National Aeronautics and Space Administration

NASA

BUCKLING ANALYSIS FOR FREQUENCY DESIGN REQUIREMENT OF COMPLEX SPACECRAFT STRUCTURE WITH LIGHTER WEIGHT

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David Paddock, presenting

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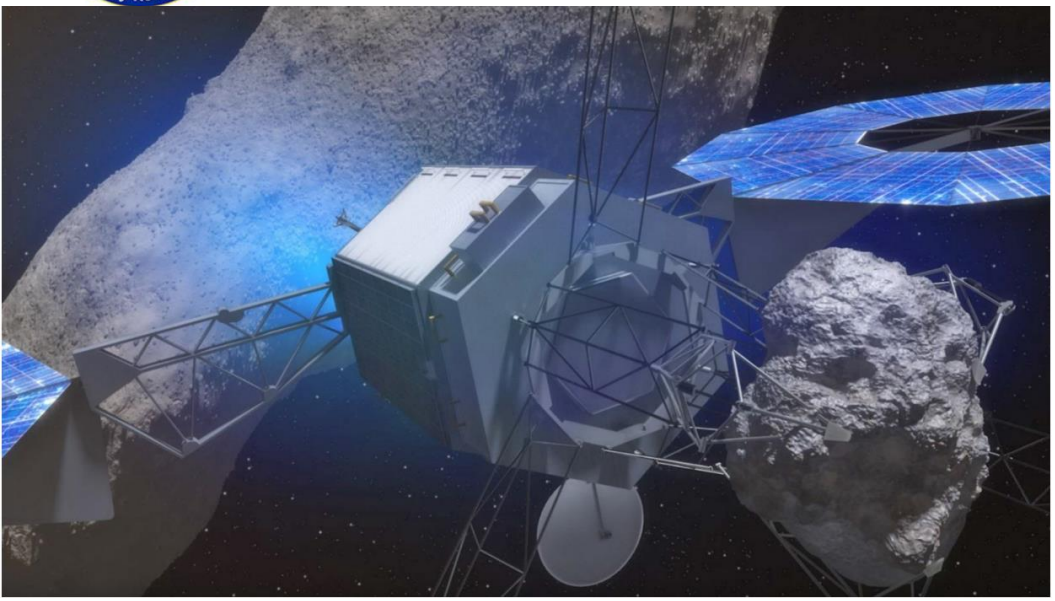
http://engineering.larc.nasa.gov/

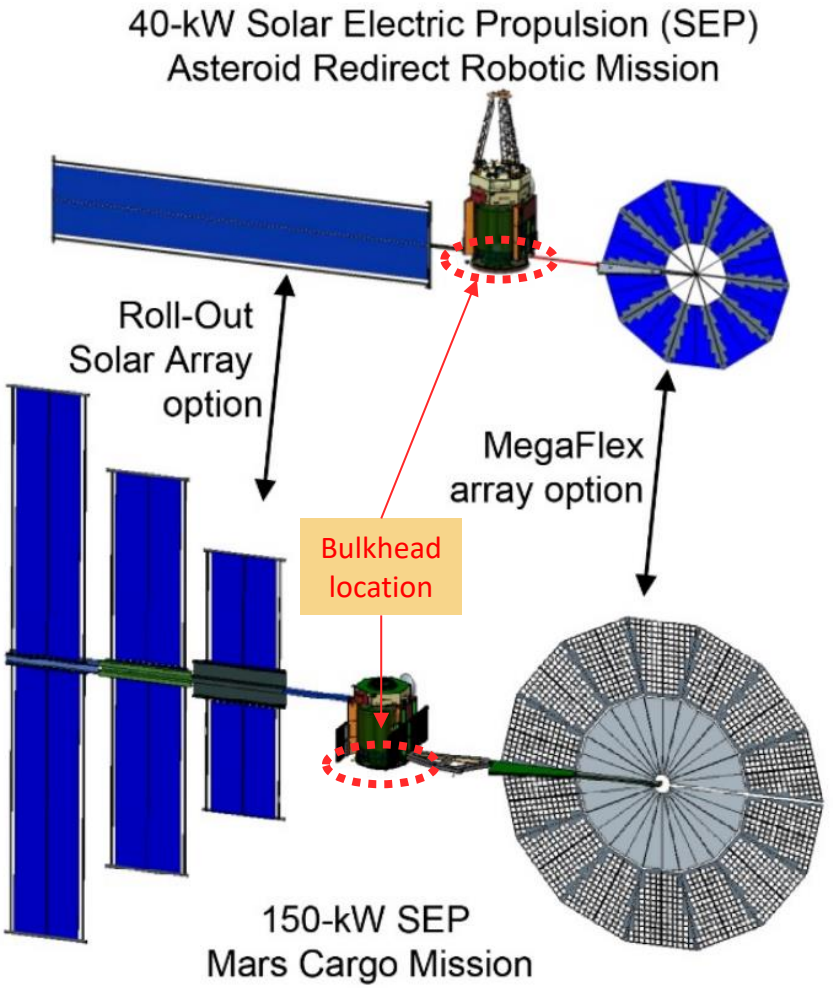
Outline

- Introduction to the ARRM-SEP* Bulkhead Concept (“Octo-pants”)
- Design and Analysis Requirements
- CAD and FEM (Finite Element Model)
- Analysis Process using HyperSizer and Nastran (HyperFEA)
- Results
- Conclusions

Asteroid Redirect Robotic Mission - Solar Electric Propulsion

ARRM and SEP

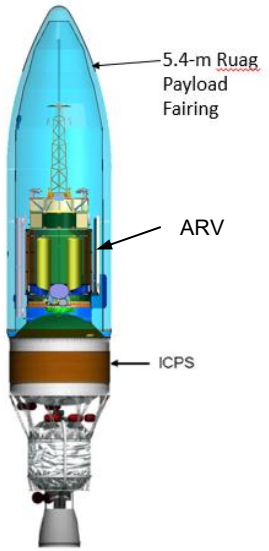




- In 2015, the Asteroid Redirect Robotic Mission (ARRM) was intended to send the Asteroid Redirect Vehicle (ARV) to the surface of an asteroid to retrieve a 20 t boulder.
- The ARRM would be enabled by high-power Solar Electric Propulsion (SEP) using Hall thrusters and xenon fuel.
- The SEP is an essential part of future missions into deep space with larger payloads.

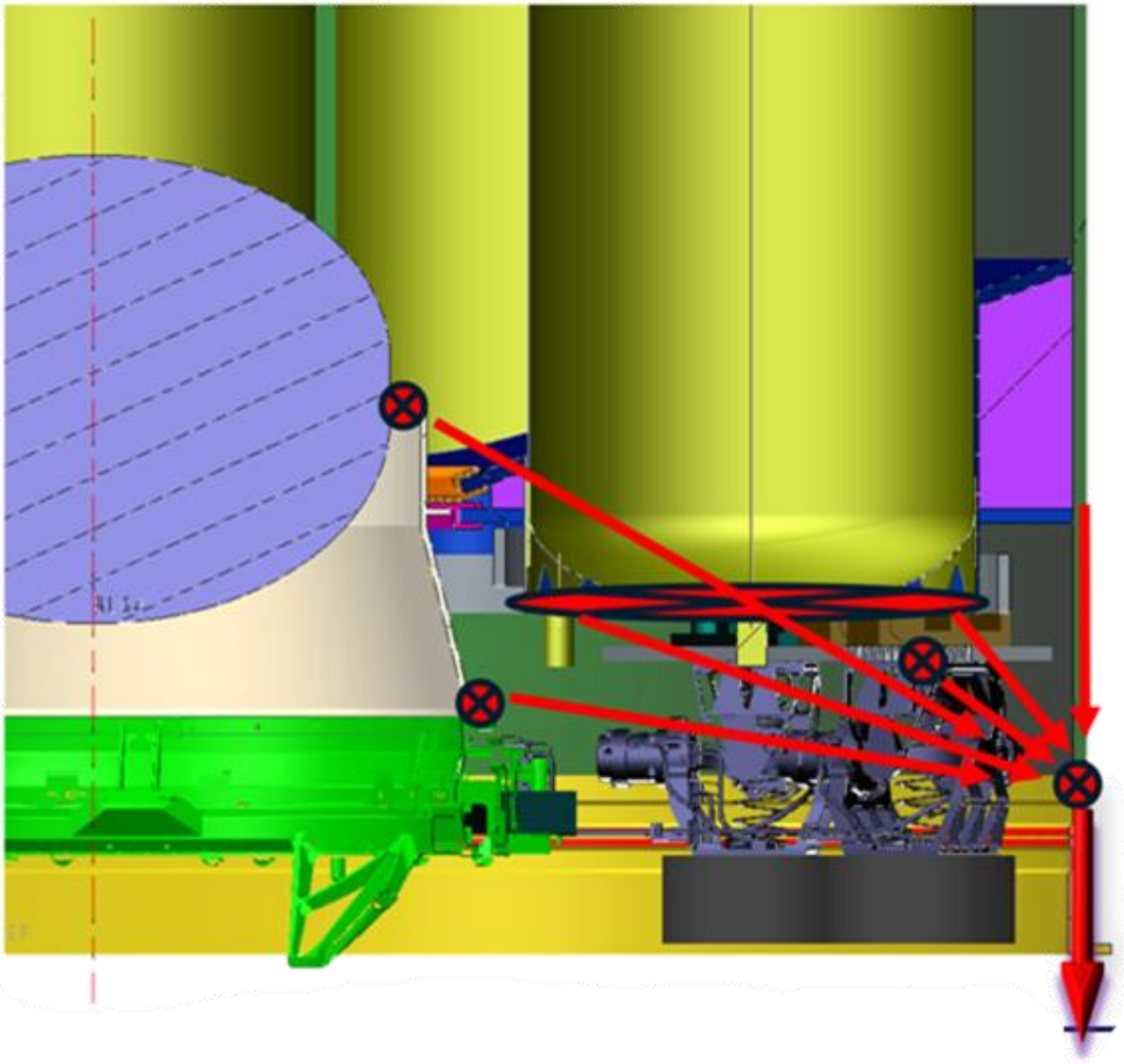
Design and Analysis Requirements

- **Design Requirements from GRC:**
  - **Positive margins under the load cases below**
    - Delta IV Heavy load cases:
      - 6g axial, 0.5g lateral
      - 2.3g axial, 2g lateral
      - -2.0g axial, 2g lateral
    - Factor of Safety = 1.4
  - **Frequency in axial mode > 15.5 Hz**
  - **Buckling knockdown factor=0.65 for curved panel (NASA SP-8007): initially, the lowest eigenvalue 1.0FS/0.65=1.54; later, eigenvalue incorporating 1.4 FS.**



