Solar Panel Deployment System for NASA

Concept Generation Ideas

Deploying Mechanism

Pressure Induced

- Roll-out & retract method
- Mimosa leaf expansion

Surface Tension Expansion

- Hydration of hydrophobic fibers
- Tri-block copolymer expansion

Nonwoven mats were not ideal for surface tension expansion

Linearly/radially aligned fibers are needed

Electric shape memory

- Electric change can cause panel to deploy & retract

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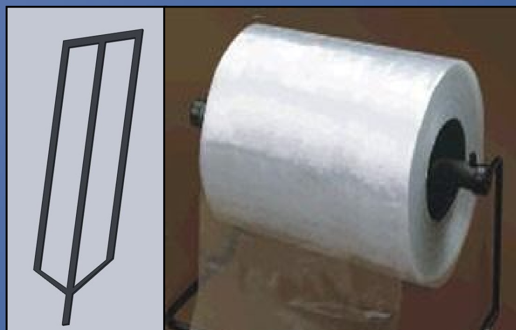
Final Design

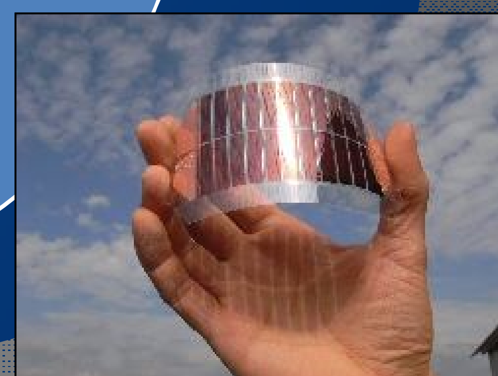


Membrane Structure

Deployment Mechanism

Triggering Source

Flexible PV Material



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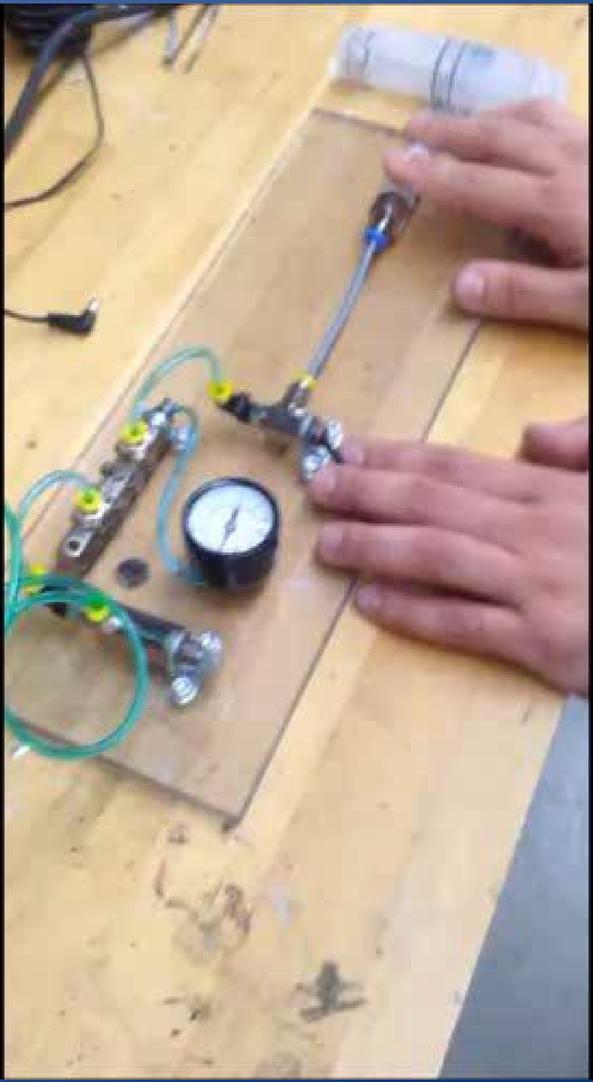
Concept Design



