Team 43 SRAD Composite Overwrapped Pressure Vessel (COPV)

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Outline

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    b. Structural Loads
    c. End Cap
    d. Composite Modelling
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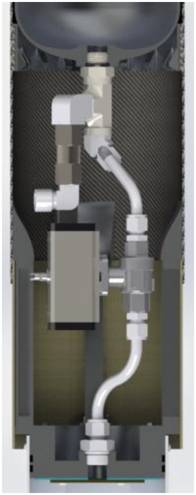
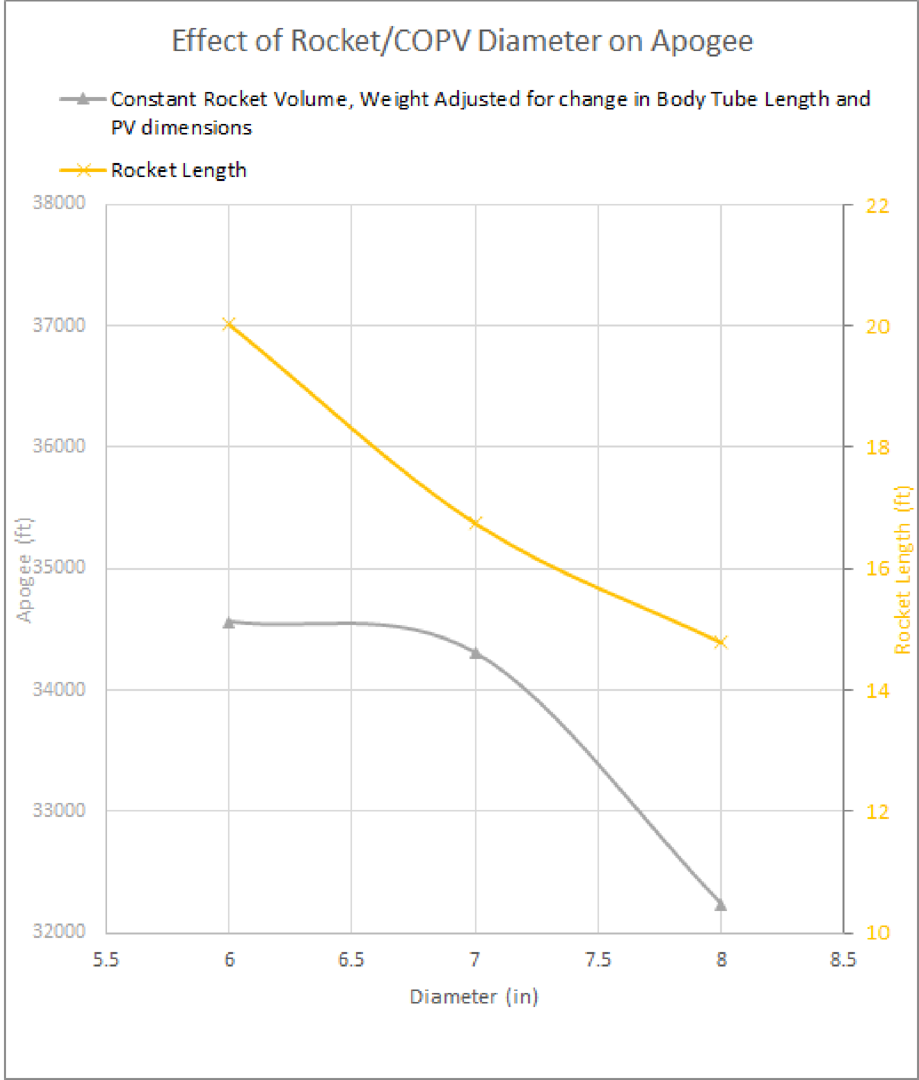


Design Problem

- Design and construct a weight saving composite overwrapped pressure vessel (COPV) to use in a Hybrid Rocket designed to reach 30,000 feet
  - Our design achieves a 50% weight reduction, 25 lbs over the previous year’s design or +5000 ft apogee
- Constraints and Design Inputs:
  - Nominal: 1000 PSI, Proof tested to 1500 PSI, Design Burst: 3000 PSI
  - Tank Volume of 42.0 L
  - Thrust data for deriving flight loads

Rocket and Vessel Size

- COPV determines rocket diameter
- Simulated a variety of rocket diameters using OpenRocket
  - Drag numbers are not from a full CFD simulation, generated by equations in OpenRocket
  - Thrust curve estimate provided by SOAR
  - Assumed engine length, nose cone weight, COPV volume, body tube volume, and nose cone aspect ratio remain constant
  - Metric used: Rocket Apogee



