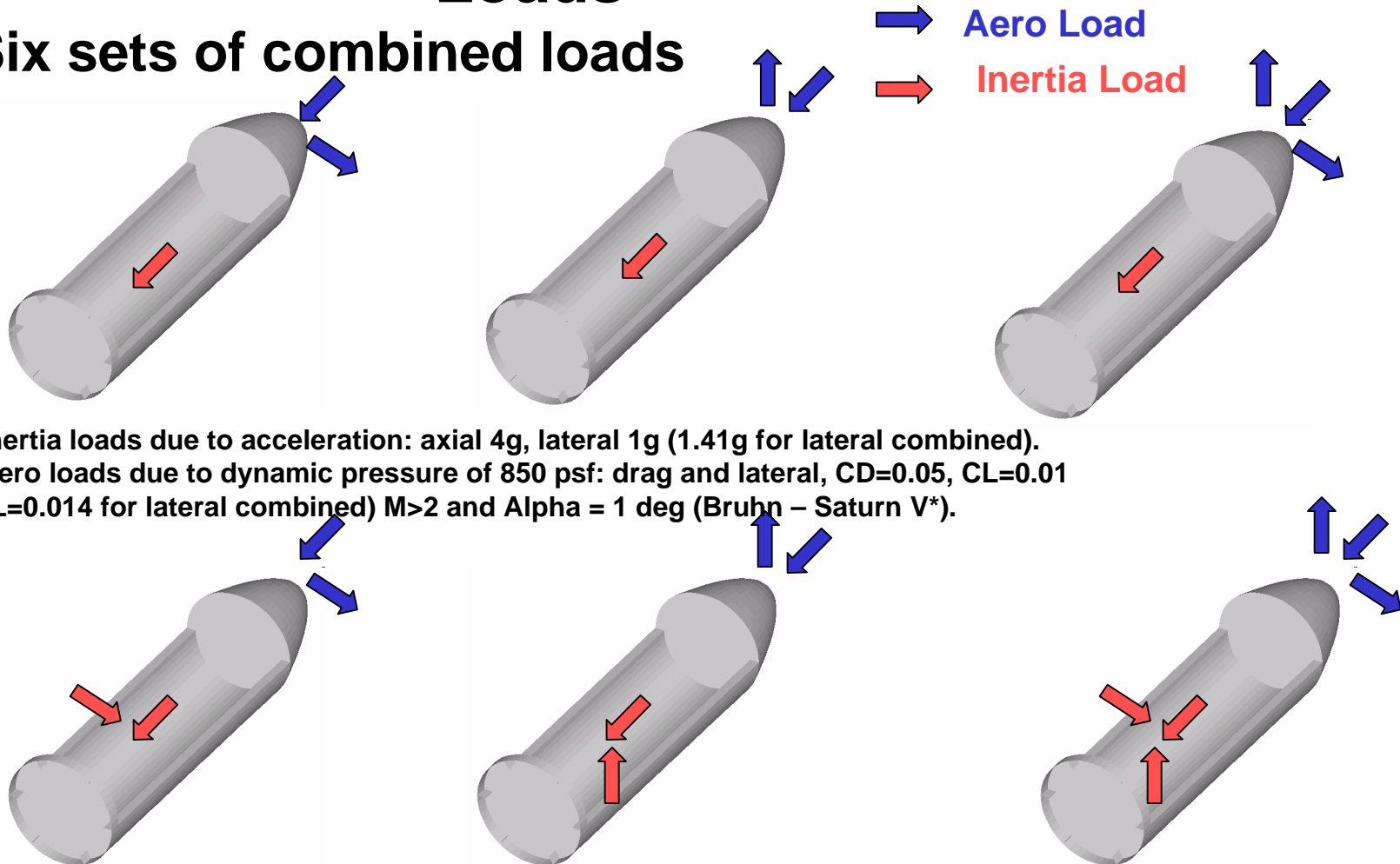
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# Loads

- **Six sets of combined loads**

Aero Load

Inertia Load



- Inertia loads due to acceleration: axial 4g, lateral 1g (1.41g for lateral combined).
- Aero loads due to dynamic pressure of 850 psf: drag and lateral, CD=0.05, CL=0.01 (CL=0.014 for lateral combined) M>2 and Alpha = 1 deg (Bruhn – Saturn V*).