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Concept Design

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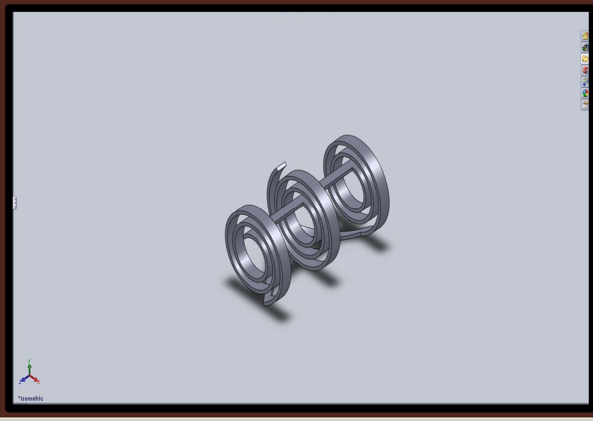
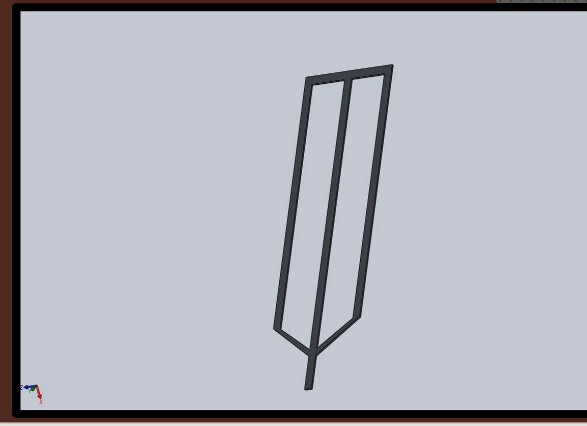
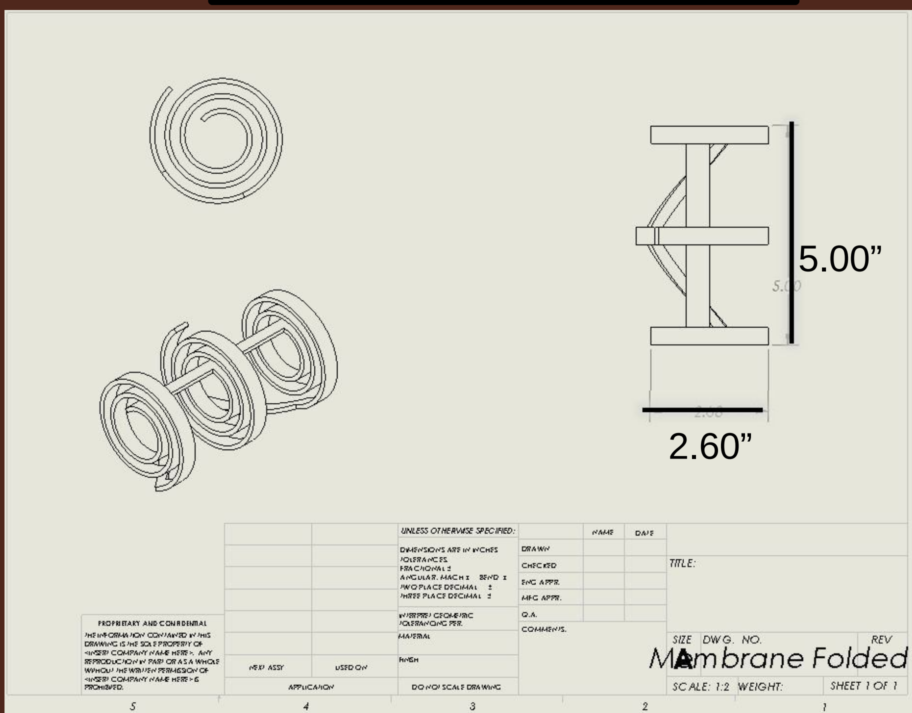
Drawings