Rocket and Vessel Size

7” diameter chosen

Pros:

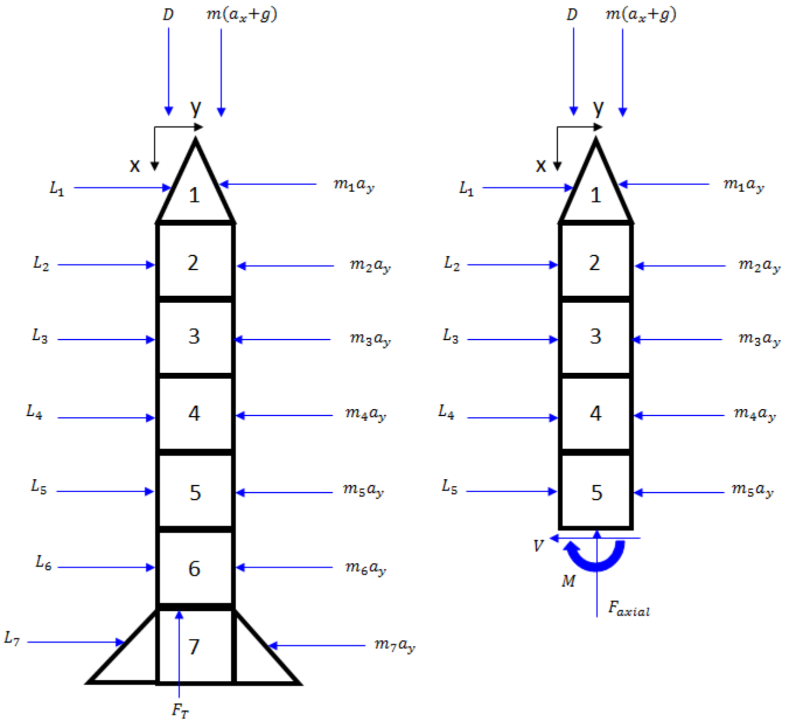
- Equivalent performance to that of a 6” rocket
- Existing SOAR equipment & parts are designed for a 7” rocket
- Shorter rocket
- Shorter pressure vessel
- More internal space
- Stronger in bending

Cons:

- 6” stock is 1/2 the price of 7” - for tube and round bar

Rocket Structural Loads

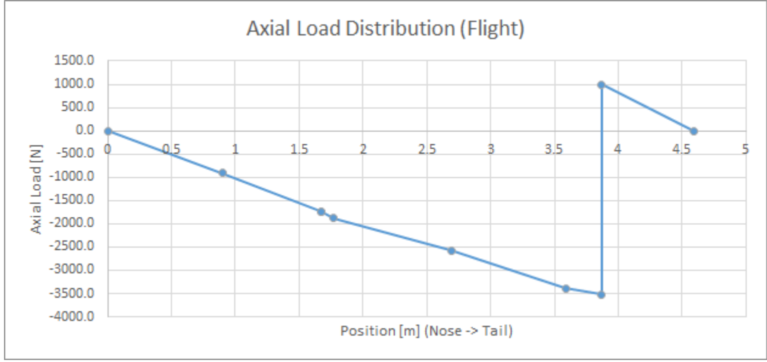
- Three load cases considered for design
  - Flight
  - Parachute Deployment
  - Ground Carrying
- Rocket modeled as a beam split into elements
  - Forces, masses, and geometry info are input to a spreadsheet
  - Calculates axial force, shear force, and bending moment diagrams
  - Key interfaces and locations selected as nodes in the model

