AME 485 – Aerospace Structures

Project 5

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All The Lessons I Have Learned

1. Structural designs should be verified by analysis and follow the product verification requirements
2. Never forget the lesson learned. Always learn from previous failure and iterate the design to make improvements
3. Have a work life balance, take care of your personal life to be as efficient as possible in the work environment
4. Always speak up when you see something wrong and take accountability for your actions even when you are wrong
5. Collaborate in a team environment and use communication effectively to be efficient and accurate when working on a problem
6. Identify, review, and asses the mission and its associated risks, potential failure modes, and outcomes
7. Design structures with the factor of safety approach and do not rely on probability of failure calculations
8. Employ nondestructive testing methods (NDT) when applicable
9. Understand material selection and the importance it has on the structure
10. Pay attention to the small details. Previous failures have occurred on structures where there was improper unit conversion or where there was a mix up in material codes (6061 Al, etc.)

- Mistakes are your best teacher, failures are acceptable, but minimize them when it impacts significant payloads or persons
- Learn facts before taking actions based on assumptions
- Understand when it is time to speak
- Make decisions but do not overthink and have all facts
- Improve constantly
- Evaluate what is urgent vs. what is important
- Learn how to brainstorm in a team environment
- How you approach work-life-balance can affect decisions at work

Part 1 #1 All The Lessons I Have Learned (Cont..)

- Stay and keep others informed and in the communication loop
- Praise in public, criticize in private
- Question analytical data – it shows functionality in an organization
- Wait to make a decision to gather more data when lives are at risk
- Never be to proud to admit you don’t have the answers or don’t know anything
- Never let a professional disagreement become a personal one
- Allow critical evaluation from ana external source can be crucial to understanding the bigger picture
- Management and organization structure can be just as big of a problem as technical or mechanical ones
- Stay vigilant and ensure that any deviance is handled as a failure to prevent “perfect storm” catastrophes
- It is your job as a leader to help someone who has the skills and capabilities to excel in their job and create more opportunities for them

Part 1

2. My mission statement: My mission as an engineer is to be a well-rounded team member who can contribute meaningfully to solving problems. I strive to be the best version of myself, seizing every opportunity to learn and improve at my skills. I am committed to serving my community, my company, and my family with pride, while pursuing work I am passionate about, with a keen attention to detail. When I make mistakes, I will take responsibility, learn from them, and grow as a more knowledgeable and capable engineer.

    - Vision statement: My long-term goals are to work on products I am passionate about, products that have inspired me to pursue engineering in the first place. While I am not currently an aerospace engineer, I deeply respect the impact that the quality of aerospace engineering work has on the world. I want to take the knowledge I've gained from classes like AME 485 and apply it to the automotive industry. My aspiration is to work for an automotive company, contributing to the design and testing of new products, powertrains, and drivetrains. My goal is to incorporate the rigorous standards and practices of the aerospace community into the automotive sector. This passion for engineering began with cars, but I also see myself expanding into aerospace. In the future, I envision myself working for Boeing, contributing to the design of the new 800 series commercial aircraft. My core values as an engineer including honesty, lifelong learning, being present, and precision will guide me through this journey. I aim to be a team leader, soaking up knowledge and learning from various experiences to help me grow and succeed in the future.

Part 2

1. The main difference in propulsion approaches between aircraft and launch vehicles.
    1. Aircraft: Gets oxygen for combustion from the atmosphere itself and cannot operate outside of the earth's atmosphere. An aircraft engine captures air (mas) from the environment and expels it, propelling the vehicle forward. Fuel is the only thing carried on board while oxygen is harvested.
    2. Launch vehicles: Carry the oxygen for combustion and can operate outside of earths atmosphere in space or in a thin atmosphere. A launch vehicle takes the mass stored in the vehicle and expels it. It utilizes a reaction force to propel itself where all the fuel and oxidizer is carried on board.

2. ISP is the specific impulse of a launch vehicle and is a ratio of the thrust produced to the weight flow rate of the propellants. Essentially, the ISP measures how effectively propellant can convert into thrust, measured in seconds.

