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An Analysis of Wing Loading on the Airbus A380

MEU33B03 Mechanics of Solids Project
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Introduction

The Airbus A380 was one of the largest commercial aircraft in production and is sadly being discontinued in 2021. A so-called "jumbo jet" it was developed to compete with the then dominant Boeing 747 as a very large commercial airliner.

Most notably the A380 has a wingspan of 79.8 metres which is 11.4 metres greater than that of the 747 [3] and has the largest wing ever produced for a civil airliner [4] making it quite a feat of engineering. As an aerospace fan and admirer of Airbus' work I decided to apply the solid mechanics methods I've learned throughout 3B3 to analyse the loads experienced by the wings on an A380 in both typical and extreme conditions and thereby evaluate the stresses experienced by the wing.

Background and Modelling

Wings are quite challenging to analyse due to their unusual cross section of an aerofoil profile which is chosen more for aerodynamic characteristics rather than structural ones. Due to the wings taper the 2nd Moment of Area is a function of spanwise distance along the wing. As such we will model the wing as a cantilevered beam with a width equal to the aerofoil chord length and thickness of the widest part of the aerofoil.

Loading is also quite complex. Aerodynamic lift and drag forces are quite complex and aren't distributed evenly across the wing (pressure forces dip near fuselage due to boundary layer interaction) [5]. Lift and drag forces are assumed to act through a point ¼ of the chord length from the leading edge of the aerofoil known as the aerodynamic centre [5] no moment is generated placing the force at this point. Distributed loads are assumed to be uniform for this analysis and we won't consider any torsional effects.

* Geometric and weight values obtained from [6] aerofoil thickness from [7]

