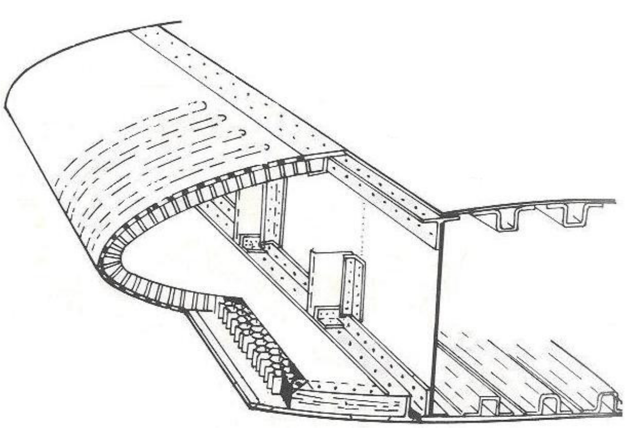
ME-212 Solid Mechanics - Computer Project

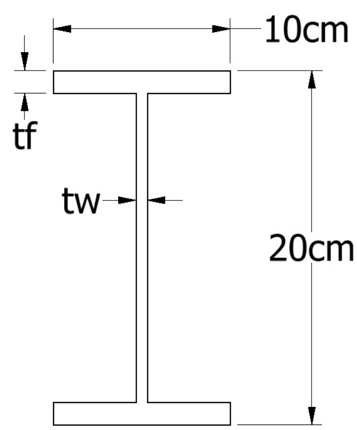
Beam Design

Spring 2024

You are part of a group developing a new aircraft design. Your team is tasked with designing the structure for the aircraft's wing. The wing is to utilize a main wing spar made of 2014-T6 aluminum (see Fig. 1). The wing's depth limits the height of the spar to 20cm. The maximum flange width is 10cm. The minimum thickness that can be manufactured for the web and flange is 2mm.



(a) Wing Section with Spar and Stringers



(b) Spar Section Detail

Figure 1: Wing and Wing Spar

The maximum takeoff weight for the aircraft design is 1113 kg. The design calls for a flight envelope with a maximum load factor of 4.5 before structural damage occurs (see Fig. 2). It follows that the total maximum allowable wing load is 49,120 N. This requires that each wing be able to withstand a 24,560 N load. The wing and airfoil have been designed such that the spanwise lift distribution is described by Eq. 1, where x is measured from the wing root.