- **Analysis Requirements:**
  - **Mesh density (basically match the GRC model mesh density in the skirt, can be easily modified if needed with topologically mesh-able geometry)**
  - **Boundary Condition: (in a cylindrical coordinate: R=free; θ and z fixed) (typical BC for cylindrical structure)**

Primary Structure Design: Load Path Analysis

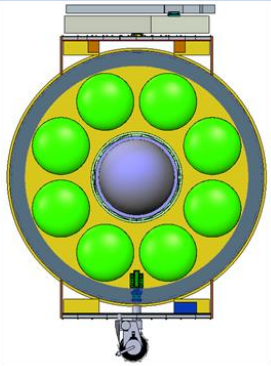


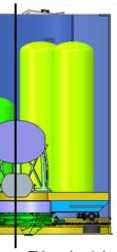
BOUNDARY CONDITIONS / LOAD INTRODUCTION

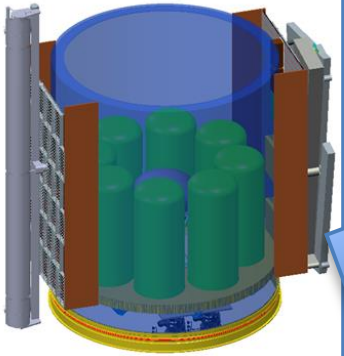
PRIMARY LOAD PATHS (LAUNCH)

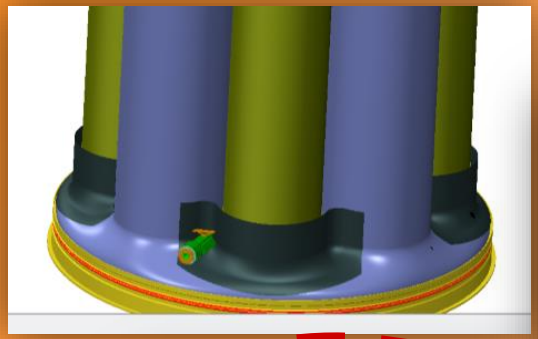
Primary Structure Design: Bulkhead Shape Study

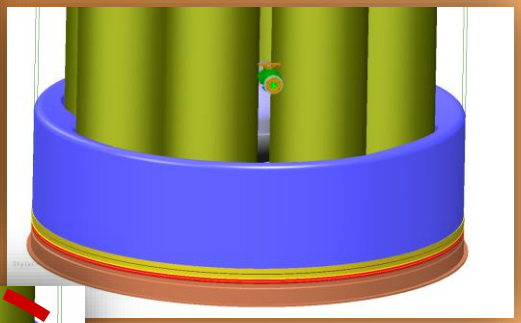
SEPM from GRC

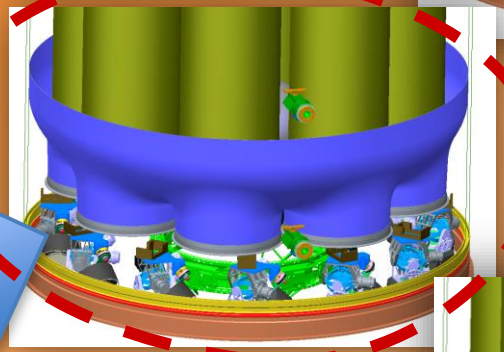




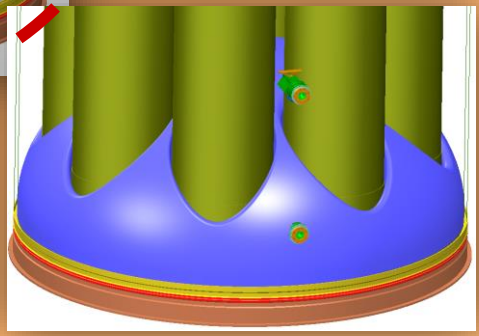






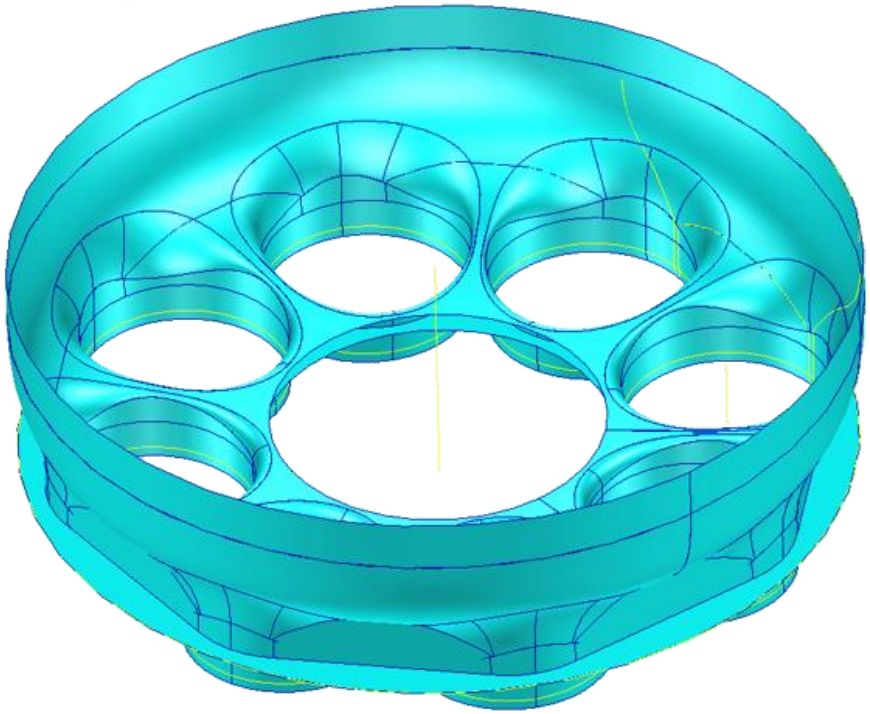


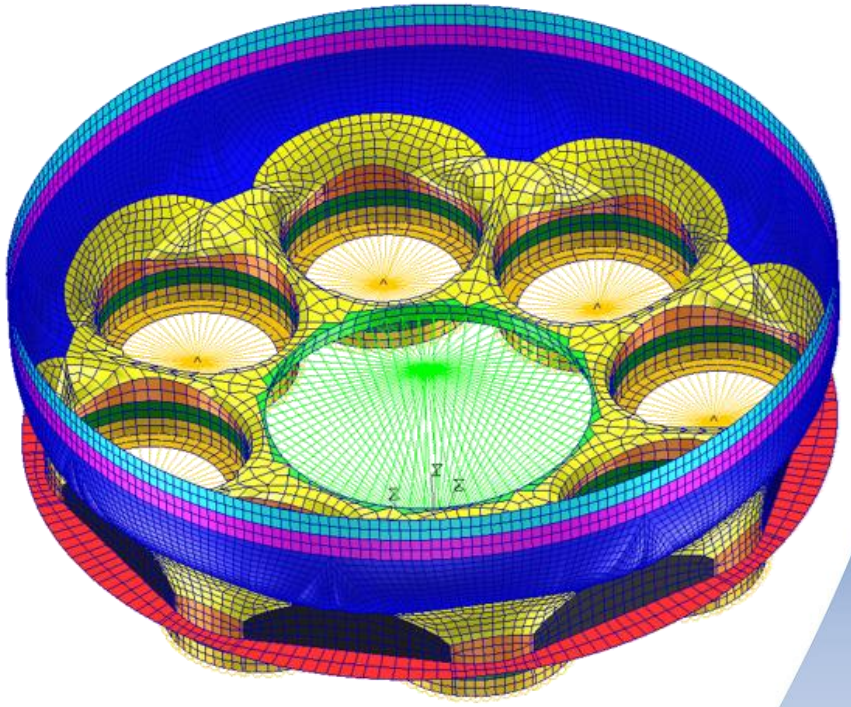
Brainstorm structures



"Octopants" chosen

Bulkhead Concept CAD and FEM





- State-of-the-art practice (average for stiffness modulus; B-basis for ultimate strength)
- M55J/954-3 unidirectional tape from ORION MATERIALS AND DESIGN ALLOWABLES
- $[-45/0/45/90]_{2S}$
- Enveloped by typical failure theories (Max Strain, Hoffman, Tsai-Hill, Tsai-Hahn, Tsai-Wu)
- CTE calculated from unidirectional tape from ORION MATERIALS AND DESIGN ALLOWABLES