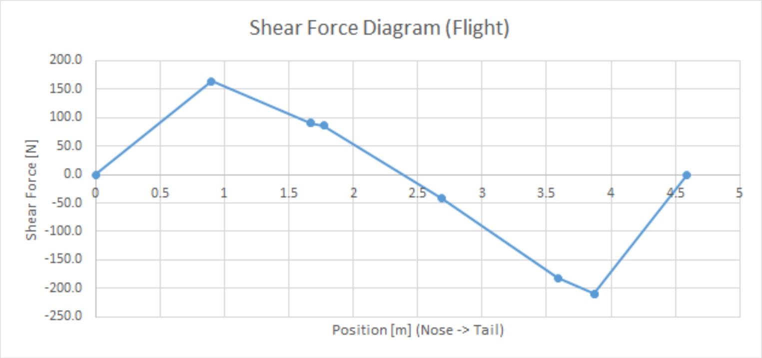


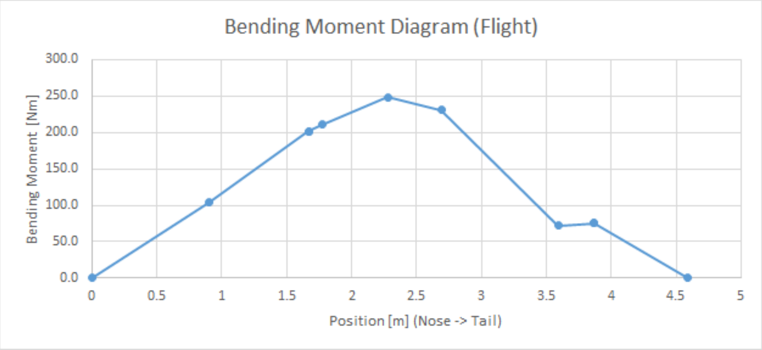
Rocket Structural Loads

Flight Case

- Lateral lift force found using a flow simulation
  - Worst case conditions of a wind shear + gust at max thrust and velocity
  - Input to spreadsheet
- Largest axial compression, smallest bending moments and shears



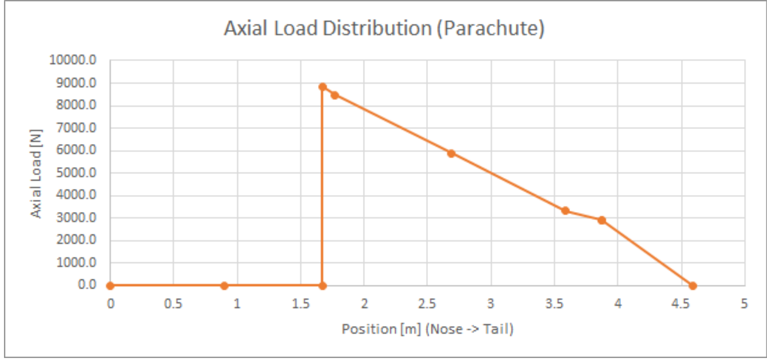


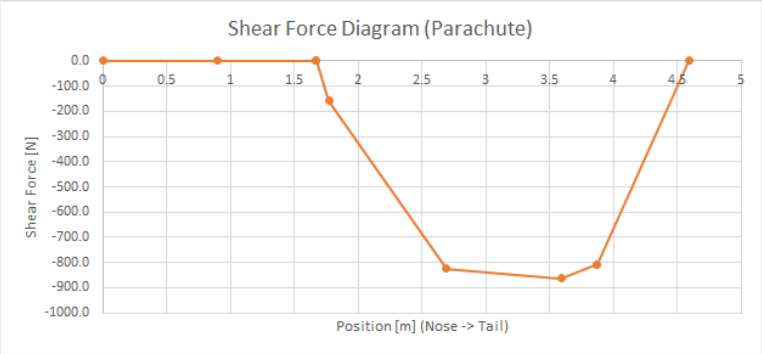


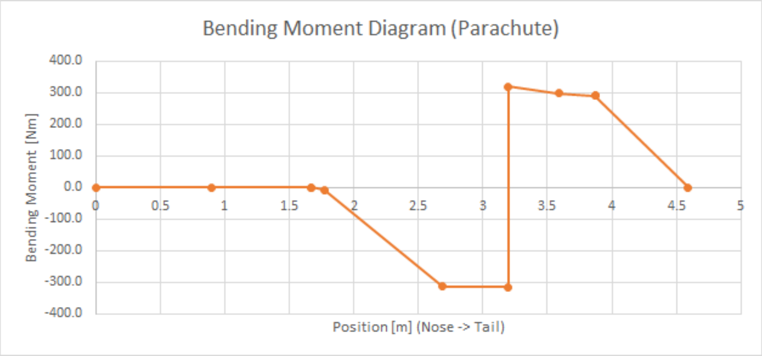
Rocket Structural Loads

Parachute Deployment Case

- Worst Case Conditions:
  - Parachute vertical tensile force - 9500 N (2136 lbf)
  - Rocket at angle of 15 degrees from vertical
    - Just an estimate, have not prioritized the accurate prediction of this angle
- Element forces come from:
  - Acceleration along the axis of the rocket
  - Angular acceleration about the CG
- Parachute Deployment Case:
  - Largest axial tension, largest shear, medium bending moments