$$w(x) = w_0\sqrt{1-\left(\frac{x}{L}\right)^2} \tag{1}$$

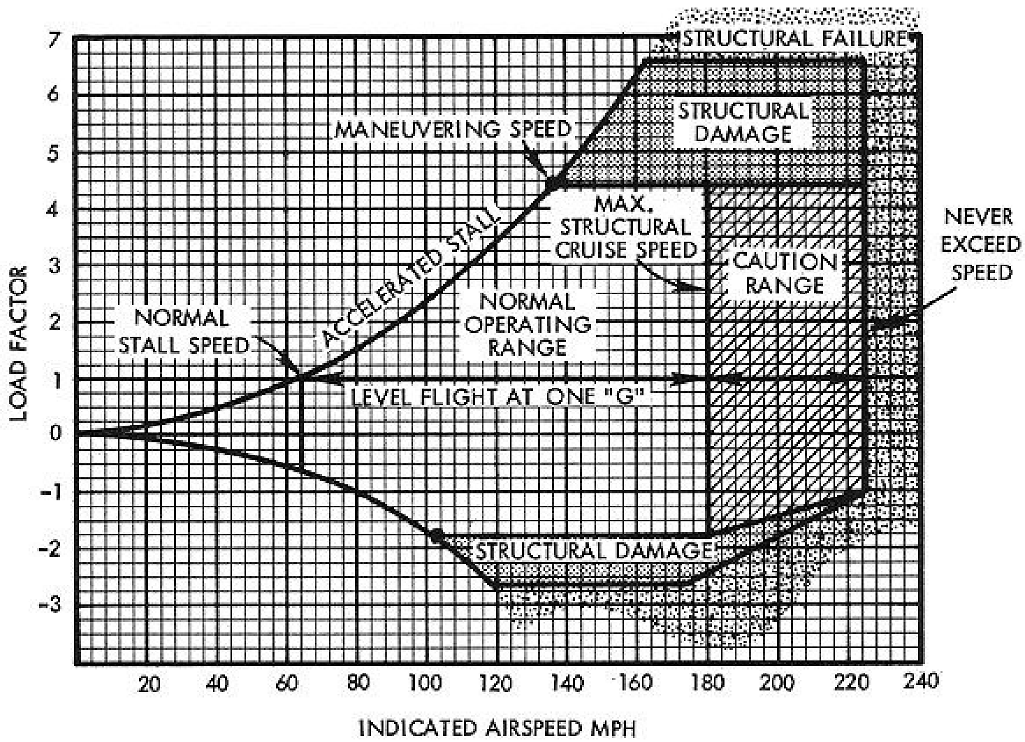


Figure 2: Flight Envelope

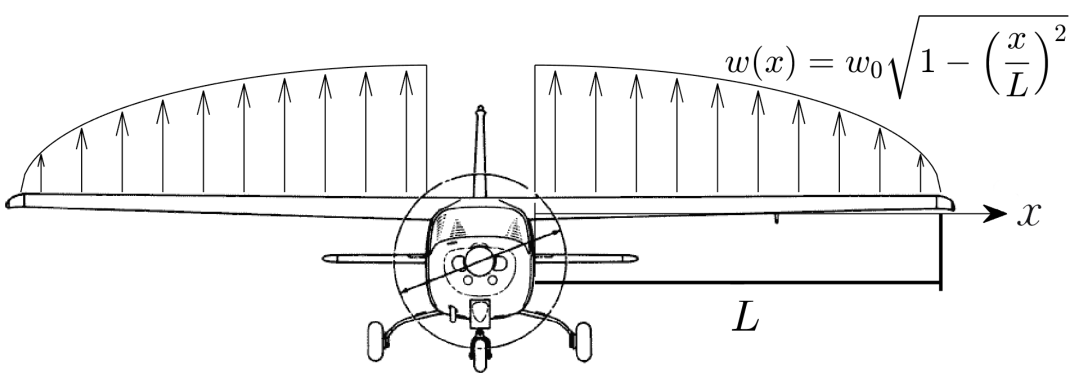


Figure 3: Maximum Wing Load

Part 1. Prismatic Spar Design

Assume the wing's structural support from members other than the main spar is negligible and that the wing may be modeled as a cantilever I-beam acted on by a distributed load.

a) Find w_0 to obtain the distributed load across the wing.

b) If each wing has a length of 4m, determine the maximum internal shear force and bending moment on the wing.

c) The FAA's Federal Airworthiness Regulation Part 25.303 requires a minimum factor of safety for aircraft structures of 1.5 (material yielding is considered failure). If the flange width of the spar is 10 cm and the beam's height is 20 cm (as shown in Fig. 1b), design a prismatic beam for the wing spar by selecting a flange thickness. Assume a web thickness of 2 mm. Calculate the maximum von-Mises stress in the flange and the web. Show that your selected flange thickness is sufficient to remain prevent yielding of the spar with the required safety factory.

d) Model your prismatic beam in Autodesk Inventor. Run a Stress Analysis Simulation. Apply a single point load to the beam to approximate the distributed wing load. One method of doing this is to add a raised section to the beam at the equivalent point load's required location. Then apply the equivalent force to that section. Add probes to display von Mises stress at the neutral axis and at the top of the beam flange at the wing root.

e) Determine the weight of the prismatic spar in kilograms. Write a detailed report of your analysis and design.

Part 2. Spar Safety Factor

a) Use the method of sections to find the resultant internal shear and bending moments due to the wing load along the length of the spar. Note that mathematical software or numerical methods may be helpful in performing the calculus necessary for this analysis (MATLAB's integral function, Wolfram Mathematica, Wolfram Alpha, or Symbolab may be useful). Plot the internal shear force and bending moment for the wing.

b) For the prismatic beam from Part 1, calculate the safety factor for bending stress relative to the allowable stress as a function of x. Plot this safety factor.

Part 3. Extra Credit (Optional)

Notice that the wing spar is overbuilt at locations other than the wing root.

a) If a uniform safety factor of 1.5 is desired throughout the length of the beam, find the minimum *flange width* (b) along the length of the spar as a function of x. Assume the web and flange thickness from Part 1 are used and remain fixed throughout the spar. Plot the minimum flange width as a function of x.

b) Create a wing spar of your own design. Take into consideration how the wing spar is to be manufactured (pressed sheet metal vs. machining vs. additive manufacturing). Use whatever means you desire to design your wing (added angles or plates, stepped or tapered thickness or width dimensions, lightening holes, etc.) to minimize the weight of the spar while remaining within the maximum allowable bending stress. Flange and web thickness must be at least 2mm and the depth of the spar must remain at 20cm. All other dimensions may be modified. Model your modified beam in Autodesk Inventor. Apply 10 point (or distributed) loads along the length of the spar to approximate the continuous loading on the wing.

Verify that the maximum Von Mises stress is below the yield stress for the material. Write a detailed report of your spar design. Include the total weight of your spar in your report.

Part 4. Additional Extra Credit Suggestions

- Team Logo
- Writeup in Overleaf with figures, citations, and bibliography
- Change of Material with Fatigue Lifetime Analysis
- Custom Spar Design with specifications on manufacturing methods employed (built up stamped sheet metal and angles, extruded aluminum with milling, additive manufacturing, tapered hot or cold rolled aluminum)
- Model the wing with ribs (use a NACA 65(2)-415 airfoil profile). Optionally with simple rear spar placed at 10% chord length from the trailing edge
- Redesign the wing