Design of a Landing Gear for DHC-2 Beaver

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Statement of Problem:

The DHC-2 Beaver is a plane manufactured by De Havilland. We were tasked with designing a landing gear for this plane. The design is subject to some given constraints and has to be able to withstand its normal loading during landing. Because of the aviation application, we are using an aircraft grade aluminum 6061-T6. This material allows us to weld the landing gear on to the plane; this will be the means of attachment. We were constrained to a length of 1.5m and a factor of safety of 1.8. The typical loading condition that we were asked to consider was a plane with a gross weight of 22.7kN, with a vertical approach of 5m/s and a horizontal approach speed of 35m/s. Subject to these constraints we analysed two different cross-sections with the aim of minimizing the weight of the landing gear.

Assumptions:

- Transmission of the force through the landing gear is slow enough so that the impact loading will be distributed over both landing gears, even with slight asymmetries in landing.
- Factor of safety is applied to the allowable stresses in our analysis.
- Forces through the wheel are exerted as net forces at the centroid of the landing gear cross section with no torsional moment because of the wheel axle's attachment.
- Strain energy due to transverse shear is small and therefore negligible.
- The runway is a flat horizontal surface, leading to a purely vertical impact load.
- During landing, the weight of the plane is taken by lift in the wings, so the loss of potential energy does not need to be considered in impact loading.
- Braking will be applied after the impact load of landing has dissipated.
- After landing, the plane will decelerate at a constant rate with a frictional, horizontal braking force applied to the wheels.
- All kinetic energy of the plane is transferred directly to strain energy in the landing gear
- Attachment of the landing is much stronger than the landing gear

Material Properties: Aluminum 6061-T6

Property	Value
Density (ρ)	2710 kg/m^3
Ultimate Tensile Strength (S_{ut})	310 MPa
Ultimate Shear Strength (S_{sut})	165 MPa
Tensile Yield Strength (S_y)	276 MPa
Shear Yield Strength (S_{sy})	160 MPa
Modulus of Elasticity (E)	70 GPa
Shear Modulus (G)	26 GPa

Summary of Approach

We started by choosing two different shapes to analyse. We chose to use a hollow cylinder and a hollow ellipse. These shapes simplified the moment of inertia analysis and allowed us to taper the cross-section along the landing gear's length. Having no sharp angles in the cross section also avoids creation of stress concentrations. When examining existing landing gear designs, we noticed that the vast majority of them had a tapered cross section of this shape. In order to analyse loading on less symmetric cross sections, we would need to calculate the stresses in various planes. We avoided this issue by using shapes with a degree of radial symmetry.

To increase the stability of the plane during landing and while stationary, we chose to angle our landing gears outward from the plane to give it a wider, more stable base. We also considered that we may angle our landing gears slightly forward to increase stability during landing at a downward angle. These angle considerations are also present in pre-existing landing gear designs.

After choosing provisional cross-sections, we examined the loading conditions for our landing gear. We chose to separate our analysis into three different failure modes: impact, yield during braking, and buckling.

We started with the impact loading. This failure mode presumes that the strain energy in the landing gears is equal to the decrease in kinetic energy of the plane as its vertical velocity suddenly becomes zero. We can then replace the ground impact with an equivalent vertical force which causes this same increase of strain energy in the landing gears. This means that we need to create a landing gear that does not fail in yield under this equivalent vertical force. After determining the equivalent force, the stress was calculated through combination of axial and bending stresses. We also applied Castigliano's Theorem to find the vertical deflection during impact loading to check that it is within an acceptable range.

Yielding analysis deals with the plane decelerating to a full stop after it has landed on the ground. During deceleration along the length of the runway, we consider the only braking force to be friction between the brakes and the wheel. In this analysis, we wanted to ensure that the stress from the weight of the plane and the force due to the deceleration do not yield the landing gear.

Lastly, we checked to make sure there will be no buckling causing uncontrolled deflection in the structure. The system of the plane, landing gear, and ground can be modeled as a free-fixed column, with an effective length of 2L. We found the critical buckling load for these loading and end conditions, and checked against the real force being applied.