    2. A high ISP is more optimal (better) because it means the propellant system can produce more thrust for the same amount of propellant. Thus, the engine is more efficient.

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Part 2

2. Comparing 5 liquid rocket engines.

LV and Liquid Rocket Engines	ISP [seconds]
Ariane 5 (Vulcain 2)	452 s – vacuum 300 s – sea level
Delta 4 (RS-68)	410 s – vacuum 350 s – sea level
Titan 4 (RS-27) First Stage	330 s – vacuum 287 s – sea level
Falcon 9 (Merlin 1D) Frist + Second Stage	348 s – vacuum 311 s – sea level
H-2 (LE-7 and LE-5A) First + Second Stage	450 s – vacuum 311 s – sea level

Part 2

3. To reach an intended orbit, a launch vehicle requires sizing using ΔV to represent the amount of velocity needed to thrust the launch vehicle to reach its goal. The change in velocity is calculated and is a key parameter in the ideal rocket equation. A rocket is designed by considering the propulsion system performance (ISP), the mission requirements (Dv), and Vehicle Masses (MR). Listed below are the intended steps to follow when sizing a launch vehicle.
    - Identify the Mission Requirements (Dv)
        - low earth orbit requires a ΔV of 30,000 ft/s with accounting for drag and gravity losses
    - Identify Propulsion System Performance (Isp)
        - How efficient the rocket uses its propellant to generate thrust
    - Identify and determine the Vehicle Masses
        - Find the initial and final mass
    - Plug everything into the ideal rocket equation
        - $\Delta V_{LV} = \ln(MR)\, Isp \cdot g$

    - The best system would have a high ISP and high MR
        - This is not possible because they work against each other, a greater ISP = a greater MR
            - More insulation to hold propellants, larger engine nozzle, thick-walled structures to withstand pressure

Part 2

4. Given:
   - ΔV = 1600 m/s
   - Payload mass = 5 kg
   - ISP = 200 s
   - Thrust (F) = 1100 N
   - $\dfrac{M_{inert}}{M_{Inert} + M_{Propulsion}} = 0.4$

   - Find MR: 2.26
   - What is the inert mass required for this system: 2.21 Kg
   - Propellant mass = 2.79 Kg
   - Total Firing time before all the propellant burns off: 4.98 s

4) $\Delta V_{LV} = \ln(MR)\, I_{sp} \cdot g$

Propellant Mass Ratio $= \dfrac{M_p + M_I + M_{pl}}{M_I + M_{pl}} = MR$

$MR = \dfrac{M_0}{M_f}$

$\Delta V_{LV} = \ln\left(\dfrac{M_0}{M_f}\right) I_{sp} \cdot g$

$\dfrac{M_0}{M_f} = e^{\left(\frac{\Delta V}{I_{sp} \cdot g}\right)}$

$\dfrac{M_0}{M_f} = \boxed{2.26}$

Propellant Mass

$M_{propellant} = 5\,kg \cdot \left(1 - e^{\left(-\frac{1600\,m/s}{200\,s \cdot 9.81\,m/s^2}\right)}\right)$

$M_{propellant} = \boxed{2.79\,kg}$

final mass = 5 kg − 2.79 kg

final mass = 2.21 kg

Inert Mass

$M_i = M_i - M_p$

$M_i = 5 - 2.79$

$\boxed{M_i = 2.21\,kg}$

Firing Time

$F = \dot{m} \cdot V$

$\dot{m} = \dfrac{F}{V}$

$\dot{m} = \dfrac{F}{I_{sp} \cdot g}$

$\dot{m} = \dfrac{1100\,N}{200 \cdot 9.81}$

$\dot{m} = 0.56\,kg/s$

$T = \dfrac{m_p}{\dot{m}}$

$T = \dfrac{2.79\,kg}{0.56}$

$\boxed{= 4.98\,s}$

Part 3

1. Transportation of Launch Vehicle
   - Shear and bending moment diagram?
   - Maximum vertical deflection?
   - Maximum tension and compression stress?
   - F.S. of 2.0 is this appropriate / robust design?
     - This is not a robust design, need to add support to the structure or else there will be catastrophic failure. Thicker or better materials could help to try and relax the concentrated stresses