**\* Analysis and Design of Missile Structures, E.F. Bruhn, Tri-State Offset Co., 1967**

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# Payload and Payload attachment

- **Payload weight 55,000 lb (25,000 kg)**
- **Payload modeled as a lump mass with inertia properties of a cylinder 500 inch long and 168 inch diameter**



PRIMARY FITTINGS; REACT LONGITUDINAL AND VERTICAL LOADS ($F_x$ & $F_z$)

5-POINT ATTACH

KEEL FITTING; REACTS SIDE LOAD ($F_y$)

STABILIZING FITTINGS; REACT VERTICAL LOAD ($F_z$)

Payload

# Carrier attachment to launch vehicle/service module

- **Six ball joints at longerons (60 deg. apart)**
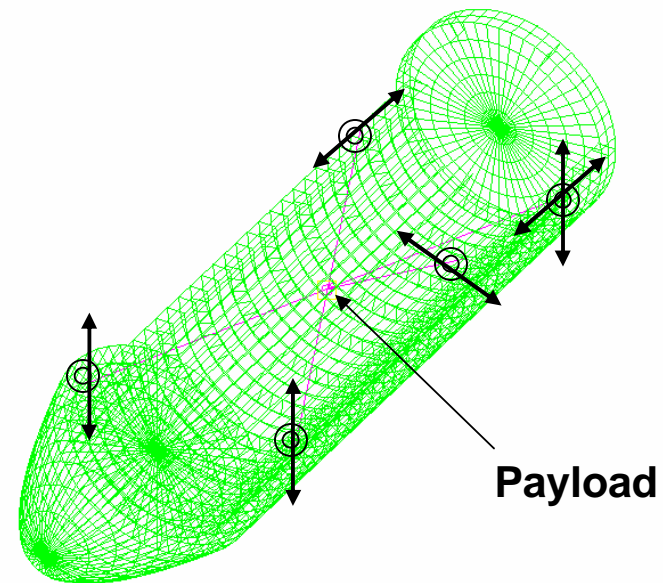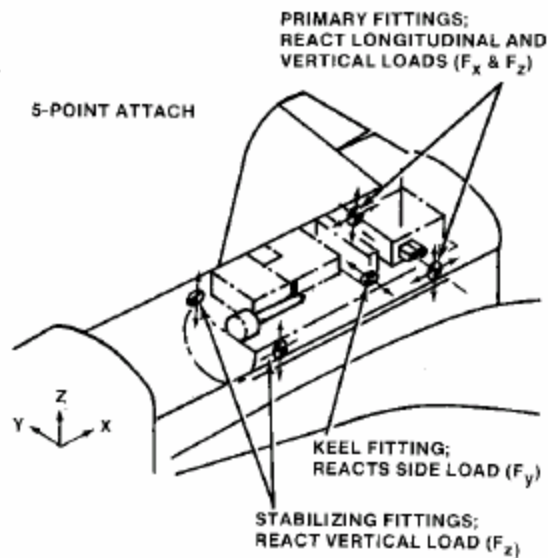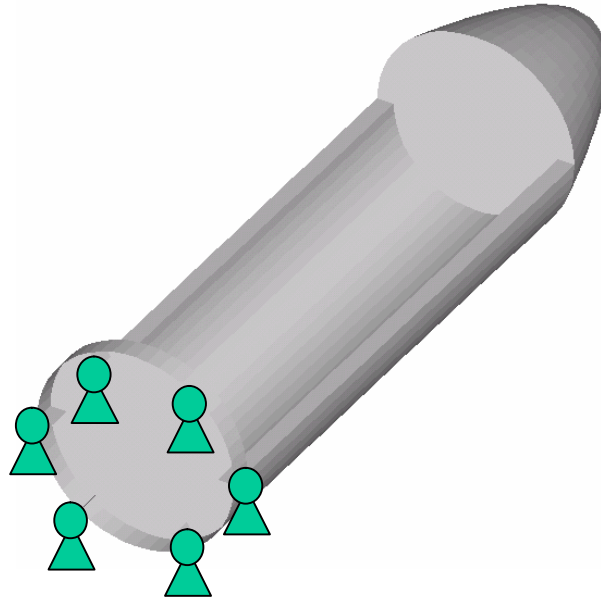
# Orbiter-like Cargo Carrier
# On CLV