Analysis

To perform our calculations, we created MATLAB scripts to check our three modes of failure for a variety of landing gear geometries. Once we found acceptable dimensions which gave appropriate safety factors, we transferred our designs into Solidworks and ANSYS for further analysis.

MATLAB Script

The MATLAB script starts by analysing the geometry based on the angle of attachment and attack. It then solves for the equivalent load in the shear (V) and axial (P) directions. The following equations were used, along with conservation of total energy, to determine our impact load P_m.

$$U = \frac{1}{2}mv^2$$

$$U = P^2 \int_0^L \frac{dx}{2AE} + V^2 \int_0^L \frac{x^2}{2EI}\,dx$$

$$U = {P_m}^2 cos^2(\theta) cos^2(\phi) \int_0^L \frac{dx}{2AE} + {P_m}^2 (1 - cos^2(\theta) cos^2(\phi)) \int_0^L \frac{x^2}{2EI}\,dx$$

We then input our shape parameters. This is accomplished by starting with a base shape and enlarging various dimensions along a specified curve. We store the cross-sectional areas as elements in a vector in MATLAB. We can specify a hollow cross-section by removing a scaled version of the cross section at every point based on a specified wall thickness. We follow a similar procedure for the moments of inertia.

We then go through and use the force and moment information and find the stress at every point. We store this is in a new vector, for both bending and axial stresses. We sum stresses and compare the maximum values against the yield strength of the material to compute a factor of safety.

We found that reducing the angle of attachment helped lower the stresses. We tried multiple cross-sections and eventually settled on a linear tapered cross-section. Our stresses were lowest at 0˚ but this created a very unstable plane. We settled on angles of 5˚ and 10˚, to give some semblance of reality. A more complex taper may reduce stresses, however a more complicated shape presents more challenges in manufacturing.

We created two other MATLAB scripts[1] to check for buckling, and yield during braking. We also used Castigliano's theorem to examine the maximum deflection of the landing gear. These calculations confirmed that the limiting factor for our landing gear designs was impact loading.

Solidworks Drawings

To perform a visual inspection of our prospective designs and ensure that the geometries look reasonable, we constructed models of our landing gears in Solidworks. We

[1] All three described MATLAB files are attached to the report

used a pre-existing CAD model of the DHC-2 Beaver as a base for our model. Images of our designs are included below:

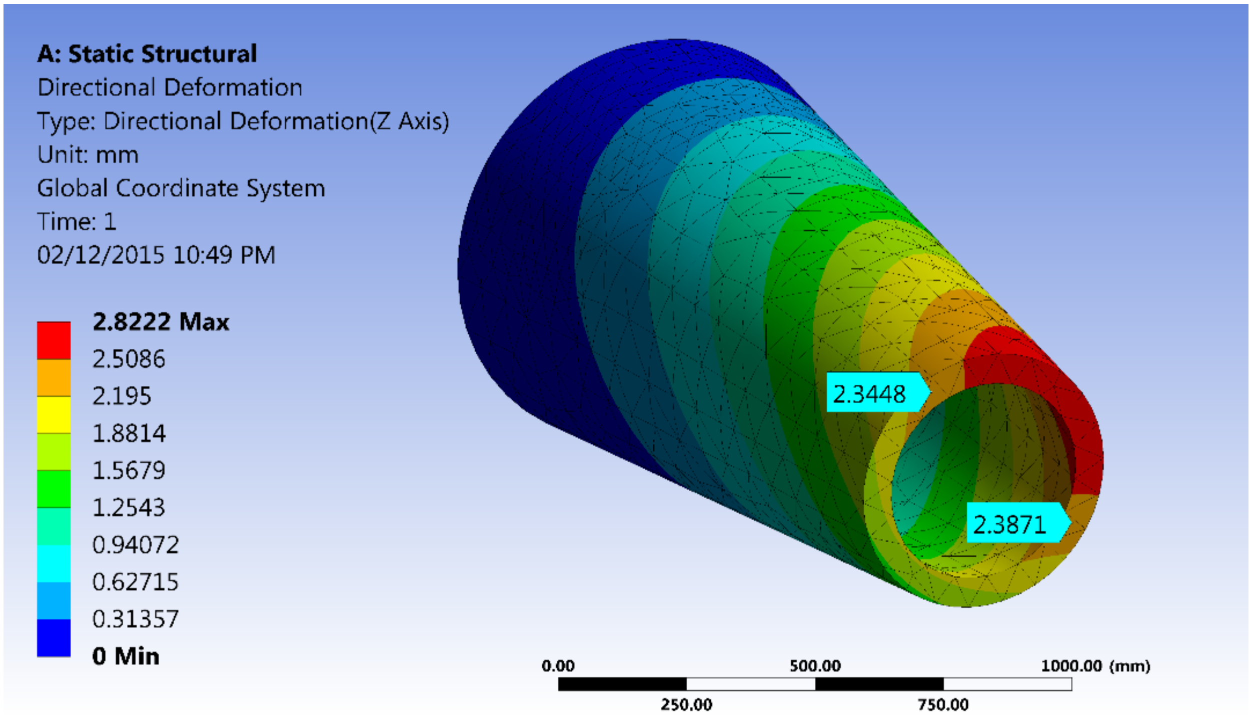
ANSYS Analysis

We used a basic FEA simulation to check that our MATLAB code was producing realistic values for our impact loading cases. We imported our Solidworks models into ANSYS then modeled our loading by applying our axial and shear forces to one end of the landing gear. We fixed the other end, as if it were rigidly attached to the plane.

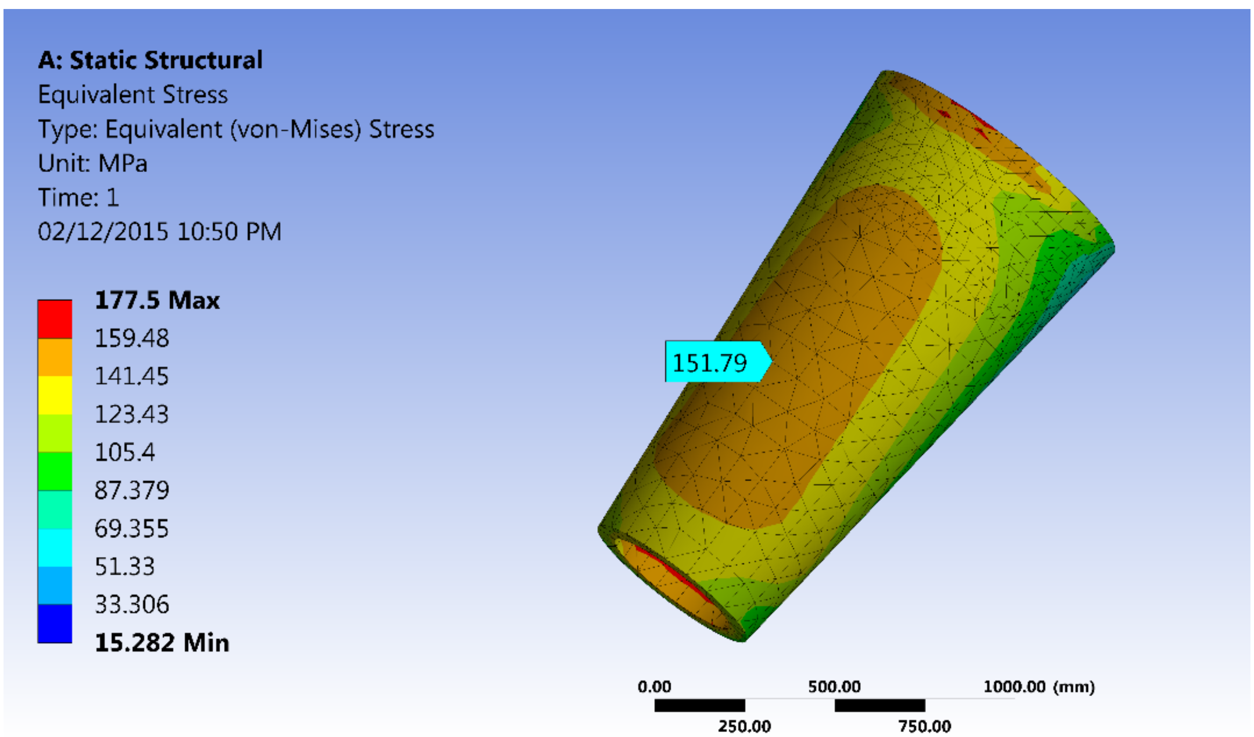
While our stress simulations did provide maxima much larger than expected, these maxima only occurred at points of stress concentration that were caused by the boundary conditions. As a result we looked the maximum stress, not at the artificial stress concentrations. We check the deflections by averaging the deflections at the bottom of each landing gear. This best matches our model since we consider the deformation of the cross section as a whole.