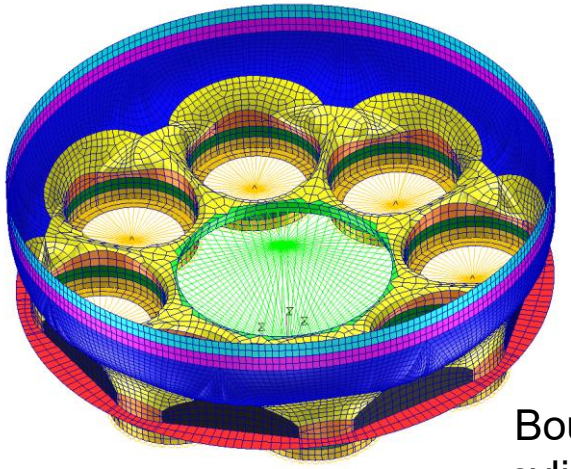
Shell elements Lumped mass

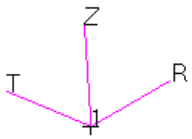
RBE2 and RBE3

(link to hardware image)

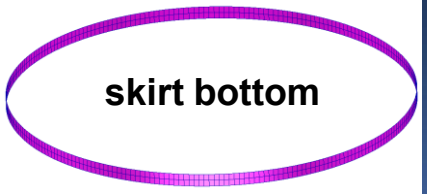
Initial FEM Details

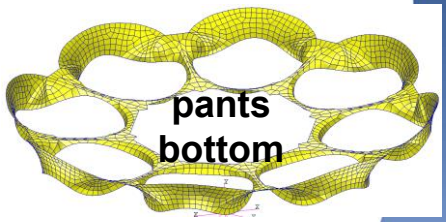
10 Components for Sizing



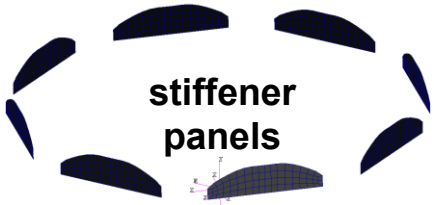


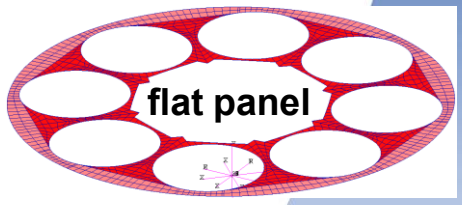
skirt top

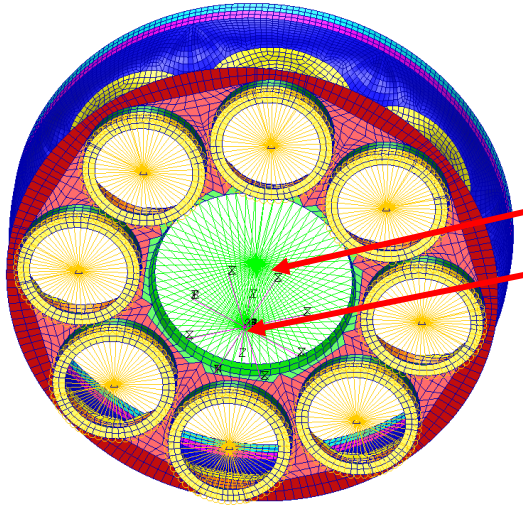




Boundary Condition:
cylindrical coordinate
23 fixed on skirt top edge





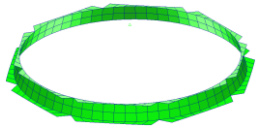


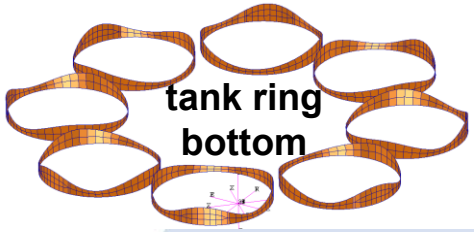
RBE2 and RBE3

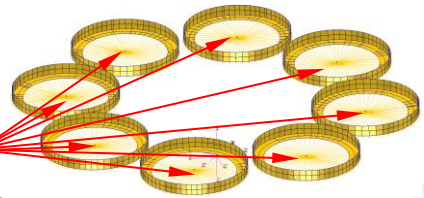
RCS* tank
mass=400 kg

NDS* mass=162 kg

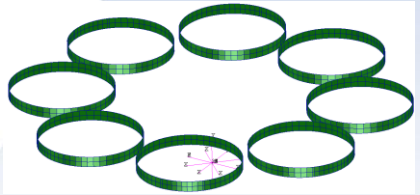
internal stiffener







tank ring top 1

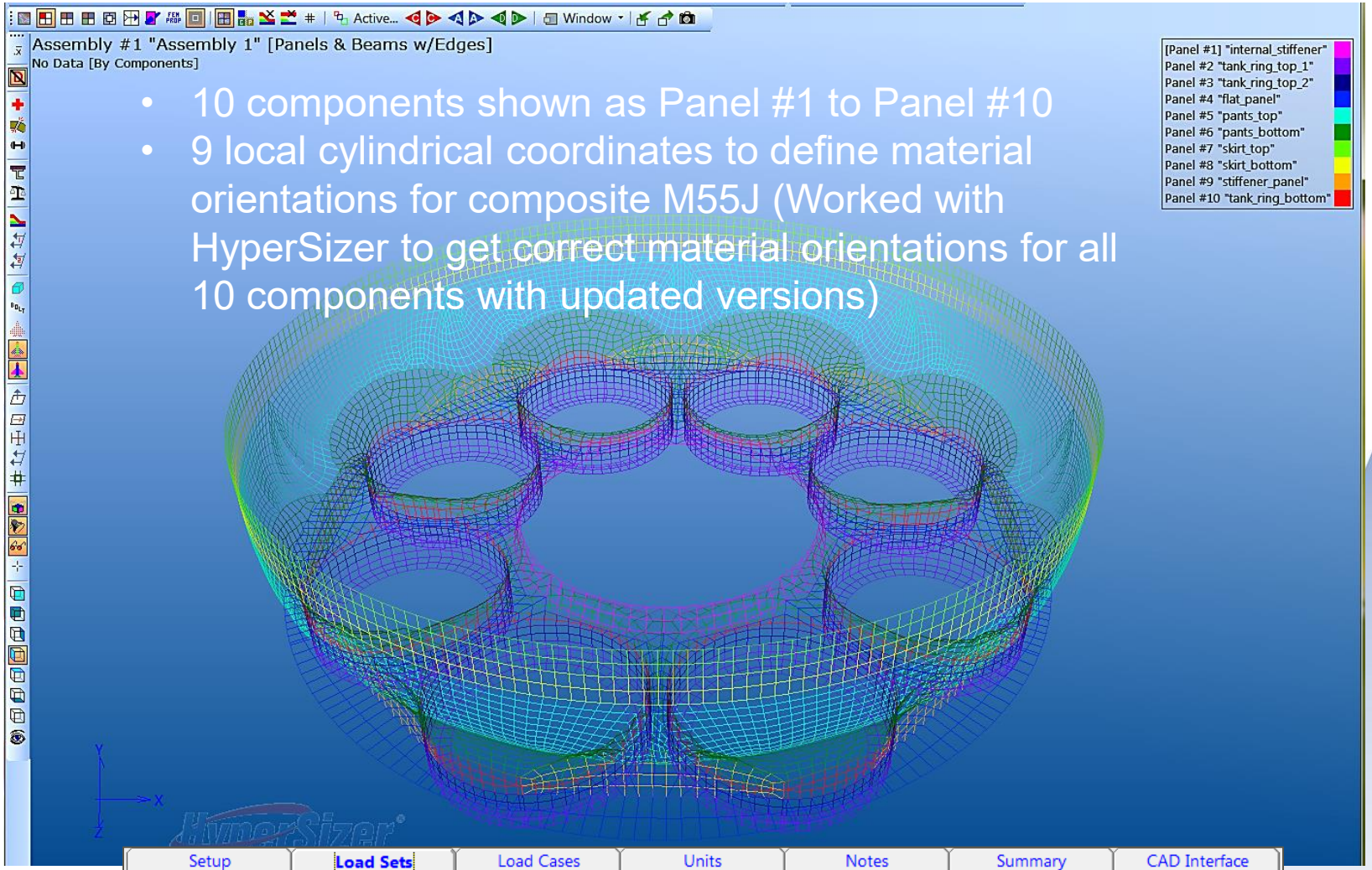


tank ring top 2

Tanks = 8 x 125kg
(fuel mass added later)

*RCS = Reaction Control System (Hydrazine Tank)
NDS = National Docking System

Bulkhead Concept in HyperSizer

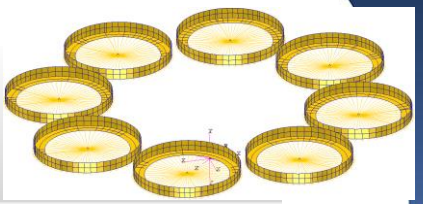


- 10 components shown as Panel #1 to Panel #10
- 9 local cylindrical coordinates to define material orientations for composite M55J (Worked with HyperSizer to get correct material orientations for all 10 components with updated versions)