## Process Outline

*Vehicle Analysis Branch*



Vehicle Geometry and Weights
**CONSIZ**

**INPUT Geometry**

**LOFT** Generated Mesh

**POST** Flight Profile with
Accelerations &
**CBAERO** generated
Aero-forces

**INPUT Gs & Fs**

A – Loading conditions 1 thru 6, and 14 thru 16 are on the ground
B – max Q
C – max ascent wing normal force
D – pre staging
E – post staging
F – max ascent axial accel
G – hypersonic entry
H – subsonic maneuver

**INPUT Lump Mass**

**I-DEAS** FE Model

**INPUT FE Mesh**

[M], [K]
Finite elements
organized in
groups/Panels

New [K] &
Struct. [M]

Load Balancing
**EXCEL Solver**

Loaded **I-DEAS** FE Model

Running loads [Nx, Ny, Nxy ……]

Panel sizing in
**HYPERSIZER**

ITERATION LOOP

**HSLoad / HYPERSIZER** Model

Assign:
• Panel/beam Concept
• Material
• Limits on design variables
• Failure Criteria

Legend
<=0.3341412
1.292374
2.250606
3.208838
4.16707
5.125303
6.083535
7.041768
>=8

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# Open Wall Design



**Al 2024-T3**

**Al 7075-T6**

**Al 2024-T3**

**Frame spacing 59.8 inch
Longeron spacing 60 deg.**

**Al 2024-T3 face-sheets
Hexcel 1/8-5052-.0015 core**

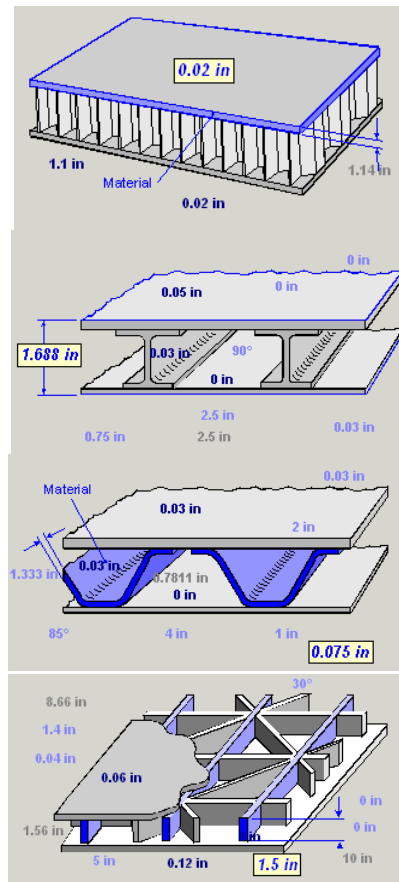**Zoran N. Martinovic/NASA LaRC/VAB October 2006**

# Earlier study showed:

**Combined fixed/simply supported aluminum panel 36 inch x 80 inch, radius 108 inch loaded with 1000 lb/in Ultimate Load = 1.5 Applied**
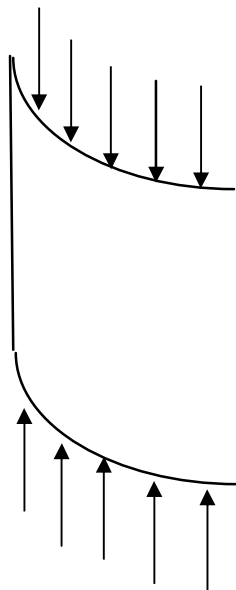
**Panel concept**