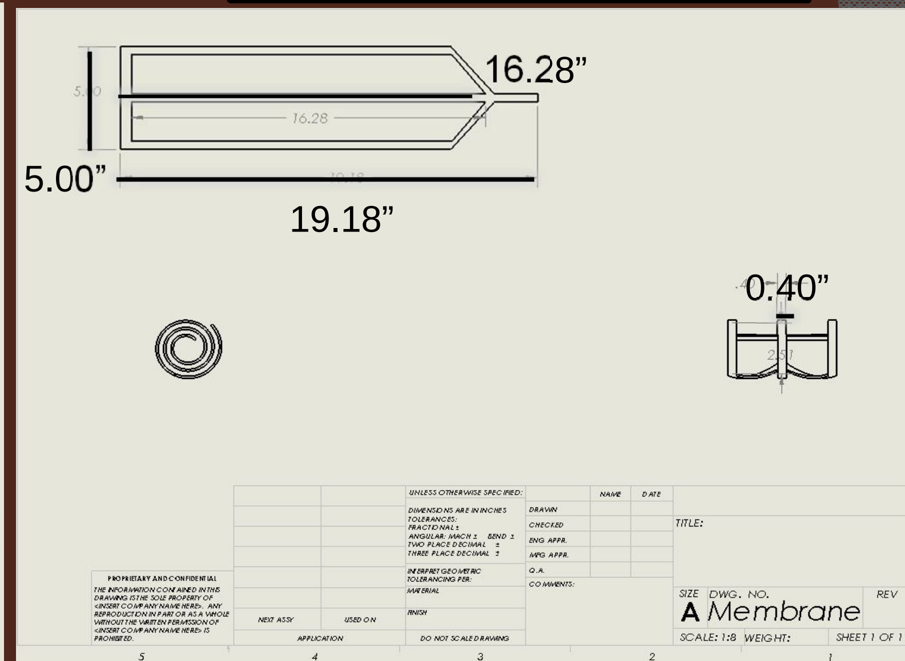
Stowed



Deployed







Analysis Topics and Equations

Topics	***Subcomponent***	***Equation***
Statics & Dynamics	Membranes	Moments of Inertia
		Static Equilibrium
	Constant Force Spring	Hooke's Law
		Angular velocity and acceleration
Fluid Mechanics	Membranes	Pressure Vessel
		Bernoulli's Equation
		Newton's 2^{nd} Law
Machine Element Design	Spring Material	Distortion Energy Theory
	Plastic Material	Stress/Strain
Intro to Nanotechnology	Photovoltaic Layers	Energy Band Gaps

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Subcomponent	Equation	Assumptions
Membranes	$\sum M = \Delta P(2R_i)LR_i - \Delta P(2R_o)LR_o$ $= \Delta P(2L)(R_i^2 - R_o^2)$	
	$\sum F_x = 0 \,; \sum F_y = 0 \,; \sum M_o = 0$	▪ All forces are at equilibrium ▪ No external body forces
	$\sigma_a = \frac{P_i r}{t} \,; P = \frac{F}{A}$	▪ Equal thickness throughout
	$\frac{P_1}{\rho} + \frac{v_1^2}{2} + gz_1 = \frac{P_2}{\rho} + \frac{v_2^2}{2} + gz_2$	▪ Steady State ▪ Ignore gravity forces (outer space) ▪ Assume frictionless (no minor losses) ▪ Incompressible flow
	$F = ma$	▪ Constant acceleration
Constant Force Spring	$\sum M = -PA\frac{y}{2} + k_t\theta = 0$	▪ k, A, & y are constant
	$\omega = \frac{\Delta\theta}{\Delta t} \,; \alpha = \frac{\Delta\omega}{\Delta t}$	▪ Time is estimated to closest second ▪ Constant acceleration ▪ Constant velocity
	$\sigma' = ({\sigma_A}^2 - \sigma_A\sigma_B + {\sigma_B}^2)^{1/2}$	▪ Homogenous and ductile material
Plastic Material	$E = \frac{\sigma}{\varepsilon} = \frac{FL_o}{A_o\Delta L}$	▪ Ideal plastics (purest form)
Photovoltaic Layers	• $\Delta E = \frac{hc}{\lambda}$ • $FF = \frac{I_{mp} \cdot V_{mp}}{I_{sc} \cdot J_{sc}}$ • $\eta = \frac{V_{oc} \cdot I_{sc} \cdot FF}{P_{in}}$ • $P_{\max} = V_{oc} \cdot I_{sc} \cdot FF$	▪ Speed of light is constant ▪ Wavelength is constant ▪ Planck's unit is constant ▪ No outside energy losses/gains