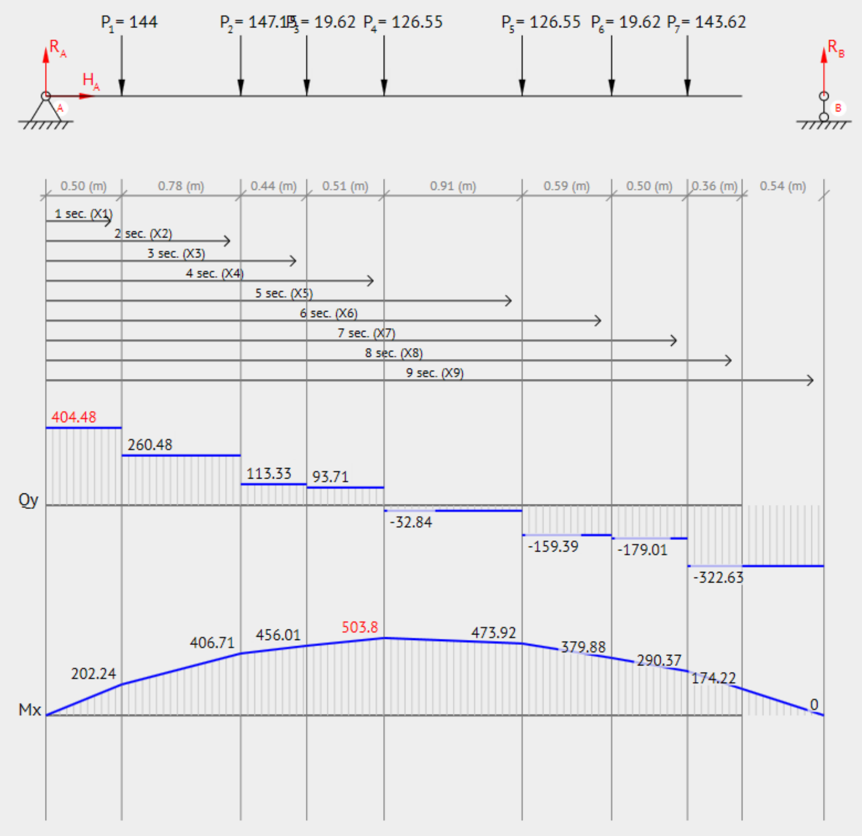




Rocket Structural Loads

Ground Carrying Case

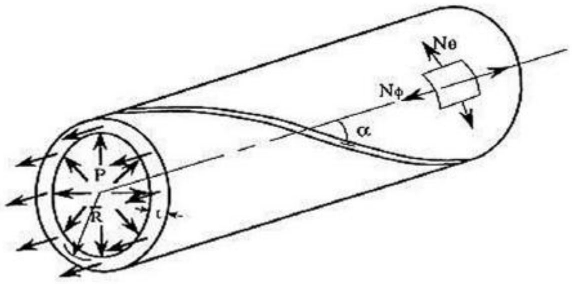
- Worst Case Conditions:
  - Two people carrying the rocket by either end
  - 2g load factor
  - Empty pressure vessel
- Simply supported beam
- Carrying Case:
  - Largest bending moments, medium shear
- Could happen easily if someone happens to pick up one end of the rocket

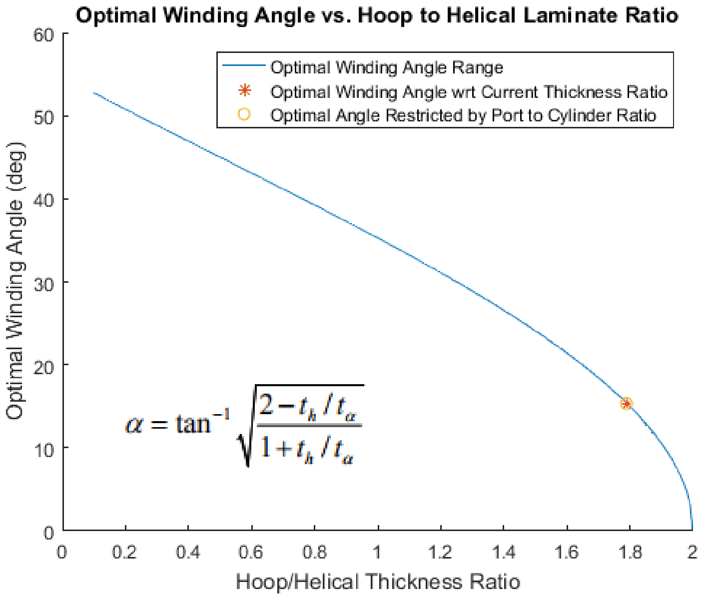


Determining Fiber Direction

- Cylindrical Section Filament (Helix) Angle, α
  - Hoop layers α ≅ 90°
  - Helical layers α ≅ 15° (for our case)
- End cap fiber orientation
  - Geodesic (natural position) or Non-Geodesic friction to curve fiber paths)