The values we found using ANSYS are tabulated in our results section. Images showing our simulation outcomes for both landing gear designs are below.

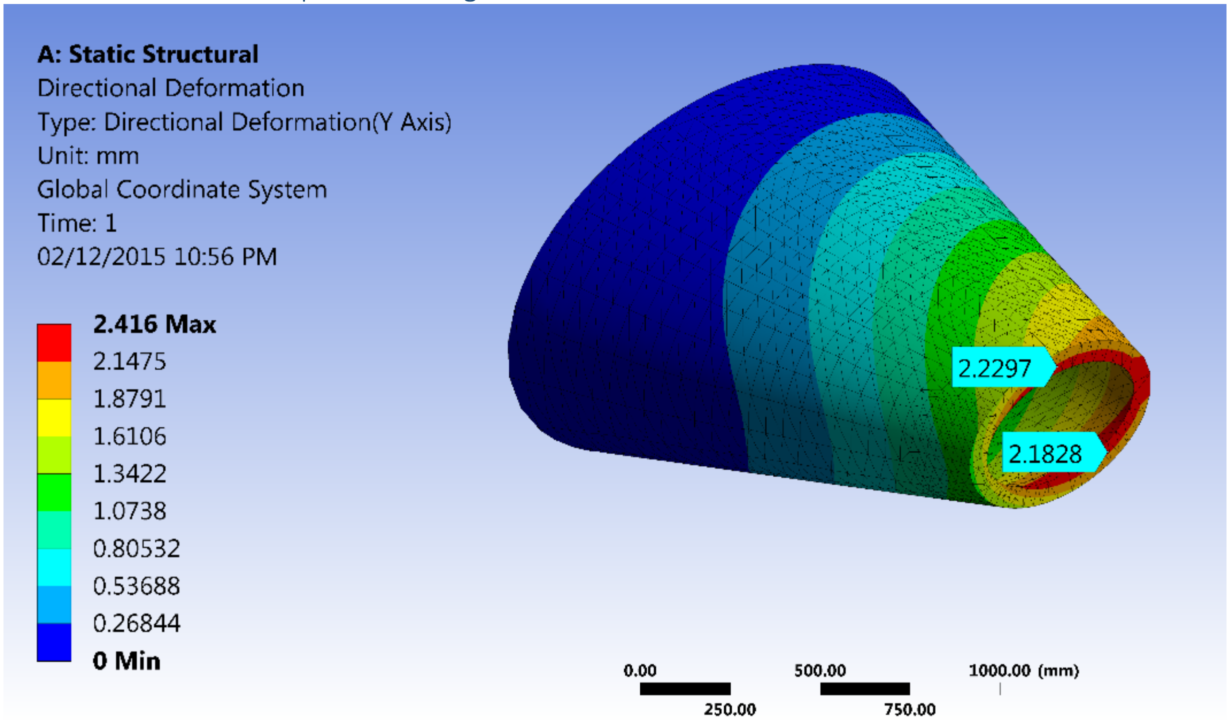
ANSYS Deflection in Circular Landing Gear