Nomenclature

M - the moment force produced around the base of the mechanism

P - pressure inside of the membrane

R_i - the inner radius of the membrane

R_o - the outer radius of the membrane

L - the length of the membrane

F_x , F_y , & F_z are forces in the x,y and z axes respectively.

E - Young's modulus (modulus of elasticity)

F - the force exerted on an object under tension

A_0 - the original cross-sectional area through which the force is applied

ΔL - the amount by which the length of the object changes

L_0 - the original length of the object.

c - the speed of light (299,792,458 m/s)

v - the frequency

λ - the wavelength

E - the energy of light

h - Planck's constant (6.626×10^{-34} m^2 kg/s)

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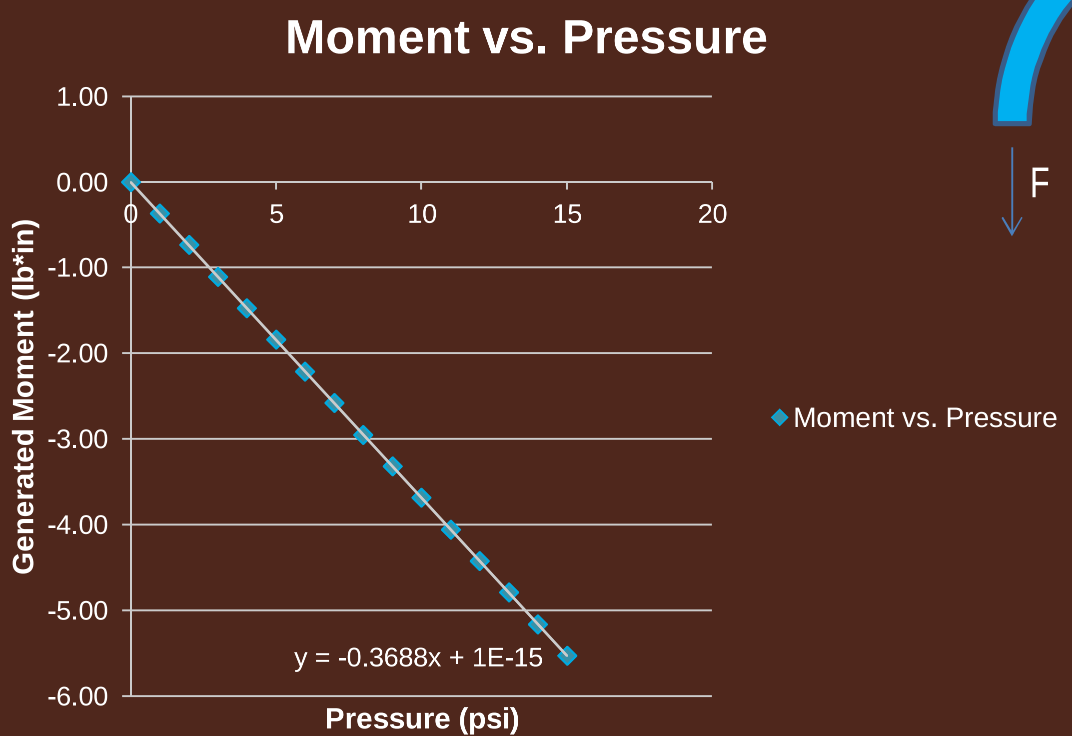
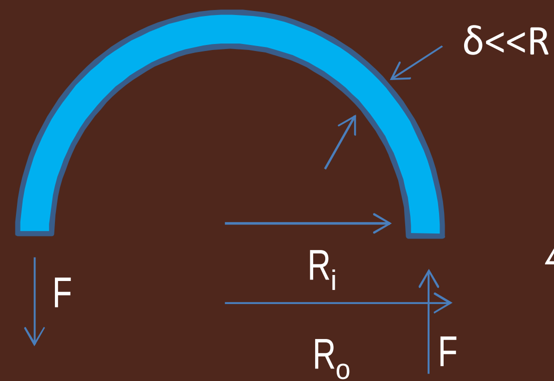
Moment Force Analysis