$$\rho \sin\alpha = cst = 3.5\sin(\alpha_0) = \rho_{port}\sin 90°$$



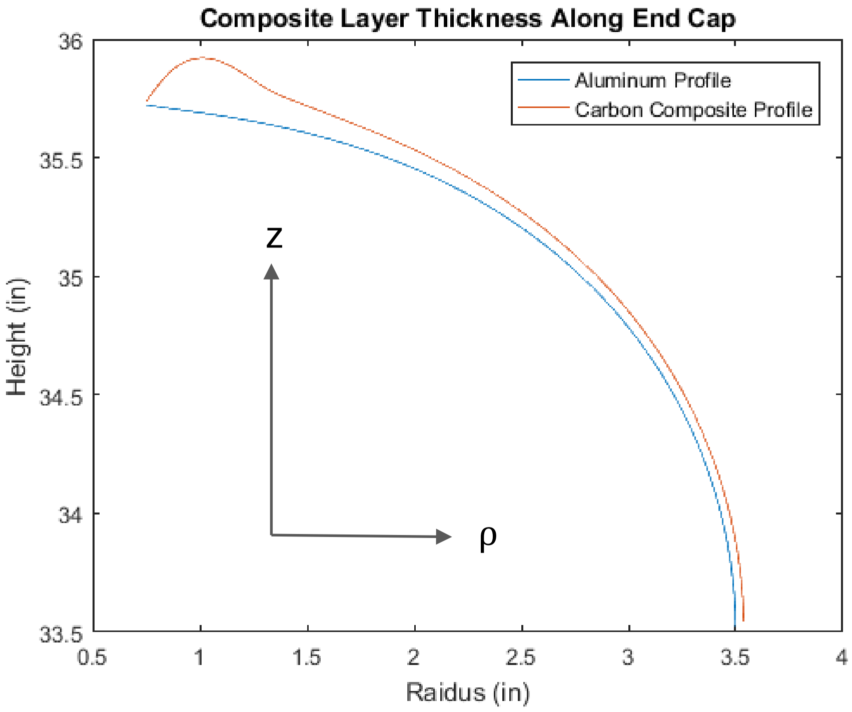


End Cap - External Profile

- Liner external profile
  - Optimal shape is not hemisphere
  - “Isotensoid” - equal tension
  - All fibers are loaded with equal stress
- Fiber build up - Not uniform
  - Many methods in literature to predict thickness profile
  - Cubic spline method

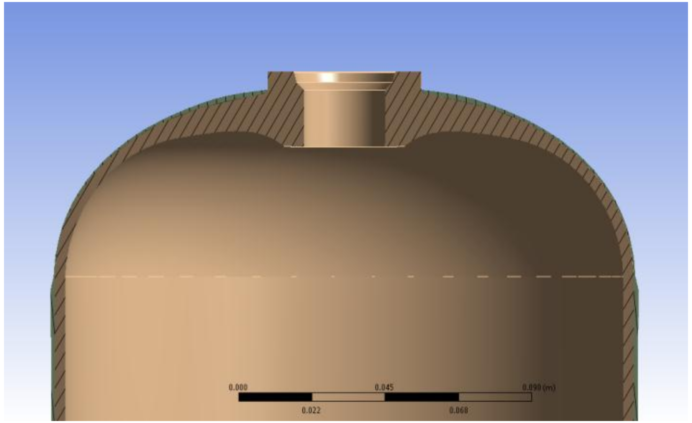
$$Z'(Y) = \pm \frac{Y(Y^2 + rY_{eq}^2)}{\sqrt{\left(\frac{k_e + Y^2 - 1}{k_e + Y_{eq}^2 - 1}\right)^{k_e+1} (1+r)^2 Y_{eq}^6 - Y^2\left(Y^2 + rY_{eq}^2\right)^2}}$$

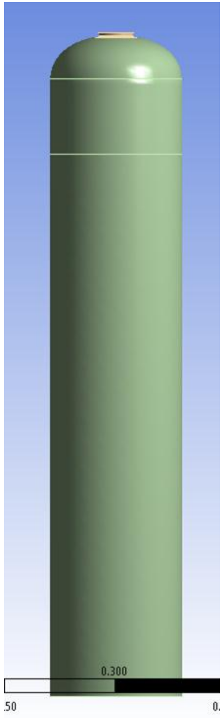
$$k_e = \frac{E_2\left(1+\nu_{12}\right)}{E_1\left(1+\nu_{21}\right)}$$