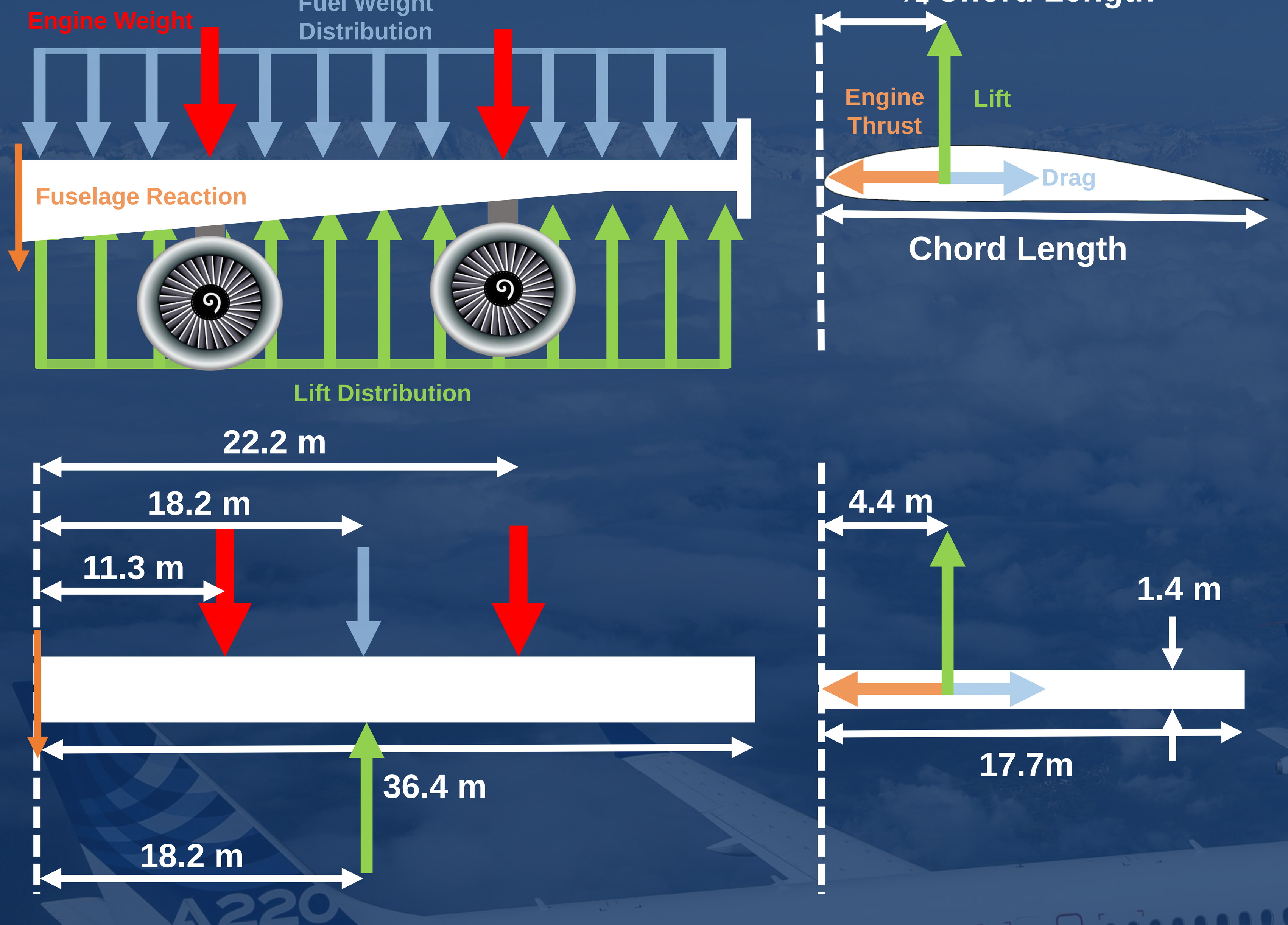

Figure 1. Wing Loading Modelling

Further assumptions include the wing being a solid body rather than the stressed skin design most aircraft use. Aircraft have a "flight envelope" in which they operate [5] which restricts their flight velocities as such for our analysis of the A380 we will look at two cases, loading at takeoff speed and another when the aircraft is over speeding.

Calculations

Take-Off

The A380 has a take-off velocity of $87.5\frac{m}{s}$. From this we can use the aerodynamic force relation to calculate the lifting force.

Equation 1. Aerodynamic Lift Force [5]

$$Lift = \frac{1}{2}C_L\rho AV^2 = \frac{1}{2}(0.98)(1.23)(644)(87.5)^2 \cong 2.97\ MN$$

$C_L = 0.98\ (10^o\ Angle)$ [7] $\quad \rho = 1.23\frac{kg}{m^3} \quad A = (Chord)(Span) \cong 644\ m^2$

Fuel Weight: $m_{fuel} \times g \cong (123{,}000\ kg) \times \left(9.8\frac{m}{s^2}\right) \cong 1.21\ MN$

Resultant Lift Force: $2.97\ MN - 1.21\ MN = 1.76\ MN$

Engine Weight: $m_{engine} \times g \cong (6{,}200\ kg) \times \left(9.8\frac{m}{s^2}\right) \cong 0.06\ MN$

Equation 2. Moment Balance [8]

$$\sum M_{fuselage} = 0$$

$$M_{fuselage} - (0.06)(11.3) - (0.06)(22.2) + (1.76)(18.2) = 0$$

$$M_{fuselage} \cong 30\ \text{MNm}$$

Equation 3. Beam Section Modulus and Normal Stress [8]

$$S = \frac{Ah}{6} = 5.78\ m^3 \qquad \sigma_{max} = \frac{M}{S} = 5.2\ MPa$$

Overspeed

Aircraft goes beyond flight envelope limit at velocity of $333\frac{m}{s}$.

$$M_{fuselage} \cong 781\ MNm \qquad \sigma_{max} = \frac{M}{S} = 135\ MPa$$

Conclusion

The wings of the A380 are manufactured from CFRP which has a yield strength of $298\ MPa$. Taking the overspeed condition as the allowable stress we calculate the factor of safety as being 2.2 for the A380 wing. While this is a conservative estimate since the wing cross section would be far smaller, and many simplifications have been made it appears to be at the higher end of safety factor [9] showing the rigor that needs to go into designing such a large aircraft.

References:

[1] Airbus A380 Graphic: https://brand.airbus.com/brand-guidelines/product-branding/aircraft.html
[2] Airbus Formation Flying Background: https://www.airbus.com/newsroom/press-releases/en/2019/06/airbus-sees-strong-demand-for-its-new-commercial-aircraft-products-at-paris-air-show-2019.html
[3] Wingspan Comparison: https://upload.wikimedia.org/wikipedia/commons/5/52/Giant_planes_comparison.svg
[4] Flaig A., *Airbus A380: Solutions to the Aerodynamic Challenges of Designing the World's Largest Passenger Aircraft*, 2008: https://www.fzt.haw-hamburg.de/pers/Scholz/dglr/hh/text_2008_01_30_A380.pdf
[5] Megson T. H. G., *Aircraft Structures for Engineering Students Sixth Edition*, 2017, Butterworth-Heinemann, 978-0-08-100914-7
[6] *A380 Aircraft Characteristics Airport and Maintenance Planning*, 2020, Airbus: https://www.airbus.com/aircraft/support-services/airport-operations-and-technical-data/aircraft-characteristics.html
[7] Olejniczak D., Nowacki M., *Assessment of the Selected Parameters of Aerodynamics for Airbus A380 Aircraft on the Basis of CFD Tests*, 2019, Elsevier, 10.1016/j.trpro.2019.07.118
[8] Gere J. M., Goodno B. J., *Mechanics of Materials Seventh Edition*, 2009, Cengage Learning, 978-0-495-43807-6
[9] The Engineering Toolbox: https://www.engineeringtoolbox.com/factors-safety-fos-d_1624.html

General Research:

[1] UNSW Aerospace Structures Playlist: https://www.youtube.com/playlist?list=PLv4AhJns8bvCP7FGrBsNtE-YDYlD1koUM
[2] Lomax T. L., *Structural Loads Analysis for Commercial Transport Aircraft: Theory and Practice*, American Institute of Aeronautics and Astronautics, 1996, 1-56347-114-0