Setup | **Load Sets** | Load Cases | Units | Notes | Summary | CAD Interface

Load Set #	Run Deck #	Loading Type	Limit Factor	Ultimate Factor	Temperature (°...	Description
1	1	Mechanical	1	1.4	72	6g_axial_05g_lateral
2	1	Mechanical	1	1.4	72	2_3g_axial_2g_lateral
3	1	Mechanical	1	1.4	72	-2g_axial_05g_lateral

Sizing in HyperSizer for Tank Ring Top 1
1/10 of All Components



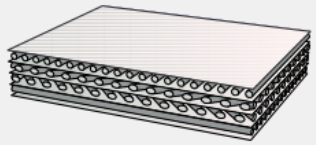
FEM Viewer | Loads | Summary | Create | Edit | Templates | Metal | Composite | Any Material | Rapid Sizing | Detailed Sizing | Final Analysis | Design Criteria | Set Variables | Detailed Sizing | Margins | Failure Mode | Unit Weight | Stress Reports | Bill of Materials | Detail

Assembly | Plot Results | Reports

Assembly 1 | Assembly 1

Component 2 | tank_ring_top_1

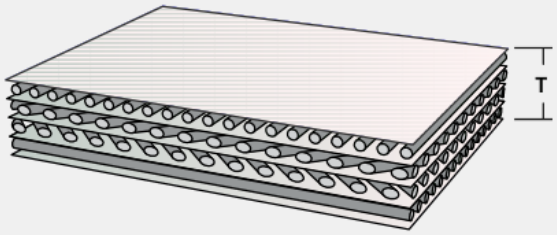
Concept: **One Stack Unstiffened (Optimum)**



Component Result

Weight (lbm)	2.8548
Unit Wt. (lb / ft²)	0.085824
Min MS	0.8221

Dimensions | Failure | Free Body | FEA Loads | Stresses | Buckling | Properties | Options | Notes



View Cross Section

Req. Designs 1 | # Candidates 51 | All Designs | Advanced | Copy

Dimension	Min	Max	Steps	Step Size
T (in)	0.01	0.5	51	0.01

Freeze	Result	Material
	0.01	Metal: quasi-isotropic M55J

Link to full properties

Available Failure Analyses

Limit MS	Ultimate MS	γ LS	Location - Analysis Description
			One-stack Panel Analysis, User 4
			One-stack Panel Analysis, User 5
			One-stack Panel Analysis, User 6
			One-stack Panel Analysis, User 7
			One-stack Panel Analysis, User 8
			One-stack Panel Analysis, User 9
			One-stack Panel Analysis, User 10
1.681 (0)	0.915 (0)	1	Top Stack Isotropic Strength, Longitudinal Direction
1.664 (0)	0.9032 (0)	1	Top Stack Isotropic Strength, Transverse Direction
7.553 (0)	5.109 (0)	1	Top Stack Isotropic Strength, Shear Direction
1.551 (0)	0.8221 (0)	1	Top Stack Isotropic Strength, Von Mises Interaction Yield Criteri
			Top Stack Isotropic Strength, Max Shear Criterion
			Top Stack Isotropic Strength, Max Principal Stress Criterion
			Top Stack Isotropic Strength, Fatigue, Tension
			Top Stack Isotropic Strength, Fatigue, Compression
			Top Stack Composite Strength, Max Strain 1 Direction
			Top Stack Composite Strength, Max Strain 2 Direction
			Top Stack Composite Strength, Max Strain 12 Direction
			Top Stack Composite Strength, Max Stress 1 Direction
			Top Stack Composite Strength, Max Stress 2 Direction
			Top Stack Composite Strength, Max Stress 12 Direction
			Top Stack Composite Strength, Tsai-Hill Interaction
			Top Stack Composite Strength, Tsai-Wu Interaction
			Top Stack Composite Strength, Tsai-Hahn Interaction

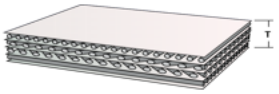
Face/Solid Laminate

(1 metallic candidate)

Metal: quasi-isotropic M55J

Analysis Process 1 (1/3)

Strength (MS>0.0), Buckling (Eigenvalue>1.54), and Frequency (>15.5 Hz)



M55J

Component
1 "internal_stiffener"
2 "tank_ring_top_1"
3 "tank_ring_top_2"
4 "flat_panel"
5 "pants_top"
6 "pants_bottom"
7 "skirt_top"
8 "skirt_bottom"
9 "stiffener_panel"
10 "tank_ring_bottom"
Totals

HyperSizer

Strength (MS>0.0)

Dimensions & Weight after HyperSizer

Comp. ID	T (in)	Area (ft²)	Wt. (lbm)
1	0.15	7.134	9.184
2	0.01	33.26	2.855
3	0.02	17.5	3.005
4	0.03	26.4	6.796
5	0.05	39.12	16.79
6	0.06	38.57	19.86
7	0.004	11.02	0.3783
8	0.004	11.02	0.3783
9	0.02	12.92	2.217
10	0.04	17.17	5.895
		Total	67.36

Buckling Analysis

Buckling (Eigenvalue>1.54)

Dimensions & Weight after Buckling

Comp. ID	T (in)	Area (ft²)	Wt. (lbm)
1	0.15	7.134	9.184
2	0.04	33.26	11.42
3	0.04	17.5	6.01
4	0.1	26.4	22.653
5	0.06	39.12	20.148
6	0.06	38.57	19.86
7	0.022	11.02	2.08065
8	0.022	11.02	2.08065
9	0.05	12.92	5.5425
10	0.04	17.17	5.895
		Total	104.80

First Mode: 14.08 Hz

Modal Analysis

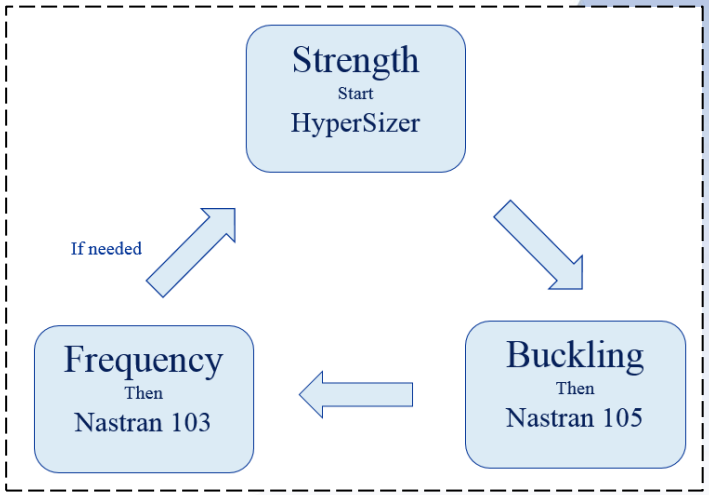
Frequency (>15.5 Hz)

Dimensions & Weight after Modal

Comp. ID	T (in)	Area (ft²)	Wt. (lbm)
1	0.15	7.134	9.184
2	0.04	33.26	11.42
3	0.04	17.5	6.01
4	0.3	26.4	67.96
5	0.06	39.12	20.148
6	0.06	38.57	19.86
7	0.022	11.02	2.08065
8	0.022	11.02	2.08065
9	0.05	12.92	5.5425
10	0.04	17.17	5.895
		Total	150.18

First Mode: 15.58 Hz

150 lb-m to meet all design requirements

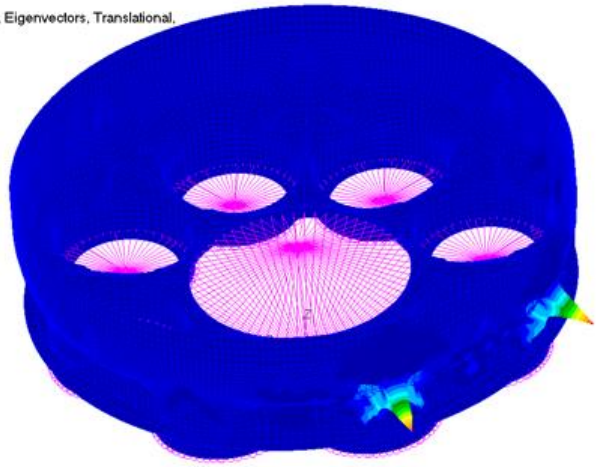


Analysis Process 1 (2/3)

Strength (MS>0.0), **Buckling (Eigenvalue>1.54)**, and Frequency (>15.5 Hz)

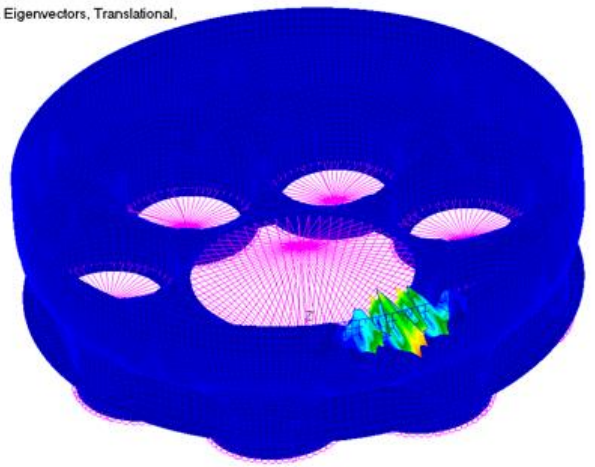
Fringe: SC101:, A1:Mode 1 : Factor = 1.9596, Eigenvectors, Translational, Magnitude, (NON-LAYERED)
Deform: SC101:, A1:Mode 1 : Factor = 1.9596, Eigenvectors, Translational,