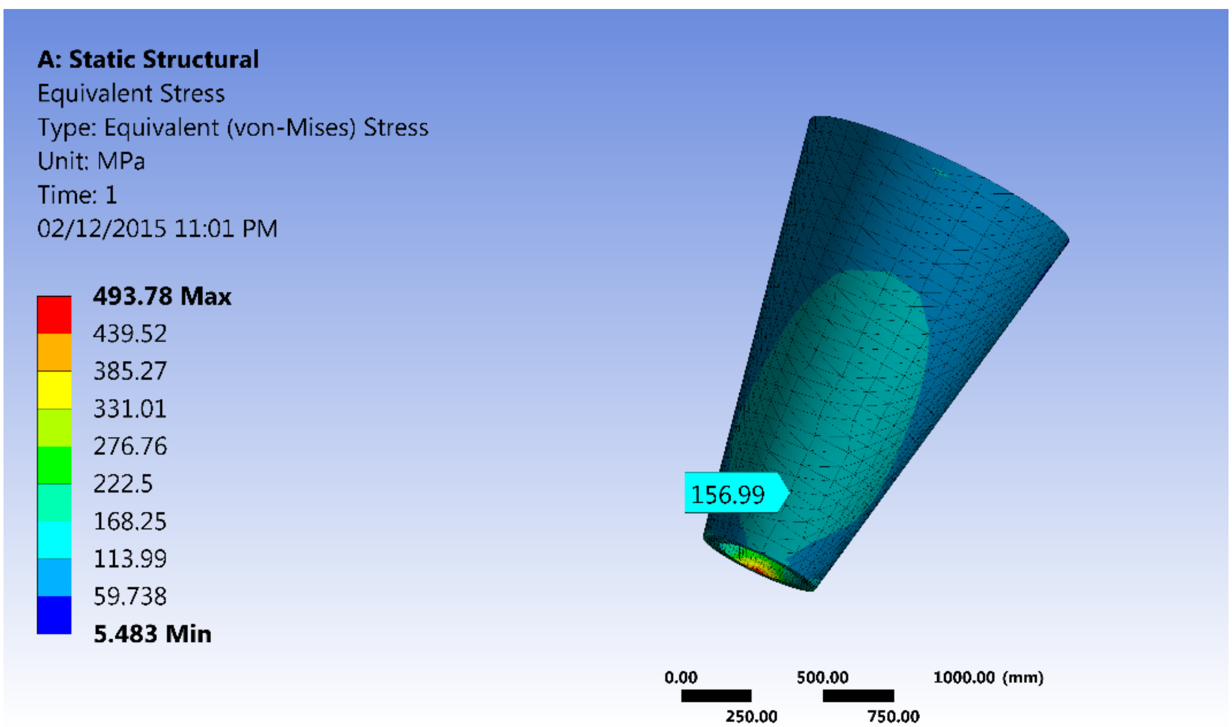
ANSYS Stress in Circular Landing Gear



ANSYS Deflection in Elliptical Landing Gear



ANSYS Stress in Elliptical Landing Gear



Results

MATLAB Calculation Results		
	Circular Cross Section	Elliptical Cross Section
Maximum Combined Stress[2]	151 MPa	153 MPa
Location of Maximum Stress	685mm	460mm
Maximum Vertical Deflection	2.44mm	2.28mm
Critical Buckling Load	179 MN	170 MN

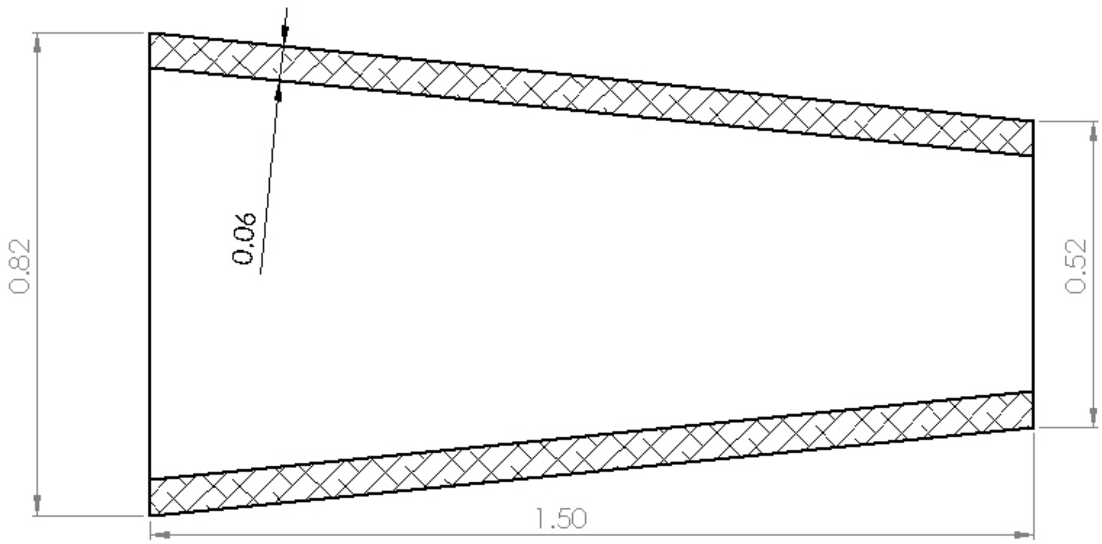
ANSYS Simulation Results		
	Circular Cross Section	Elliptical Cross Section
Maximum Combined Stress[2]	152 MPa	157 MPa
Location of Maximum Stress	~720mm	~430mm
Maximum Vertical Deflection	2.32mm	2.42mm