**Unit weight**



0.88 lbs/sq.ft

1.16 lbs/sq.ft

1.23 lbs/sq.ft

1.52 lbs/sq.ft
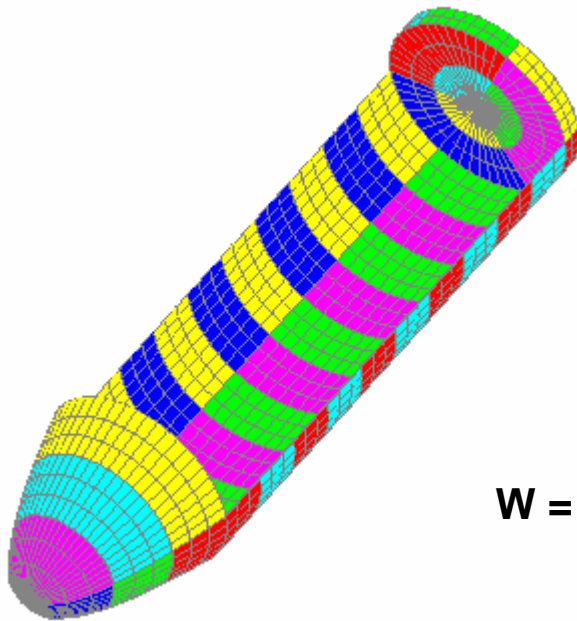
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# Open Wall Design (cont.)

• **Sizing of panels and beams done by an iterative  process between UGS/I-Deas (analysis) and Collier/HyperSizer (sizing) tools.**



| Iteration | Weight (lbs) |
|-----------|--------------|
| 1 | 12,408 |
| 2 | 13,671 |
| 3 | 15,104 |
| 4 | 14,944 |
| 5 | 15,307 |

W = 15,307 lbs = 5,333 lbs (Panels) + <u>9,974</u> lbs (Beams)

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# Closed Wall Design



**Beam
Cross
Section**

**Al 7075-T6
Beam Caps**

**Sandwich**

**Extrusion**

**Al 2024-T3
Outer skin**

**Al 2024-T3**

**Inner Skin**

**Beam webs**

**Al 2024-T3 face-sheets
Hexcel 1/8-5052-.0015 core**

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# Closed Wall Design (cont.)

- **Same process used for sizing as in Open Wall Design**

| Iteration | Weight (lbs) |
|-----------|--------------|
| 1 | 8,643 |
| 2 | 7,858 |
| 3 | 8,062 |
| 4 | 8,171 |

**W = 8,171 lbs = 6,675 lbs (Panels) + 1,496 lbs (Beam Caps)**

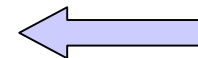| Open Wall Weight (lbs) | 15,307 |
|------------------------|--------|
| Closed Wall Weight (lbs) | 8,171 |