Eigenvalue=1.96 at load case 1



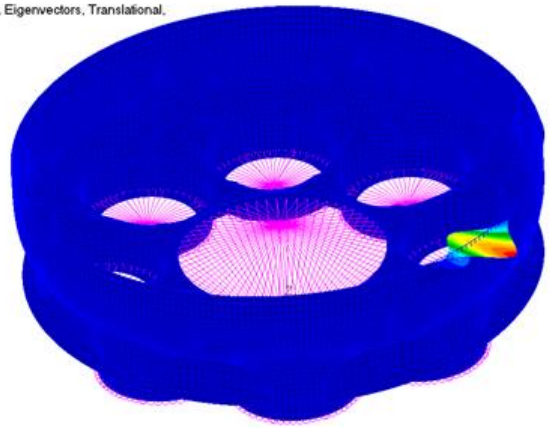
Fringe: SC101:, A2:Mode 1 : Factor = 1.7445, Eigenvectors, Translational, Magnitude, (NON-LAYERED)
Deform: SC101:, A2:Mode 1 : Factor = 1.7445, Eigenvectors, Translational,

Eigenvalue=1.74 at load case 2



Fringe: SC101:, A3:Mode 1 : Factor = 1.8218, Eigenvectors, Translational, Magnitude, (NON-LAYERED)
Deform: SC101:, A3:Mode 1 : Factor = 1.8218, Eigenvectors, Translational,

Eigenvalue=1.82 at load case 3



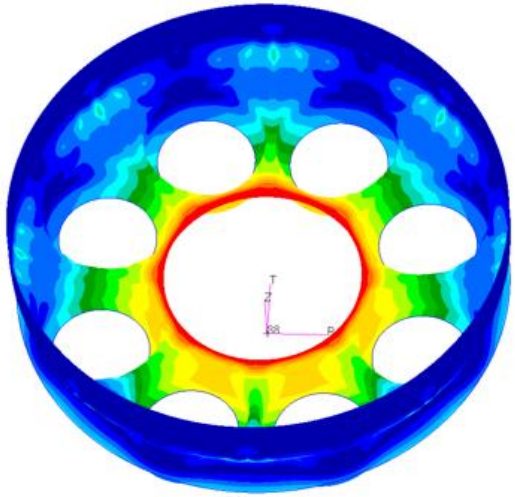
Analysis Process 1 (3/3)

Strength (MS>0.0), Buckling (Eigenvalue>1.54), and **Frequency (>15.5 Hz)**

Patran 2012.2.1 64-Bit 03-Feb-16 12:08:53

Fringe: SC1:2_3_FIXED, A1:Mode 1 : Freq. = 15.578, Eigenvectors, Translational, Magnitude, (NON-LAYERED)

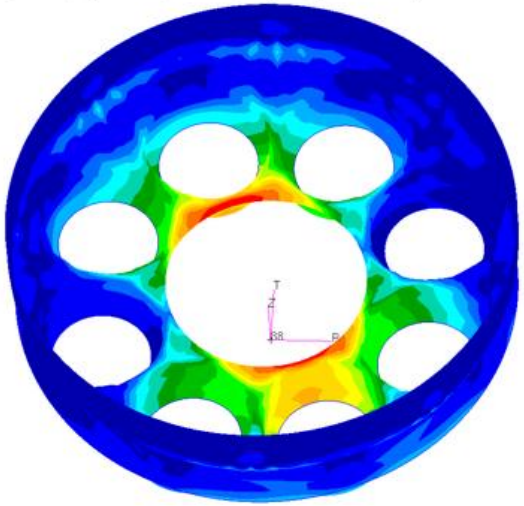
First Mode: 15.58 Hz axial mode



Patran 2012.2.1 64-Bit 03-Feb-16 12:11:02

Fringe: SC1:2_3_FIXED, A1:Mode 2 : Freq. = 33.853, Eigenvectors, Translational, Magnitude, (NON-LAYERED)

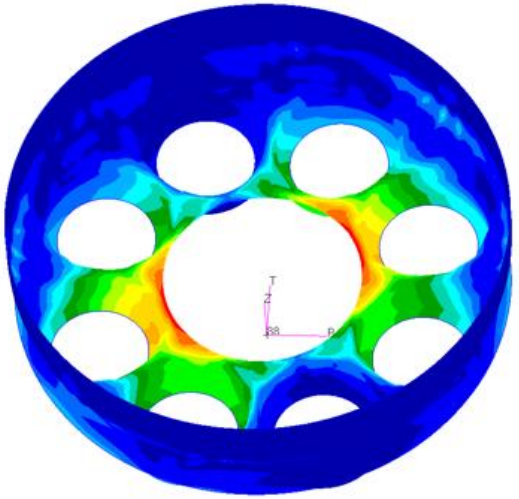
Second Mode: 33.85 Hz lateral mode



Patran 2012.2.1 64-Bit 03-Feb-16 12:12:16

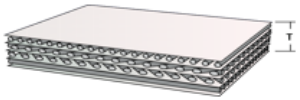
Fringe: SC1:2_3_FIXED, A1:Mode 3 : Freq. = 33.853, Eigenvectors, Translational, Magnitude, (NON-LAYERED)

Third Mode: 33.85 Hz lateral mode



Analysis Process 2 (1/3)

Strength (MS>0.0), Buckling (Eigenvalue>2.15), and Frequency (>15.5 Hz)



Component
1 "internal_stiffener"
2 "tank_ring_top_1"
3 "tank_ring_top_2"
4 "flat_panel"
5 "pants_top"
6 "pants_bottom"
7 "skirt_top"
8 "skirt_bottom"
9 "stiffener_panel"
10 "tank_ring_bottom"
Totals

M55J

HyperSizer → **Strength** (MS>0.0)

Dimensions & Weight after HyperSizer

Comp. ID	T (in)	Area (ft²)	Wt. (lbm)
1	0.15	7.134	9.184
2	0.01	33.26	2.855
3	0.02	17.5	3.005
4	0.03	26.4	6.796
5	0.05	39.12	16.79
6	0.06	38.57	19.86
7	0.004	11.02	0.3783
8	0.004	11.02	0.3783
9	0.02	12.92	2.217
10	0.04	17.17	5.895
		Total	67.36

Buckling Analysis → **Buckling** (Eigenvalue>2.15)

Dimensions & Weight after Buckling

Comp. ID	T (in)	Area (ft²)	Wt. (lbm)
1	0.15	7.134	9.184
2	0.04	33.26	11.42
3	0.04	17.5	6.01
4	0.1	26.4	22.653
5	0.065	39.12	21.827
6	0.065	38.57	21.515
7	0.03	11.02	2.83725
8	0.03	11.02	2.83725
9	0.05	12.92	5.5425
10	0.04	17.17	5.895
		Total	109.72

First Mode: 14.54 Hz

Modal Analysis → **Frequency** (>15.5 Hz)

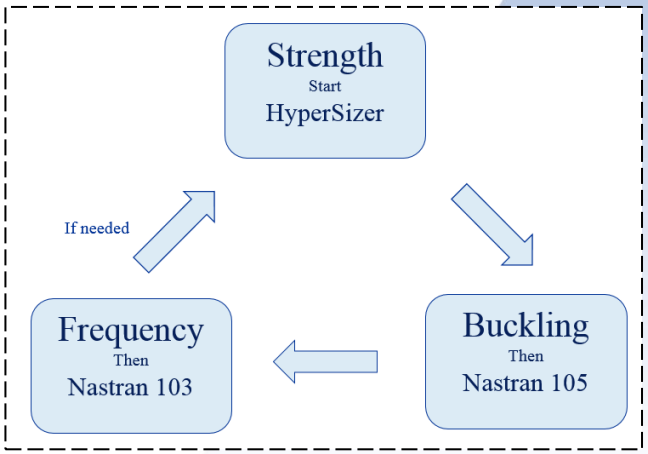
Dimensions & Weight after Modal

Comp. ID	T (in)	Area (ft²)	Wt. (lbm)
1	0.15	7.134	9.184
2	0.04	33.26	11.42
3	0.04	17.5	6.01
4	0.162	26.4	36.6884
5	0.07	39.12	23.506
6	0.07	38.57	23.17
7	0.04	11.02	3.783
8	0.04	11.02	3.783
9	0.05	12.92	5.5425
10	0.04	17.17	5.895
		Total	128.99

First Mode: 15.58 Hz

129 lbs design satisfies or exceeds all design requirements even if buckling requirements are increased

(Analysis process 1: 150 lbs mass met all design requirements)

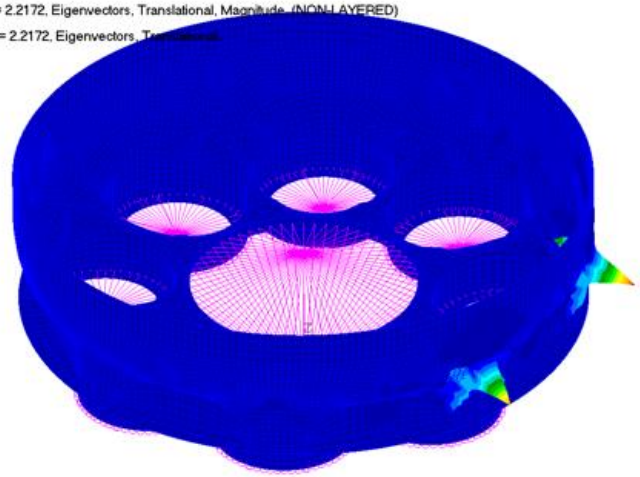


Analysis Process 2 (2/3)