Composite Modelling - FEA

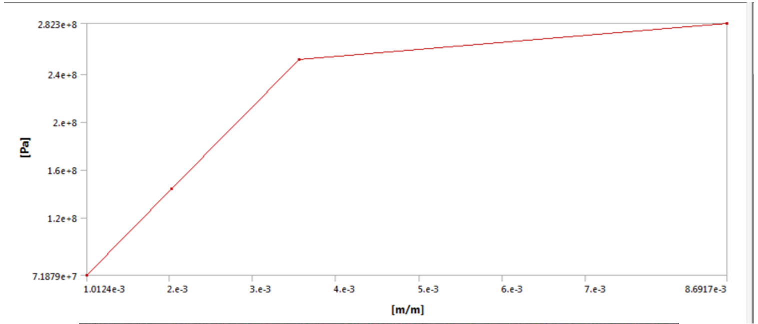
- Analysis in ANSYS ACP
  - Aluminum liner
  - Composite overwrap
- Iterative simulation to optimize the model
  - Liner end cap internal surface determined iteratively
- Loading conditions considered
  - Carrying load
  - Flight loads
  - Parachute loads





Composite Modelling - FEA

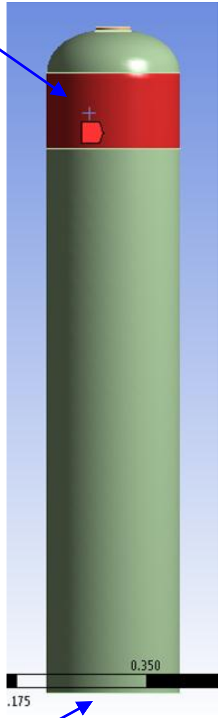
- Previously mentioned methods used to set up look-up table to define fiber volume and orientation
- Aluminum liner will be yielded at burst pressure
    - Non-linear stress-strain model for the liner is required



	Steps	Time [s]	[B] Equivalent Stress 3 (Max) [Pa]	Equivalent Total Strain 2 (Max) [m/m]
1	1	0.2	7.1879e+007	1.0124e-003
2	1	0.4	1.4396e+008	2.0276e-003
3	1	0.7	2.5245e+008	3.5556e-003
4	1	1.	2.823e+008	8.6917e-003

- Attachment of the COPV is in the form of a larger composite tube called a skirt
- Loading conditions are run for the upper half of the pressure vessel

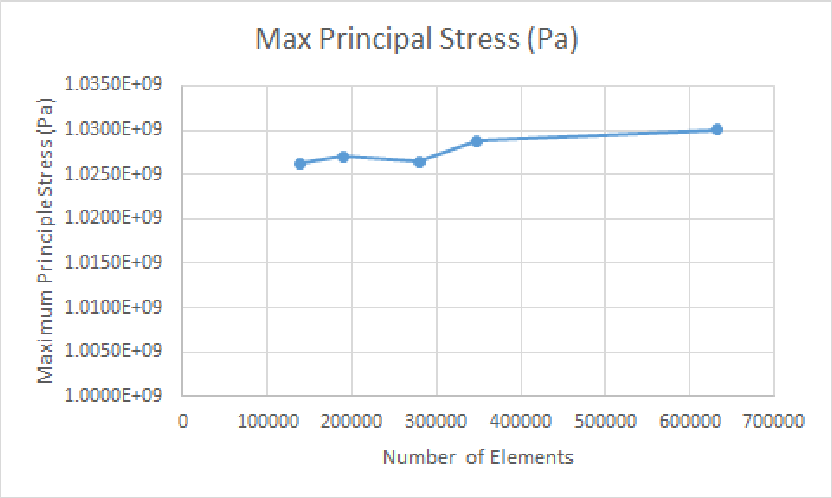
Attachment surface

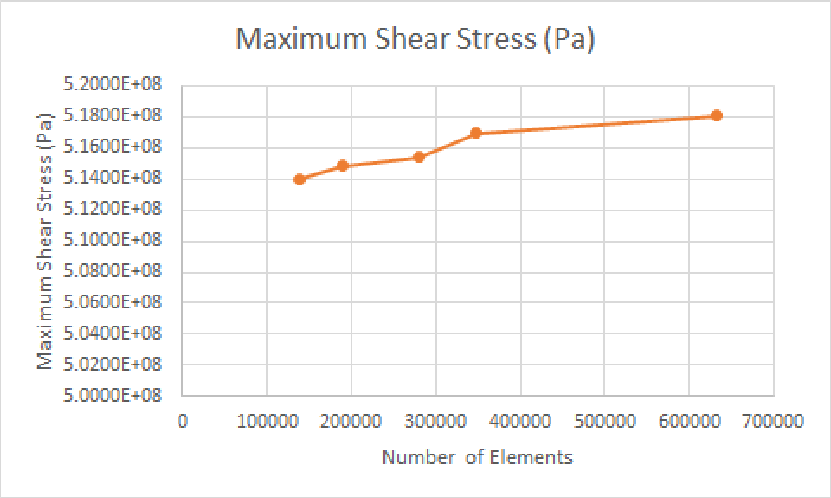


Fixed support

Composite Modelling - FEA

- Mesh Independence
  - Mesh density increased to validate that the solution is mesh independent