# Adding symmetry to the Closed Wall Design

- Optimization produces an asymmetric structure about the central vehicle plane due to asymmetric loads
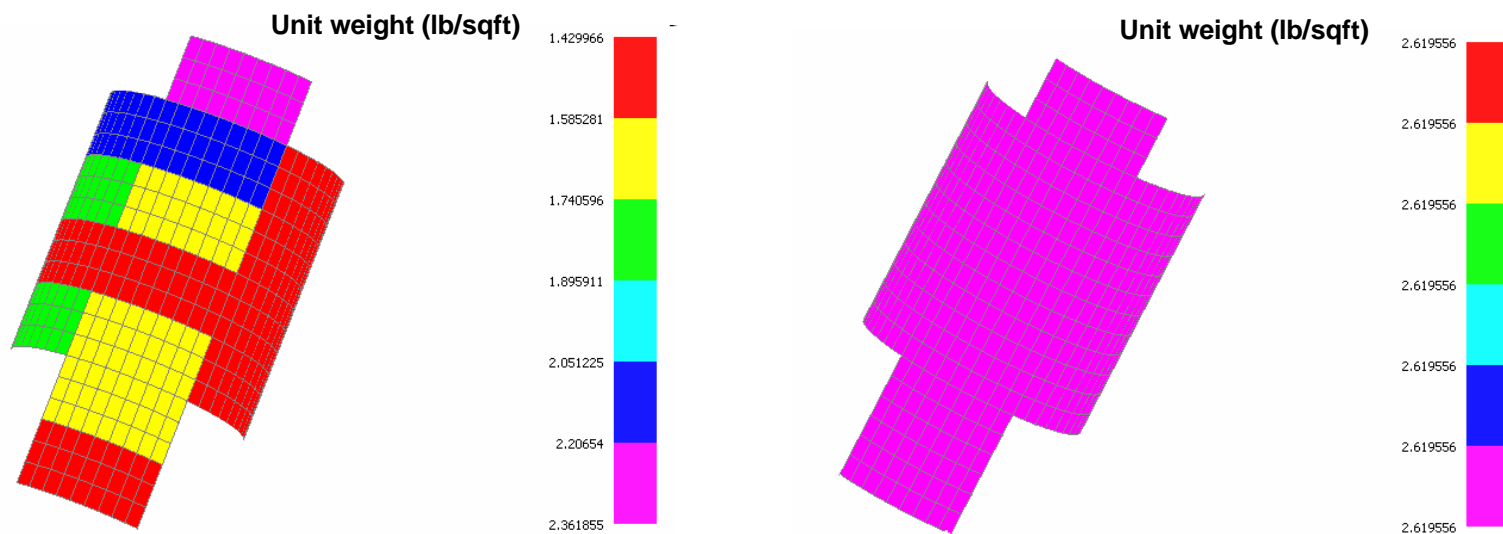


| | |
|---|---|
| **Sym. Closed Wall Weight (lbs) After 5th Iteration** | **10,525** |
| **Closed Wall Weight (lbs)** | 8,171 |

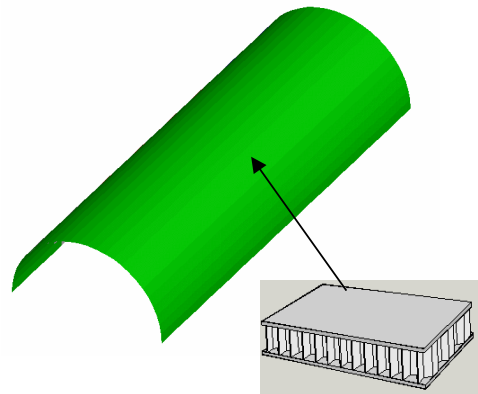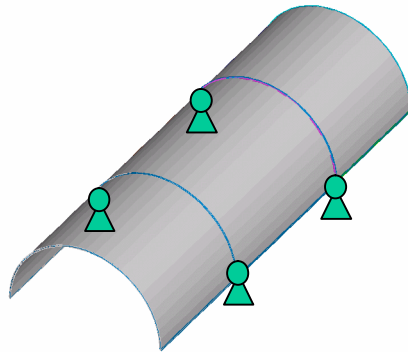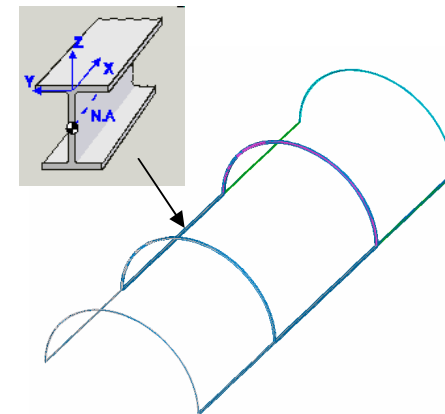**Zoran N. Martinovic/NASA LaRC/VAB October 2006**