Strength (MS>0.0), Buckling (Eigenvalue>2.15), and Frequency (>15.5 Hz)

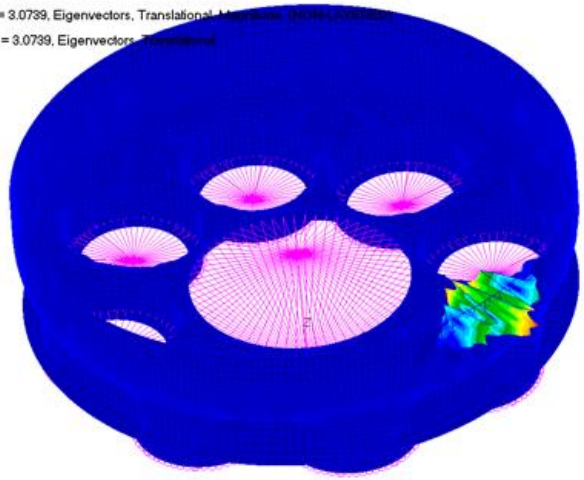
Patran 2012.2.1 64-Bit 07-Apr-15 11:18:59
Fringe: SC101:, A1:Mode 1 : Factor = 2.2172, Eigenvectors, Translational, Magnitude, (NON-LAYERED)
Deform: SC101:, A1:Mode 1 : Factor = 2.2172, Eigenvectors, Translational

Eigenvalue=2.22 at load case 1



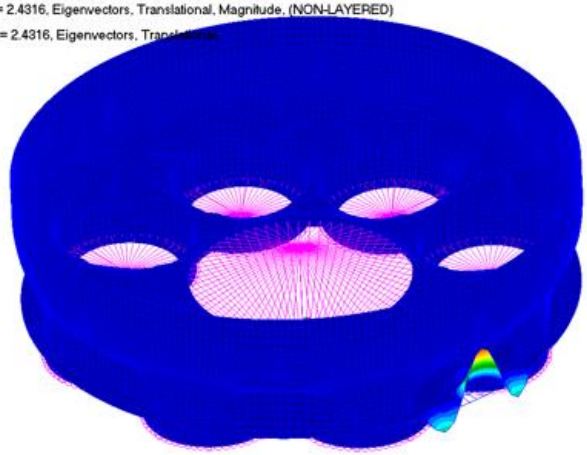
Patran 2012.2.1 64-Bit 07-Apr-15 11:21:16
Fringe: SC101:, A2:Mode 1 : Factor = 3.0739, Eigenvectors, Translational, Magnitude, (NON-LAYERED)
Deform: SC101:, A2:Mode 1 : Factor = 3.0739, Eigenvectors, Translational

Eigenvalue=3.07 at load case 2



Fringe: SC101:, A3:Mode 1 : Factor = 2.4316, Eigenvectors, Translational, Magnitude, (NON-LAYERED)
Deform: SC101:, A3:Mode 1 : Factor = 2.4316, Eigenvectors, Translational

Eigenvalue=2.43 at load case 3

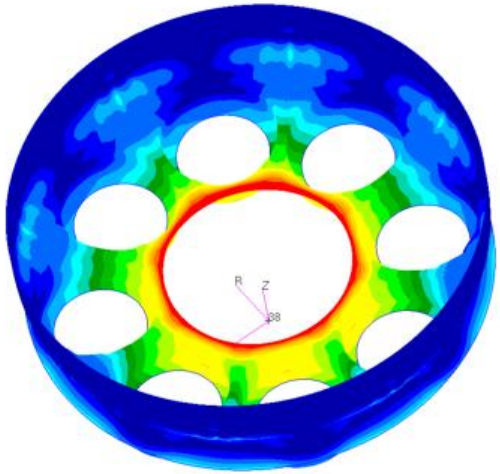


Analysis Process 2 (3/3)

Strength (MS>0.0), Buckling (Eigenvalue>2.15), and Frequency (>15.5 Hz)

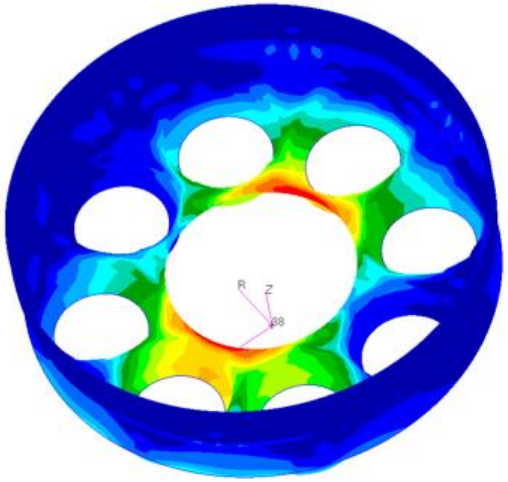
Patran 2012.2.1 64-Bit 07-Apr-15 11:31:52
Fringe: SC1:2_3_FIXED, A4:Mode 1 : Freq. = 15.585, Eigenvectors, Translational, Magnitude, (NON-LAYERED)

First Mode: 15.58 Hz axial mode



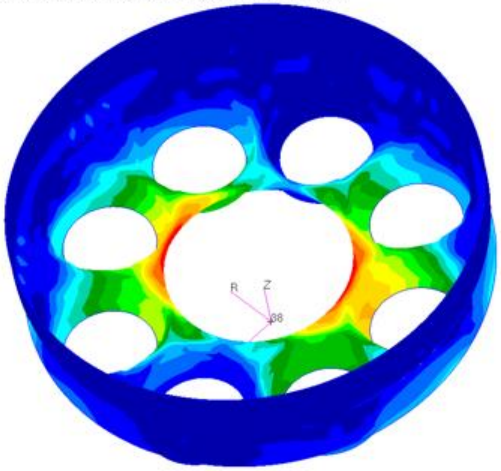
Patran 2012.2.1 64-Bit 07-Apr-15 11:34:28
Fringe: SC1:2_3_FIXED, A4:Mode 2 : Freq. = 33.331, Eigenvectors, Translational, Magnitude, (NON-LAYERED)

Second Mode: 33.33 Hz lateral mode



Patran 2012.2.1 64-Bit 07-Apr-15 11:35:46
Fringe: SC1:2_3_FIXED, A4:Mode 3 : Freq. = 33.331, Eigenvectors, Translational, Magnitude, (NON-LAYERED)

Third Mode: 33.33 Hz lateral mode



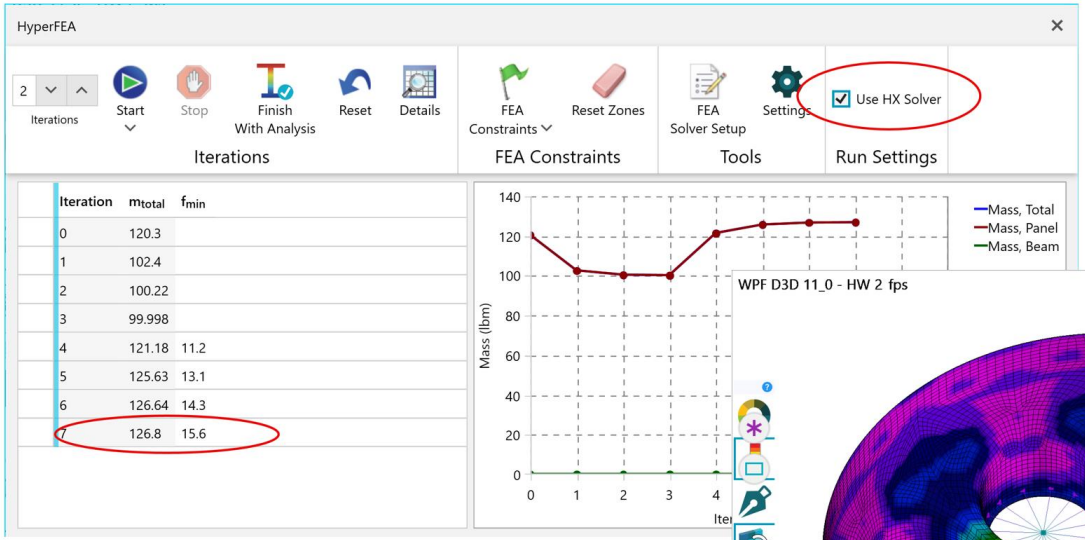
Let's Give it a whirl in HyperX

- **This structure was previously sized in 2015, using HyperSizer. We decided to give it a whirl in HyperX, using the latest composite optimization tools.**

- **HyperX has many new tools that are useful for sizing composite laminate structure, including..**
  - Global buckling and frequency optimization (HyperFEA)
  - Automatic laminate family creation
  - Laminate study tools to evaluate the producibility of laminate families
  - Global ply sequencing and visualization tools
  - Export/Import ply books to Catia and FiberSim