Moment as a function of stiffness, :

$$\sum M = \Delta P(2R_i)LR_i - \Delta P(2R_o)LR_o = \Delta P(2L)(R_i^2 - R_o^2)$$



Membrane analysis depiction:



L: depth

$$\Delta P = P_{in} - P_{\infty}$$

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Moment Force Analysis Continued..

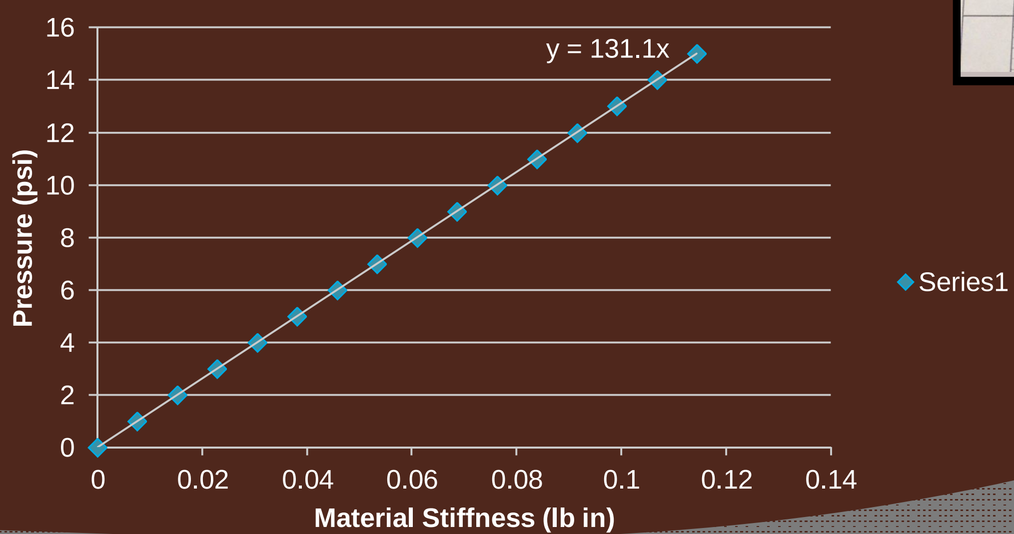
Moment as a function of rotational stiffness, pressure, and rotation :