Composite Modelling - FEA

Carrying Load

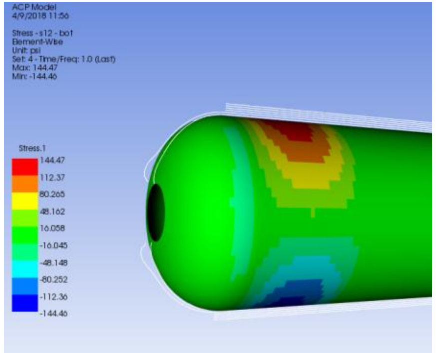
- Largest bending moment encountered by COPV
- Safety Factor: 60.0

Flight Loads

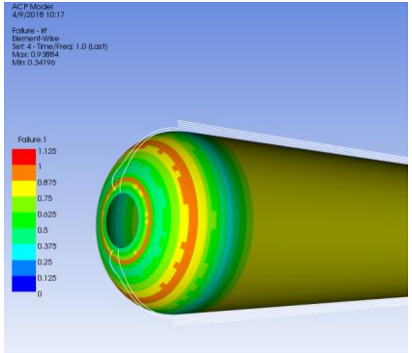
- Largest axial compressive load encountered by COPV
- Safety Factor: 3.20

Parachute Loads

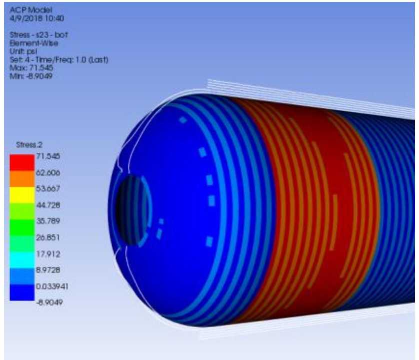
- Largest axial load
- Determined to be applied at 15° from vertical
- Safety Factor: 63.5