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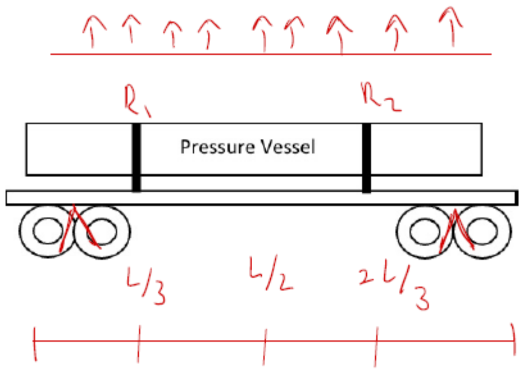


Given: $L = 600$ in $P = 5$ psi

out $D = 50$ in

$t = 0.1$ in

in $D = 49.8$ in

$\rho = 0.1$ lb/ft^2

$\nu = 0.25$

$E = 20 \cdot 10^6$ PSI

$g = 9.81$ m/s^2

A basis (5%)

30 failed so,

UTS A = 45 ksi

Volume = V_{cyl} + 2 ends

$$\left[600 - 2(0.1)\right]\left[\pi\left(\frac{50}{2}\right)^2 - \pi\left(\frac{49.8}{2}\right)^2\right] + \left[2\left(\pi\left(\frac{50}{2}\right)^2 \cdot 0.1\right)\right]$$

$$V = 9795.492 \text{ in}^3 = 5.67 \text{ ft}^3$$

$$m = V \cdot \rho = 5.67 \text{ ft}^3 \cdot 0.1 = 0.567 \text{ lb}$$

$$w = 0.567 \text{ lb} \cdot 9.81 \text{ m/s}^2 = 5.56 \text{ lb m/s}^2$$

Part 3

1. Total stress was greater than allowable stress. Shown in the image to the right

$$\sigma = \frac{M_c}{I} = 45\ \text{ksi} = \frac{Mc}{I}$$

$$I = \pi/8 \cdot \frac{OD^4 - ID^4}{2^4} \leftarrow \text{cylinder}$$

$$I = \frac{\pi}{8}\left(\frac{50^4 - 49.8^4}{2^4}\right) = 2439.68$$

$$\delta_{max} = \frac{5wL^4}{384EI} = \frac{5(5.56)\,600^4}{384\,(20\cdot10^6)\,2439.68}$$

$$\boxed{\delta_{max} = 0.1923''}$$

Max Tension and Compression

$$\sigma_{hoop} = \frac{PD}{2t}$$

$$\sigma_{hoop} = \frac{5 \cdot 50\text{in}}{2(0.1)} = 1250\text{psi}$$

Tensile max

$$\sigma_{long} = \frac{\sigma_{hoop}}{2} = 650\ \text{psi} \rightarrow \text{compression}$$

$$\sigma_{tot} = \sigma_{hoop} + \sigma_{bend} \rightarrow \sigma_{ben} = \frac{M \cdot c}{I} = \frac{2400\ \text{in}(25)}{2.44\text{in}}$$

$$= 1250\ \text{psi} + 24{,}715$$

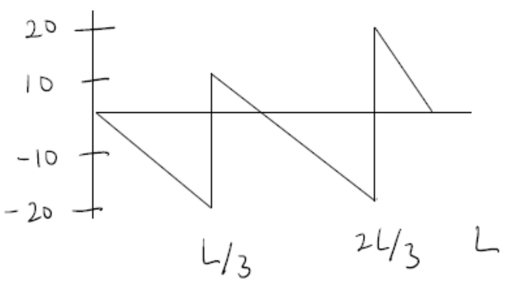
$$= 24.7\ \text{ksi}$$

$$\sigma_{allowable} = \frac{45}{2} = 22.5\ \text{ksi}$$

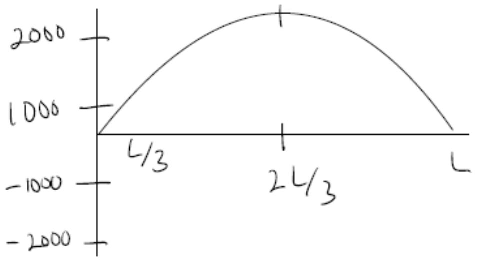
$$\boxed{\sigma_{all} < \sigma_{tot}}$$

Shear and bending Moment diagram

Shear



Bending



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Part 3

2. Axial and lateral acceleration were found
   - The gimbal force was found
   - The skin thickness was found

Given:

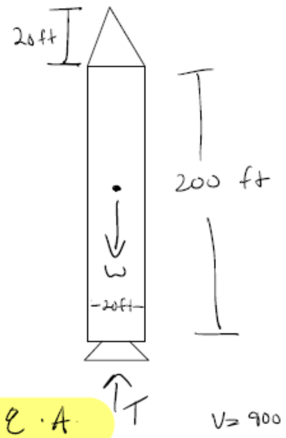
700 psf | 100,000 lbs

$\alpha = 3°$ | 1,000,000 lbs

V = 900 mph | Thrust = 2,000,000 lbf

$C_L = 0.4$ | CG = 100 ft

$C_D = 0.7$



$V = 900 \cdot \frac{5280}{3600}$

$V = 1320$ ft/s

Lift $= C_L \cdot q \cdot A$ Drag $= C_D \cdot q \cdot A$

$q = \frac{1}{2}\rho \cdot V^2 \rightarrow \frac{1}{2}(.002378) \cdot 1320\ \text{ft/s}^2$

$= 2071.71$

$A = \frac{\pi (D)^2}{4}$

$A = \frac{\pi (20\,\text{ft})^2}{4} = 314.159\ \text{ft}^2$

$L = 0.4 \cdot 2071.71 \cdot 314.159\ \text{ft}^2$

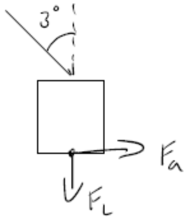
$= 260,338.54$ lbf

$D = 0.7 \cdot 2071.71 \cdot 314.159\ \text{ft}^2$

$= 455,592.44$ lbf

$F_L = \cos(\alpha) \cdot L + \sin(\alpha) \cdot D$

$F_A = \sin(\alpha) \cdot L - W + T - \cos(\alpha) \cdot D$



$F_L = 283,825.62$ lbf

$F_A = 548,189.8$ lbf

$a_x = \frac{548,189}{1,000,000} = \boxed{0.55g}$

$\text{Lateral} = \frac{283,825.62}{1,000,000} = \boxed{0.28g}$

B) $F_{gimbal} = \frac{F_L \cdot l}{L}$

$l = 220 - 100$

$= 120$ ft

$F_{gimbal} = \frac{283,825.62 \cdot 120}{220}$

$\boxed{F_{gimbal} = 154,813.9\ \text{lbf}}$

C) Skin thickness

$t = \frac{p \cdot r}{\sigma_{max}} \rightarrow \sigma_{max} = \frac{\sigma_{yield}}{FS}$

$\sigma = \frac{35\ \text{ksi}}{1.4} = 25\ \text{ksi} = \frac{F_a}{A_c} = \frac{548,189}{2\pi(120)(t)}$