Safety Factors		
	Circular Cross Section	Elliptical Cross Section
Yield from Impact	1.829	1.804
Buckling	15.15	13.65
Yield from Braking	398.1	503.3

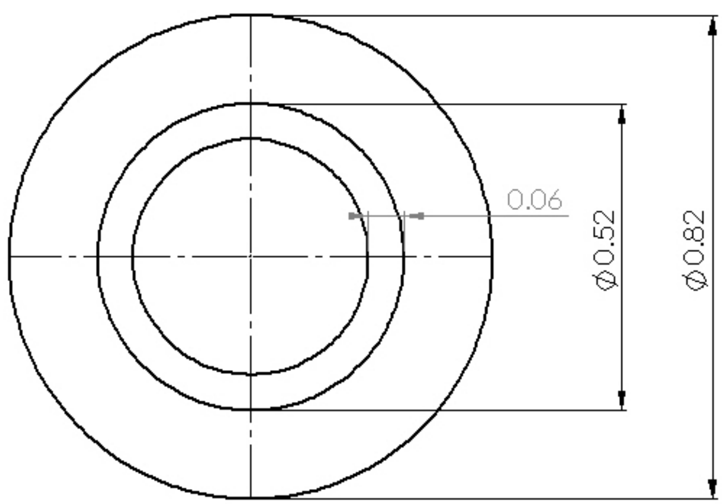
Landing Gear Design Info		
	Circular Cross Section	Elliptical Cross Section
Mass of Single Landing Gear	467 kg	577 kg
Angle of Attachment	5°	10°