In Plane Shear Stress - s12



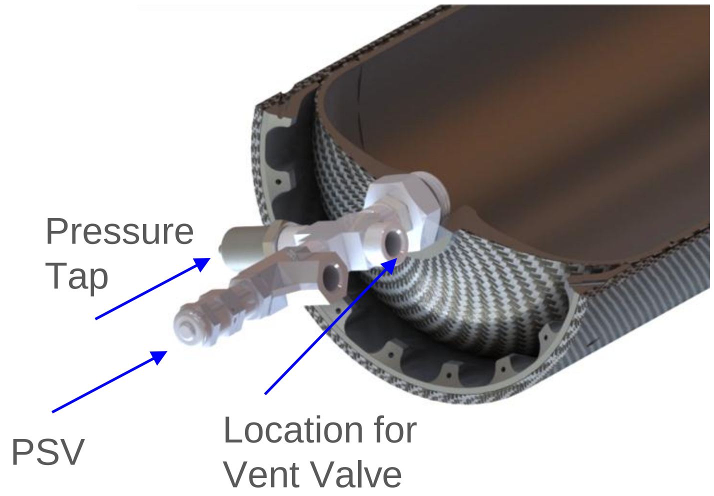
Safety Factor

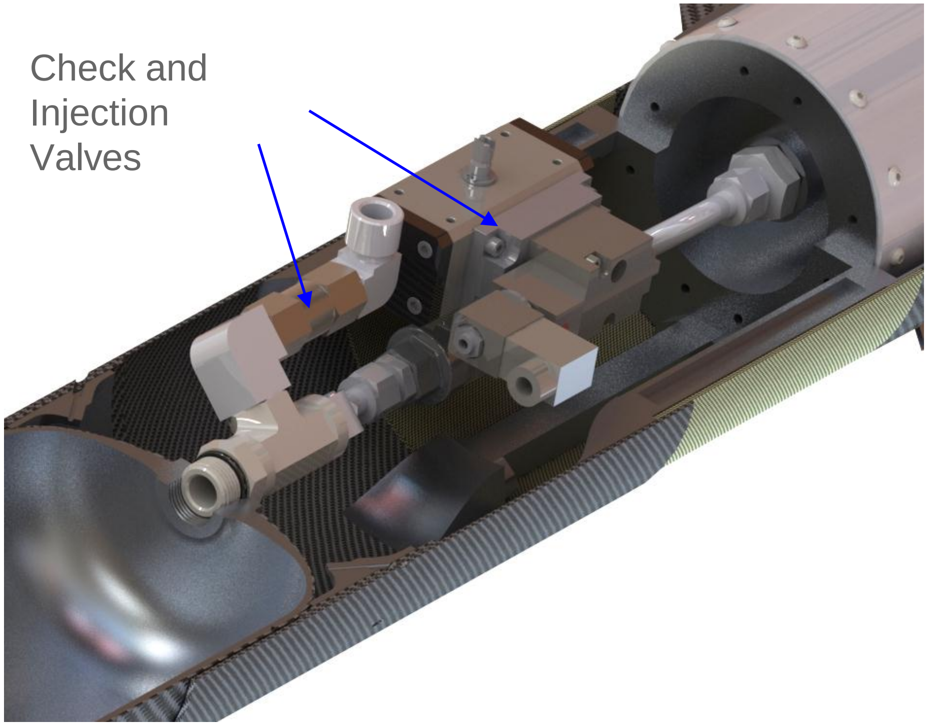


Out of plane shear stress - s23

Rocket Integration - Fittings and Valving

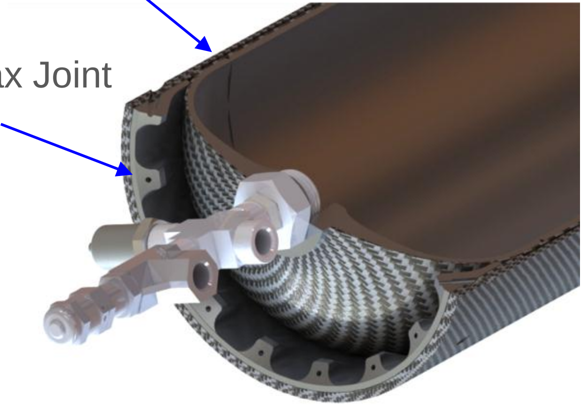
- Valves - Injection, safety, and check
- ½” or ¾” Nominal sizes

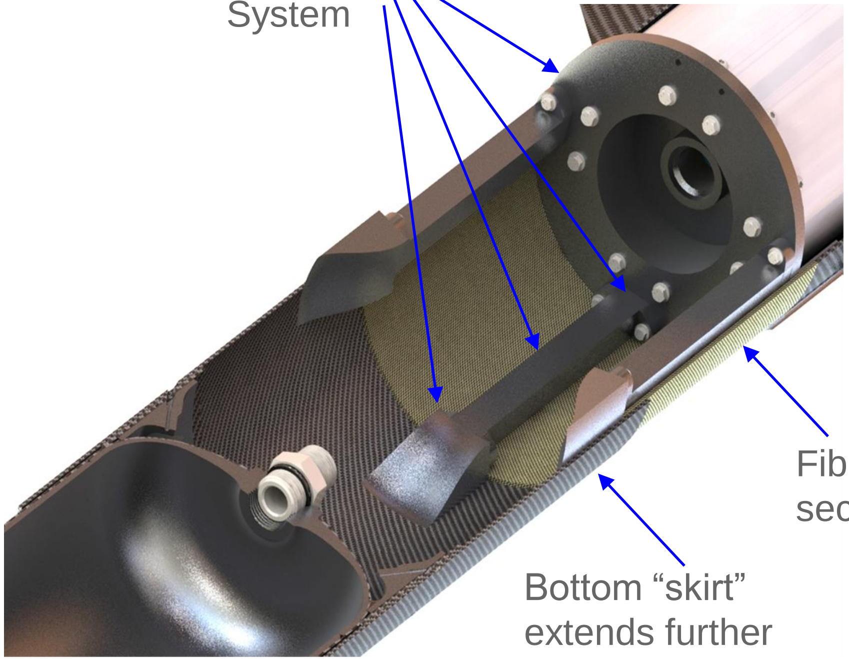




Rocket Integration - Mechanical

- Removable, reliably realigned with the rocket





Conclusions

- A significant weight reduction can be achieved going from all Aluminum to COPV
- The most weight efficient design has the tank exist as a structural member of the rocket body
- The optimal mounting method is a concentric carbon fiber tube epoxied to the exterior of the pressure vessel