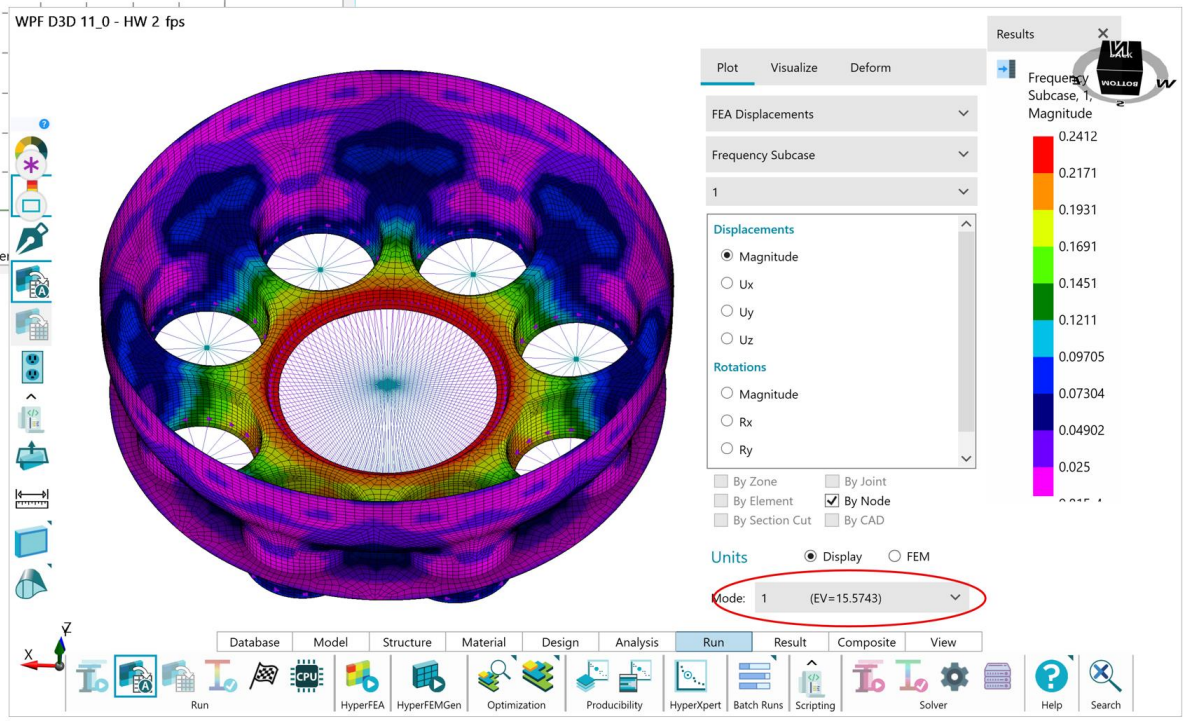
Global Frequency Sizing with HyperFEA

- **Note that ‘HyperX Solver’ used for this study**

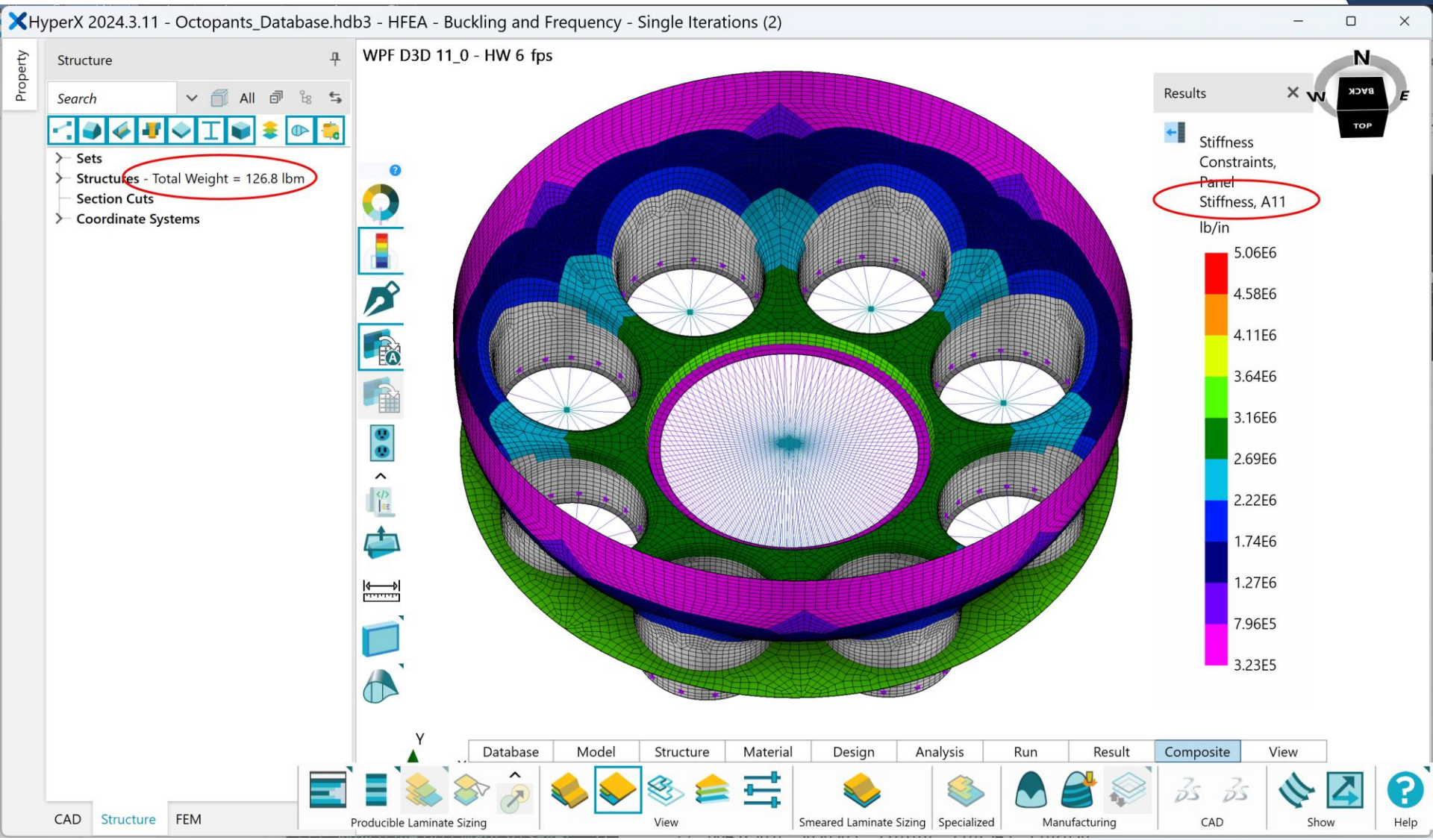


Iterated wt (lbm) = 126.8

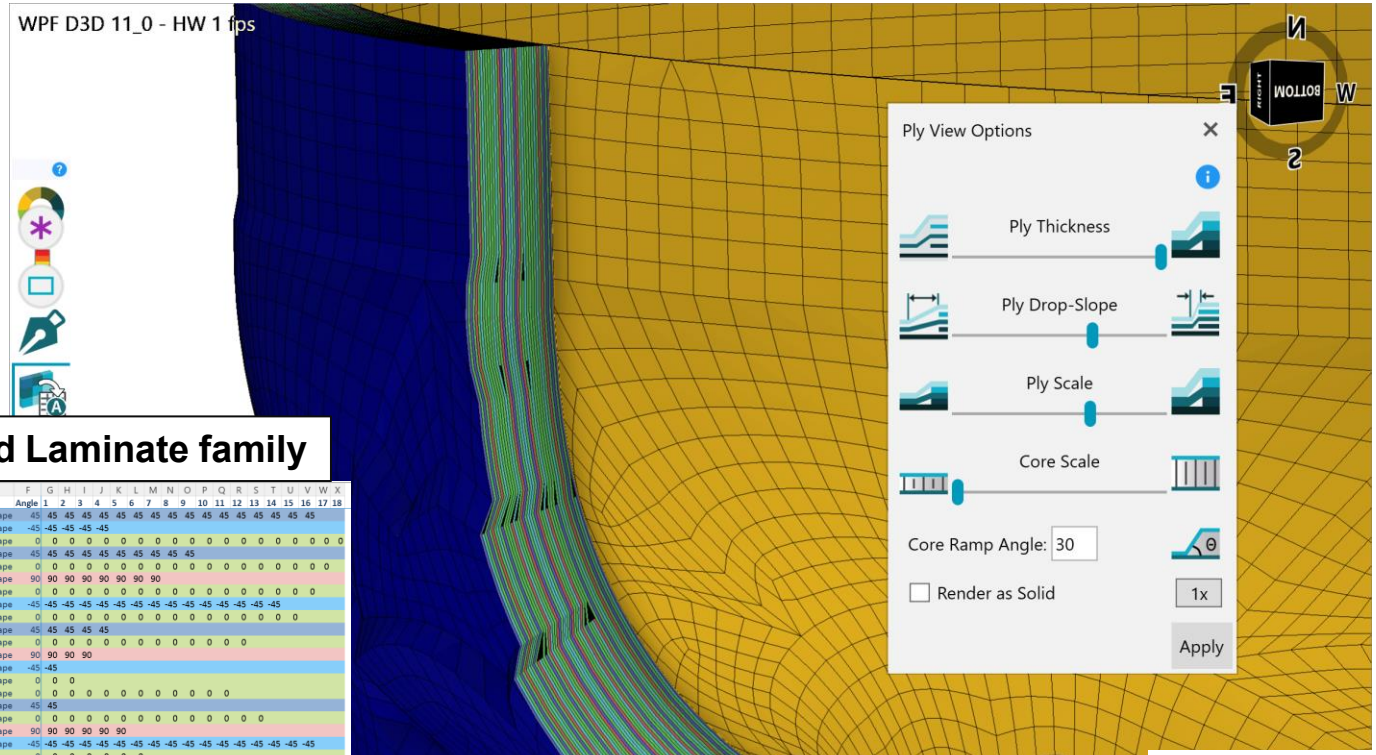
Minimum ‘axial’ frequency = 15.6 Hz



Stiffness Requirements to Achieve 15.5Hz

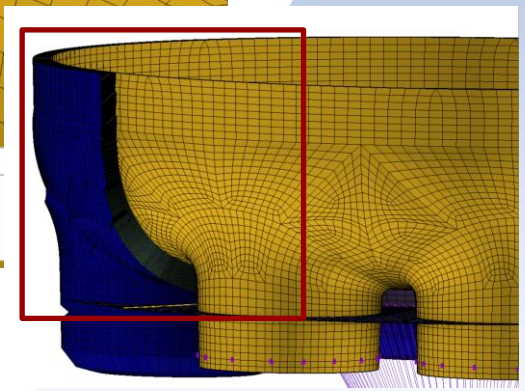


Laminate Sequencing and Visualization Tools



Interleaved Laminate family

Layer	Thickness (in)	Material	Angle	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	0.0024	M55J /954-3 unidirectional tape	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	
2	0.0024	M55J /954-3 unidirectional tape	-45	-45	-45	-45	-45														
3	0.0024	M55J /954-3 unidirectional tape	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0.0024	M55J /954-3 unidirectional tape	45	45	45	45	45	45	45	45	45	45									
5	0.0024	M55J /954-3 unidirectional tape	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0.0024	M55J /954-3 unidirectional tape	90	90	90	90	90	90	90	90											
7	0.0024	M55J /954-3 unidirectional tape	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
8	0.0024	M55J /954-3 unidirectional tape	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45			
9	0.0024	M55J /954-3 unidirectional tape	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
10	0.0024	M55J /954-3 unidirectional tape	45	45	45	45	45														
11	0.0024	M55J /954-3 unidirectional tape	0	0	0	0	0	0	0	0	0	0	0	0	0						
12	0.0024	M55J /954-3 unidirectional tape	90	90	90	90															
13	0.0024	M55J /954-3 unidirectional tape	-45	-45																	
14	0.0024	M55J /954-3 unidirectional tape	0	0	0																
15	0.0024	M55J /954-3 unidirectional tape	0	0	0	0	0	0	0	0	0	0	0	0	0						
16	0.0024	M55J /954-3 unidirectional tape	45	45																	
17	0.0024	M55J /954-3 unidirectional tape	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
18	0.0024	M55J /954-3 unidirectional tape	90	90	90	90	90	90													
19	0.0024	M55J /954-3 unidirectional tape	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45		
20	0.0024	M55J /954-3 unidirectional tape	0	0	0	0	0	0	0												
21	0.0024	M55J /954-3 unidirectional tape	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
22	0.0024	M55J /954-3 unidirectional tape	90	90	90	90	90	90	90	90	90	90									
23	0.0024	M55J /954-3 unidirectional tape	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45			
24	0.0024	M55J /954-3 unidirectional tape	0	0	0	0	0	0	0	0	0	0	0	0	0						
25	0.0024	M55J /954-3 unidirectional tape	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45						
26	0.0024	M55J /954-3 unidirectional tape	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45						
27	0.0024	M55J /954-3 unidirectional tape	0	0	0	0	0	0	0	0	0	0	0								
28	0.0024	M55J /954-3 unidirectional tape	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45			
29	0.0024	M55J /954-3 unidirectional tape	90	90	90	90	90	90	90	90	90										
30	0.0024	M55J /954-3 unidirectional tape	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
31	0.0024	M55J /954-3 unidirectional tape	0	0	0	0	0	0	0												
32	0.0024	M55J /954-3 unidirectional tape	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45		
33	0.0024	M55J /954-3 unidirectional tape	90	90	90	90	90	90													
34	0.0024	M55J /954-3 unidirectional tape	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
35	0.0024	M55J /954-3 unidirectional tape	45	45																	
36	0.0024	M55J /954-3 unidirectional tape	0	0	0	0	0	0	0	0	0	0	0	0	0						
37	0.0024	M55J /954-3 unidirectional tape	0	0	0																
38	0.0024	M55J /954-3 unidirectional tape	-45	-45																	
39	0.0024	M55J /954-3 unidirectional tape	90	90	90	90															