[2] Neglecting Stress Concentrations

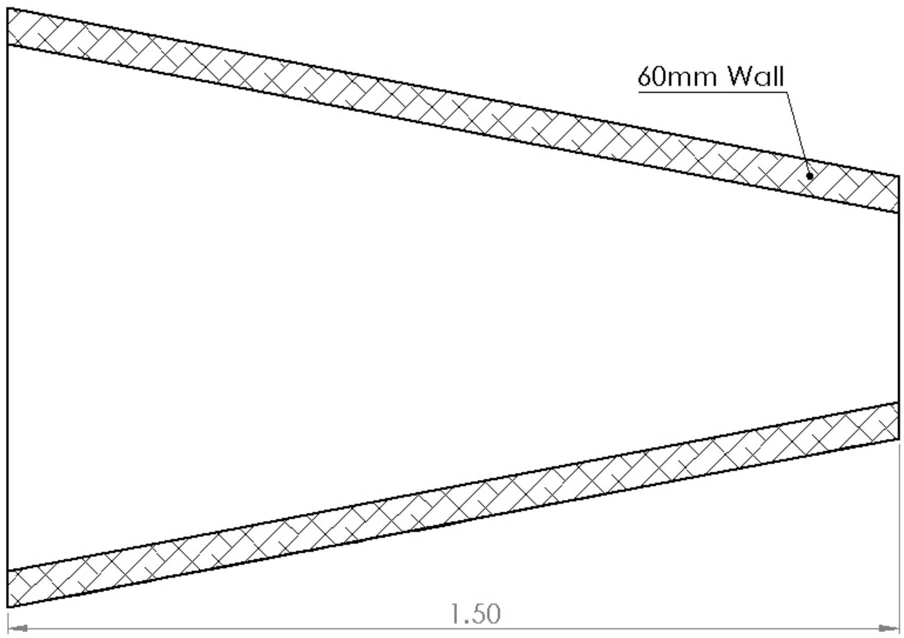
Circular Landing Gear Design



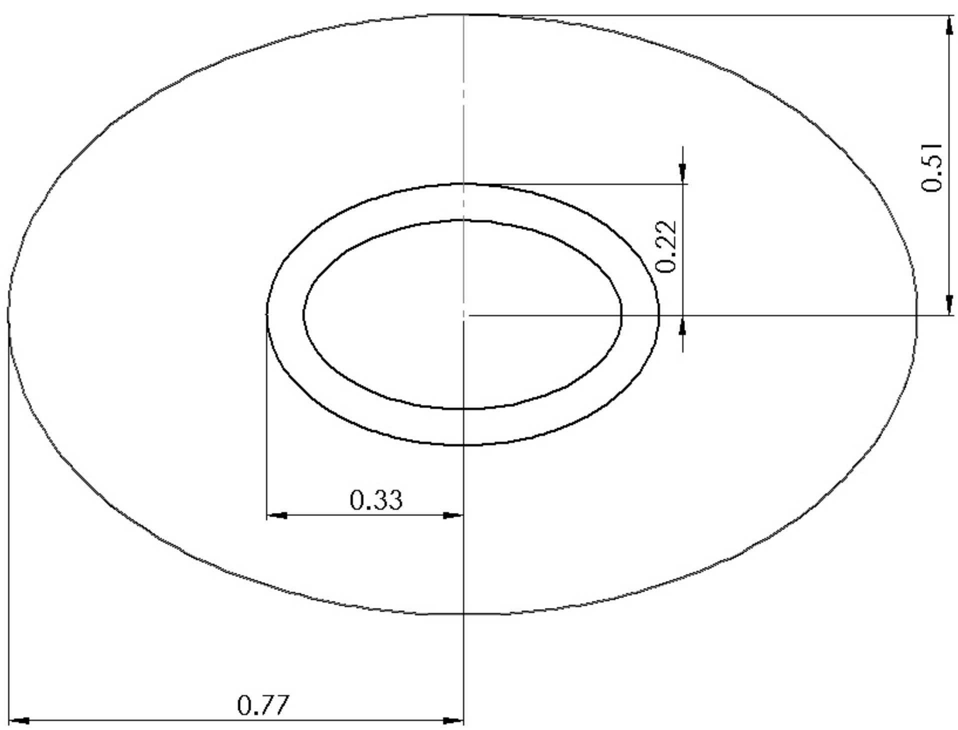
SECTION A-A
SCALE 1 : 10



Elliptical Landing Gear Design



SECTION A-A
SCALE 1 : 10



Conclusion

Using our analysis methods, we were able to produce two different landing gears capable of withstanding the specified loading. We ran a finite element analysis alongside our MATLAB simulation, to increase confidence in our results. Our choice of hollow elliptical and circular cross sections proved to be effective in resisting yield and buckling when sized appropriately.

However, the dimensions we found do not represent ones that could be implemented in a functional design. Our models are considerably larger than existing landing gear designs, posing problems in aerodynamics, mounting, and mass manufacturability. We also found that the angulation of our landing gears is small and could lead to plane instability. In practice, a more angled and smaller landing gear would be implemented on an aircraft of this size.

We assert that this discrepancy between our designed landing gears and engineering expectation, is a result of conservative simplifications in our model. All energy dissipation during landing has been neglected. In practice, heat, vibration, and deflection/rebound contribute significantly to energy dissipation. If we were to consider these effects, the landing gear could be designed with a more reasonable size and angle. Unfortunately, this kind of analysis is outside the scope of this course.

If we wanted to further this design, we would add several more considerations. Firstly, we would look to model the energy dissipation. We could then examine the attachment of the landing gear and the role this plays in loading and aerodynamics. This may lead to more complex cross-sections being desirable. Lastly, we would look to examining other failure modes such as fatigue from repeated landings and thermal stresses from changing altitude and environment.