$$\sum M = -PA\frac{y}{2} + k_t\theta = 0$$

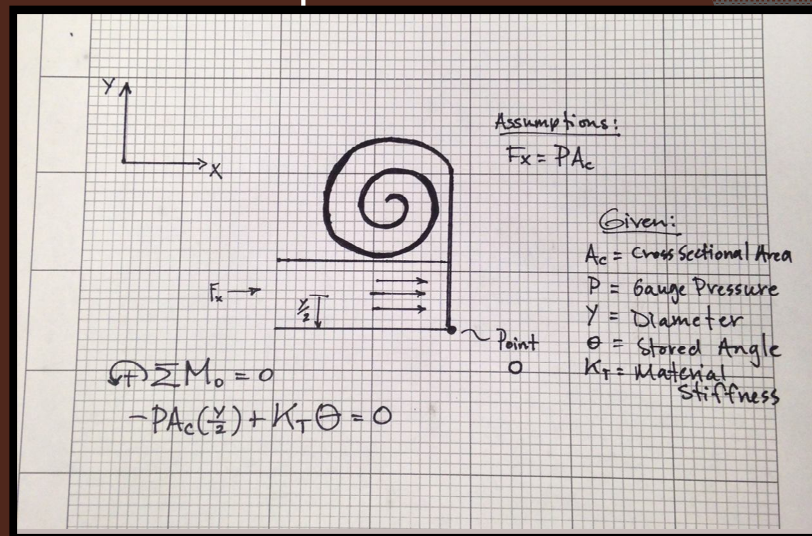
$$k_t\left(\frac{lb \cdot in}{rad}\right) = constant$$

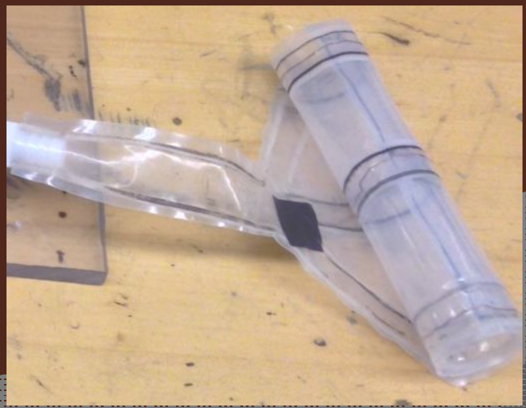
$$k_t\,(k_{spring}, k_{PV})$$

Stiffness vs. Pressure



Membrane analysis depiction:

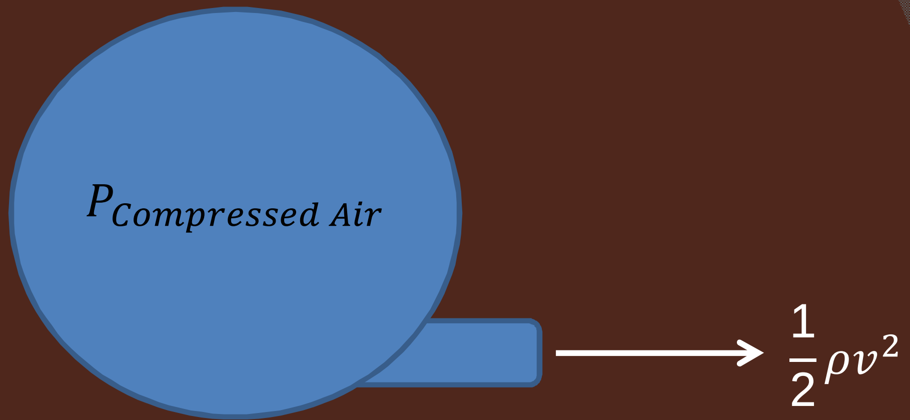


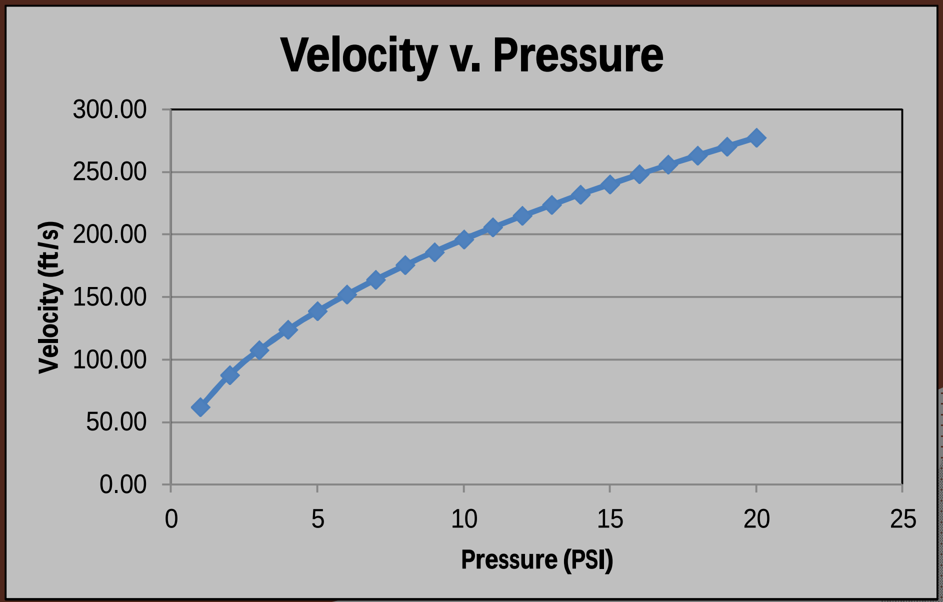


Velocity vs Pressure Analysis

Air velocity as a function of air pressure:

Gauge Pressure (PSI)	Velocity of Air (ft/s)
1	62.01
2	87.70
3	107.41
4	124.03
5	138.67
6	151.90
7	164.07
8	175.40
9	186.04
10	196.11
11	205.68
12	214.82
13	223.60
14	232.04
15	240.18
16	248.06
17	255.69
18	263.11
19	270.31
20	277.34





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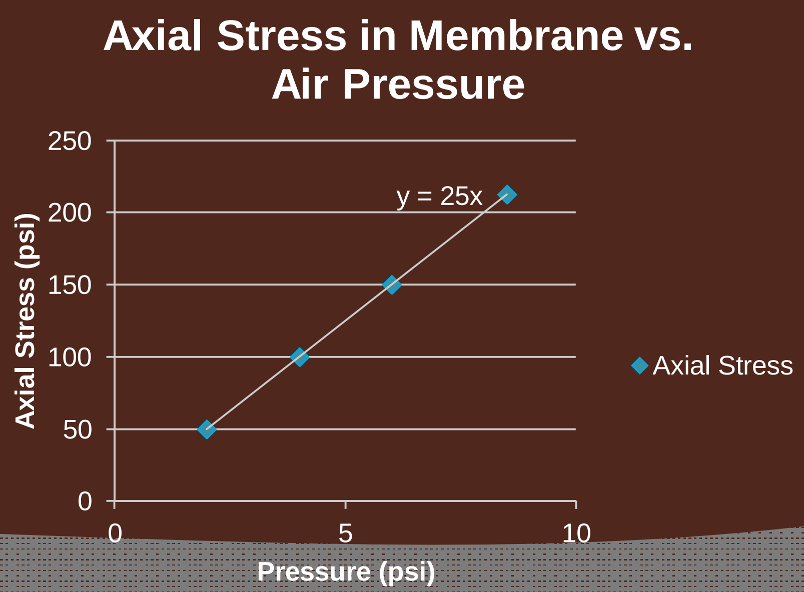
Axial & Tangential Stress of Membrane Structure