40	0.0024	M55J /954-3 unidirectional tape	0	0	0	0	0	0	0	0	0	0	0	0	0						
41	0.0024	M55J /954-3 unidirectional tape	45	45	45	45	45														
42	0.0024	M55J /954-3 unidirectional tape	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
43	0.0024	M55J /954-3 unidirectional tape	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45				
44	0.0024	M55J /954-3 unidirectional tape	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
45	0.0024	M55J /954-3 unidirectional tape	90	90	90	90	90	90	90	90											
46	0.0024	M55J /954-3 unidirectional tape	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
47	0.0024	M55J /954-3 unidirectional tape	45	45	45	45	45	45	45	45	45	45									
48	0.0024	M55J /954-3 unidirectional tape	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49	0.0024	M55J /954-3 unidirectional tape	-45	-45	-45	-45	-45														
50	0.0024	M55J /954-3 unidirectional tape	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45		



Conclusions

- WRT mass optimization, the frequency design requirement was the primary design driver, followed by the strength design requirement and buckling design requirement.
- The frequency design requirement was less sensitive to weight change than the buckling design requirement.
- Running buckling analysis with higher eigenvalue assisted in achieving the frequency design requirement with a lower mass for the SEP ARRM bulkhead structure.
  - Buckling analysis was shown to identify overall structural stiffness design weaknesses for stability examination and also resulted in an optimized bulkhead geometry for achieving the frequency design requirement at a lower mass than previous design concepts.
- **Primary lesson is to adapt our design/analysis process to include an early sensitivity study for buckling eigenvalue vs. natural frequency, optimizing for mass.**

QUESTIONS OR COMMENTS?

Laminate Study Tool

Laminate Family Design Study

Input Selection

Zones: 2:25,27:39

Designs: Non-orthogonal Eff. Lam. (4)

Input Laminate Families

CONSERVATIVE OCTOPANTS FAM_Hourglass (140)

Internal Ring Lam Fam_Diamond_SB (78)

Internal Ring Lam Fam_Hourglass_SB (78)

Trials to run: 64

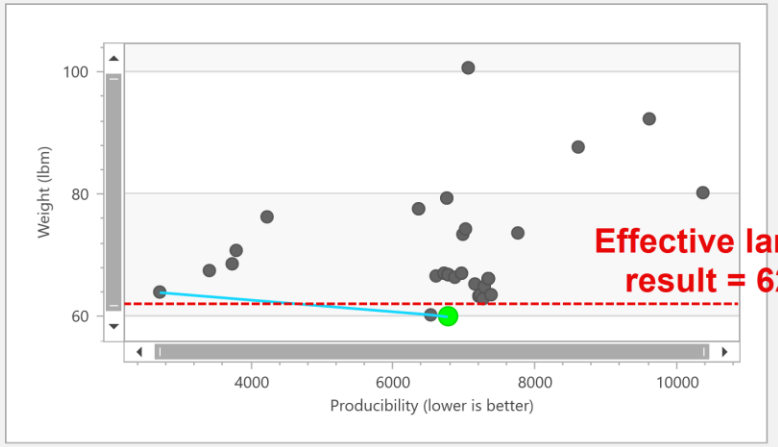
Run Trials

Always use Detail Sizing

Output

Producibility Complexity: AFP and Tape | Hand Fabric and Uni's

	Inputs		Producibility (lower is better)				
Tri	FamilyName	Weight	Metric A	Metric B	Metric C	Plies	Ply Cuts
4	Internal Ring Lam Fam_Interleaved_SB	66.98	6789.04	1696.2742	6.8351	94	6664
5	Lam_fams_Hourglass_SB	65.36	7168.5484	1572.43	7.848	86	6588
6	Lam_fams_Interleaved_SB	77.72	6367.246	1397.1794	34.3442	84	7324
7	Lam_fams_InterleavedHourglass_SB	77.72	6367.246	1397.1794	34.3442	84	7324
8	Non-ortho Lam Fams_Diamond_SB	63.49	7396.5933	1884.7028	90.0312	96	6640
9	Non-ortho Lam Fams_Hourglass_SB	66.31	7356.7159	2082.4483	112.0334	102	6688
10	Non-ortho Lam Fams_Interleaved_SB	80.33	10383.1624	2174.257	1.4802	112	9584
11	Octo Recreation Lam. Fam._Hourglass	59.97	6783.4563	1779.0987	10.2427	88	6212
12	Ortho Lam Fams_Diamond_SB	62.85	7285.6666	1784.5432	90.0312	92	6640
13	Ortho Lam Fams_Hourglass_SB	66.31	7356.7159	2082.4483	112.0334	102	6688
14	Ortho Lam Fams_Interleaved_SB	73.47	6988.3833	1677.6344	31.0779	92	7092



Effective laminate result = 62 lbs

Selected Trial

General	
Family	Octo Recreation Lam. Fam.Hourglas
Weight (lbm)	59.97
Producibility (lower is better)	6783

Critical Margins of Safety	
Criteria	Composite, Max Stress 1
Zone	PCOMP 20: transitione1 20
Margin	2.5E-3

Laminate Statistics	
Plies	88
Sequences	53
Ply Cuts	6212

Producibility (lower is better)		
	Laminate	Avg Ply
Metric A	6783	77.08
Metric B	1779	20.22

Make Design | Update Design | Close

Supplemental Section

HyperX processes run on the 2015 model