# Cargo Bay Doors Design

• **The same six combined aero/inertia loads were applied as for the rest of the vehicle.**
• **Four ball joints modeled doors attachments to the vehicle.**

**Al 7075-T6**



**Al 2024-T3 face-sheets
Hexcel 1/8-5052-.0015 core**

# Cargo Bay Doors Design (cont.)

• **During the last iteration, constraint forces, caused by door loads, were computed at hinge locations and saved for further design**
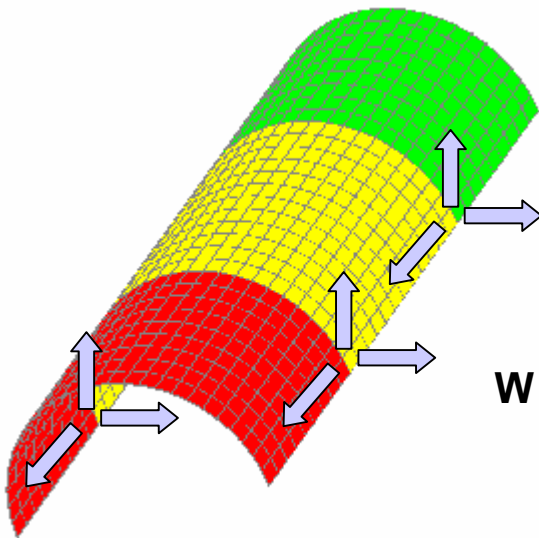
| Iteration | Weight (lbs) |
|-----------|--------------|
| 1 | 1,596 |
| 2 | 1,483 |
| 3 | 1,484 |

**W = 1,484 lbs = 1,333 lbs (Panels) + 151 lbs (Beams)**

# Closed Wall Design with Bay Doors loads

• **Six sets of concentrated loads on cargo bay hinges added to six load cases**

| Iteration | Weight (lbs) |
|---|---|
| 1 | 7,882 |
| 2 | 7,897 |
| Symmetry run | 10,613 |

**Note:
One out of
six loads shown**
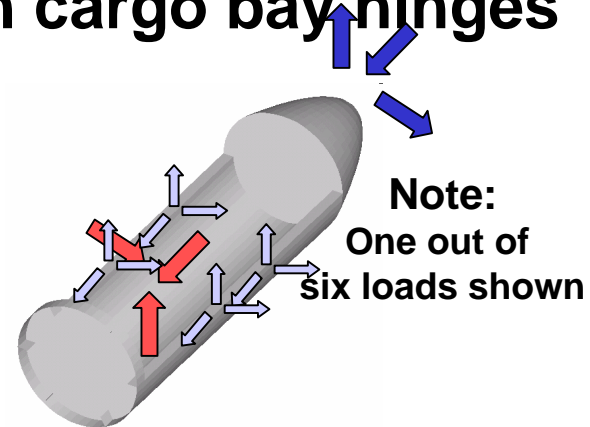
**W = 10,613 = 8963 lbs (Panels) + 1,650 lbs (Beam Caps)**

| Weight no hinge loads (lbs) | 10,525 |
|---|---|
| Weight with hinge loads (lbs) | 10,613 |

**Total vehicle primary structure weight (with doors) = 10,613+1,484 = 12,097 lbs (5,499 kg)**

# Non Optimal Weight Estimates

- 12,097 lb is weight of <u>primary analytical</u> structure
- Assume that non optima and secondary structure add 15% to the weight:

**Total structural "as-built weight"
estimate  would be 13,912 lb**

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# Summary

- Process for rapid design and structural weight estimation was applied to Orbiter-like Cargo Carrier
- Two structural design concepts were analyzed and one of them – Closed Wall Design was selected as a superior among the two
- Process produced analytical structural weight of 12,097 lb
- Estimated total structural weight, with non-optimal weight and secondary structure weight, was 13,912 lb