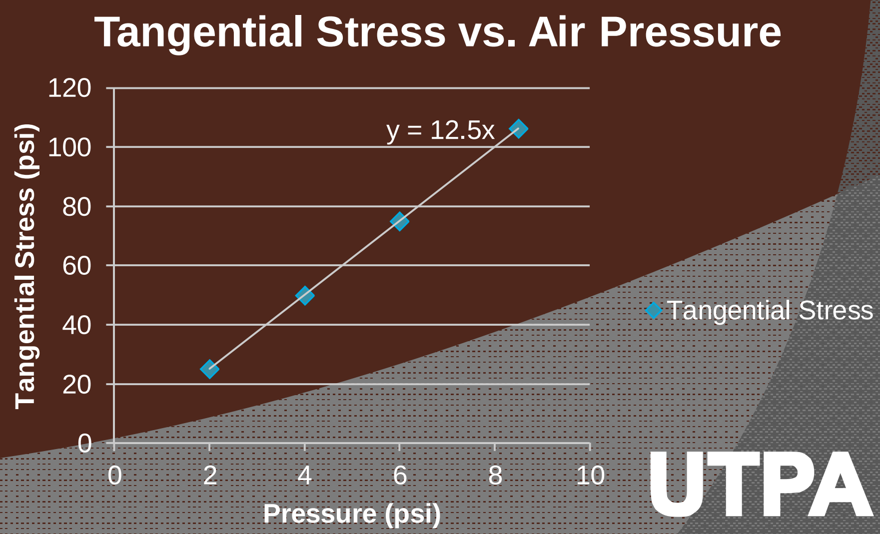
Pressure vessel stress of polymer membrane as a function of pressure, radius, and thickness:

$$\sigma_a = \frac{P_i r}{t}$$

$$\sigma_t = \frac{P_i r}{2t}$$

Max Pressure					
8.5 psi					
US CUSTOMARY UNITS					
Pressure (psi)	Radius (in.)	Thickness (in.)	Cross Sectional Area (in^2)	Tangential Stress (psi)	Axial Stress (psi)
2	0.125	0.005	0.049	25	50
4	0.125	0.005	0.049	50	100
6	0.125	0.005	0.049	75	150
8.5	0.125	0.005	0.049	106.25	212.5





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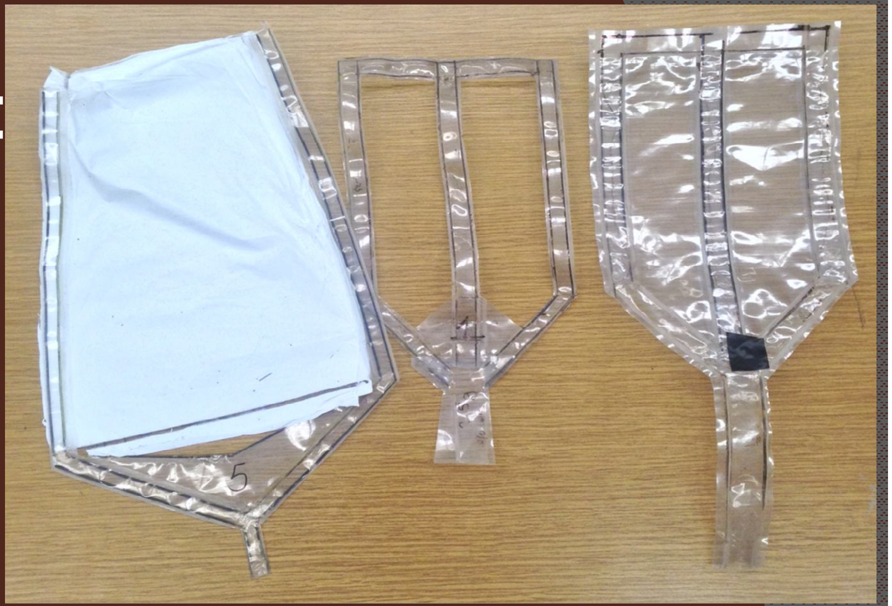
Design for Manufacturability

- Membrane manufacturing:
  - Prototype Manufacturing:
    - L = 16.28 ± 0.1 in
    - $D_{channel}$ = 0.25 ± 0.01 in
    - W = 5 ± 0.1 in
    - Impulse sealing
      - Temperature setting → T = 5 ± $\frac{1}{2}$
      - Duration of seal → t = 10 ± 1 s



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