$t = 0.029 \cdot 0.15 = 0.00435$

$\boxed{t = 0.034''}$

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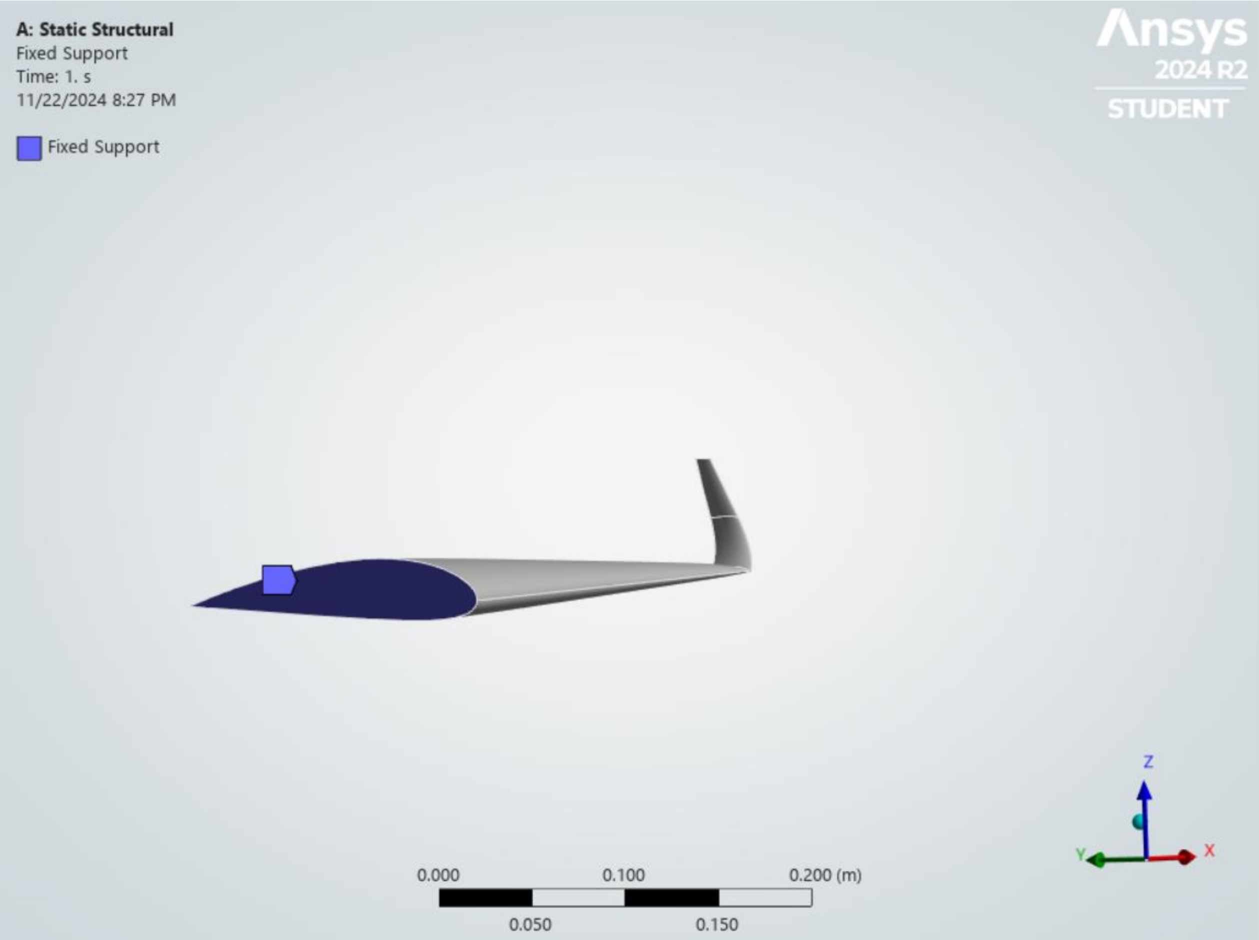
Part 4

ANSYS

1. The ANSYS geometry was given and uploaded to the Static Structural program
   - The fixed support was located at the edge of the wing simulating where the wing would be attached to the body



Part 4

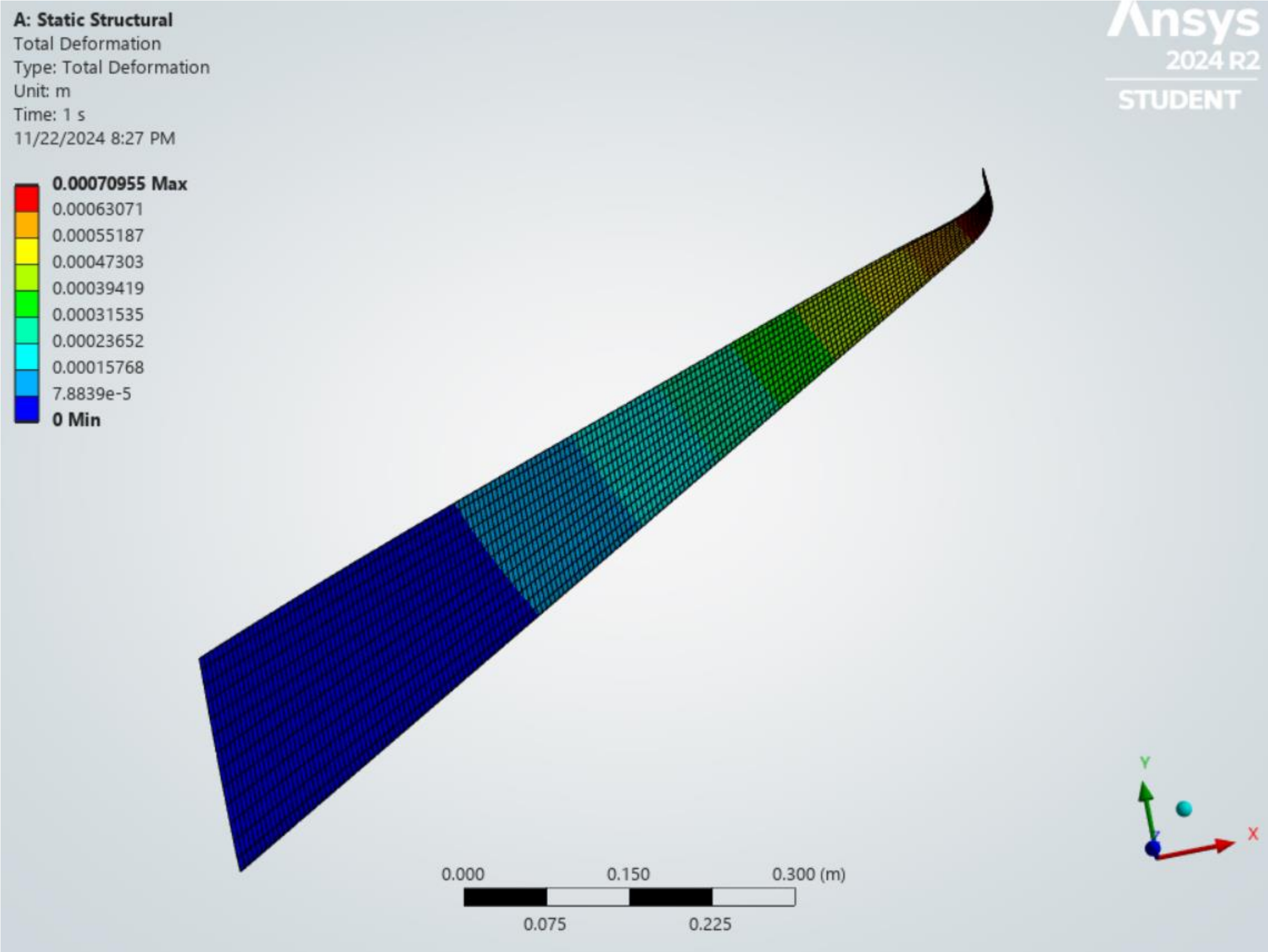
ANSYS

1. A pressure was applied to the underside of the aircraft wing, highlighted in red
   - The pressure was set to 1000 Pa

Part 4

ANSYS

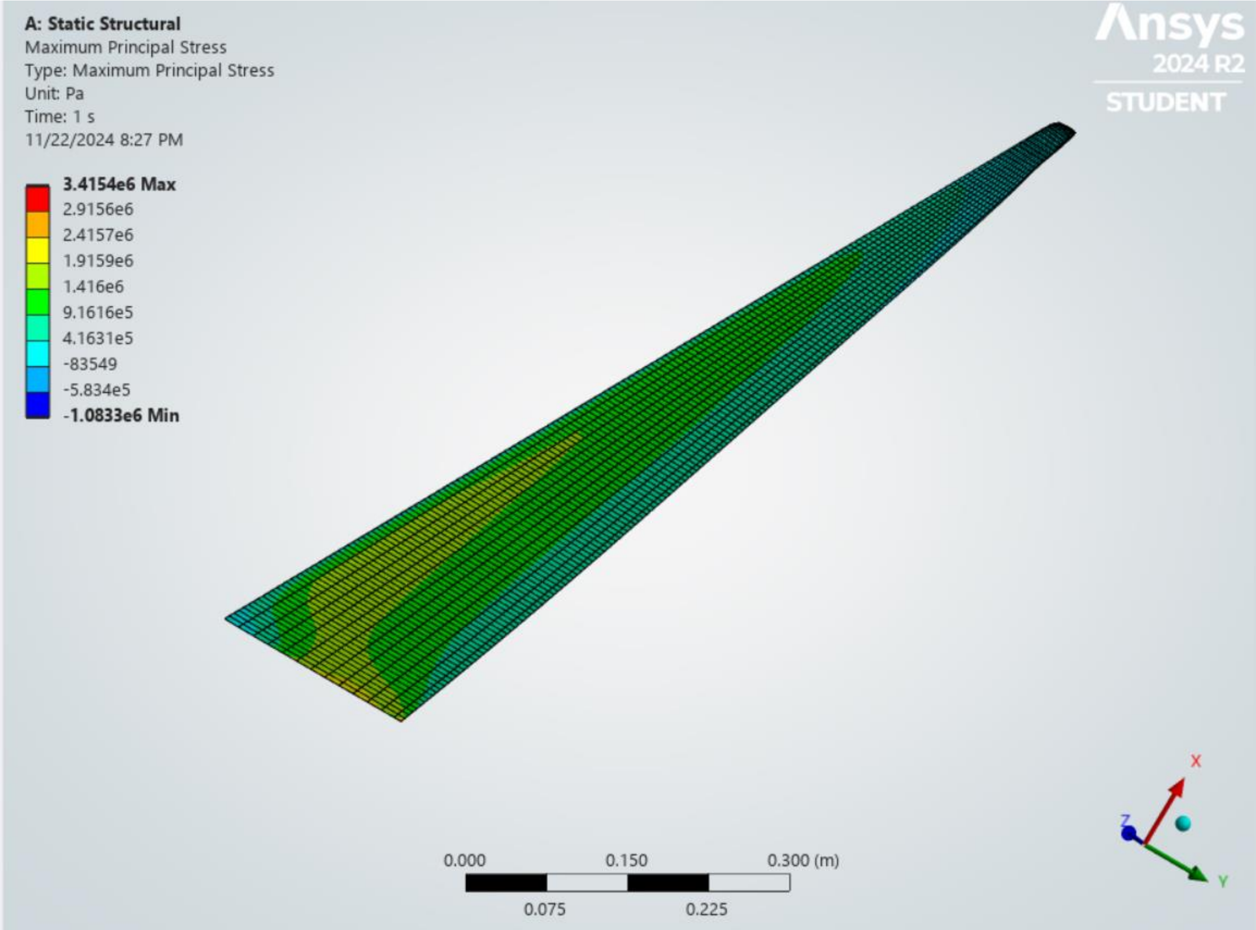
1. The total deformation is shown to the left
   - The max deformation was found to be 0.00071 m, this was located on the trailing edge of the wing highlighted in red
   - The min deformation was found to be 0 m, located where the wing attaches to the body of the aircraft



Part 4

ANSYS

1. The maximum principal stress was found
   - The max principal stress located on the underside of wing closest to the body attachment point was 3.4154 MPa
   - The minimum principal stress located on the underside of the wing closest to the trailing edge was -1.0833 MPa



Part 4

ANSYS

1. With aluminum 6061 - T6 where the max principal stress is 3.4154 MPa and with a factor of safety of 1.4 the allowable stress is 4.782 MPa
   - If we throw a 15% pocket margin the adjusted allowable stress is 5.4988 MPa
   - The maximum lift pressure the wing can withstand based on the material and safety factors applied is approximately 1609 Pa
     - A pressure of 1609 Pa would equate to a max principal stress of 5.4954 MPa, just slightly below the F.S. of 1.4 and the 15% pocket margin