AE4233 Advanced design methods

MDO Practical session 4

Quasi-Analytical Weight Estimation Method

Background theory and introduction to EMWET tool for wing weight estimation

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Outlines of this tutorial

- Introduction to different weight estimation methods
- Quasi-Analytical (class II & ½) weight estimation methods
- Structure and functionality of EMWET

- Interactive tutorial on the use of EMWET

Impact of weight on aircraft performance

- The success of any new aircraft program depends on the aircraft...
  - Performance
  - Selling price
  - Direct Operating Cost
  - Safety
  - ....

Weight influences more aircraft performance variables than any other single parameter!

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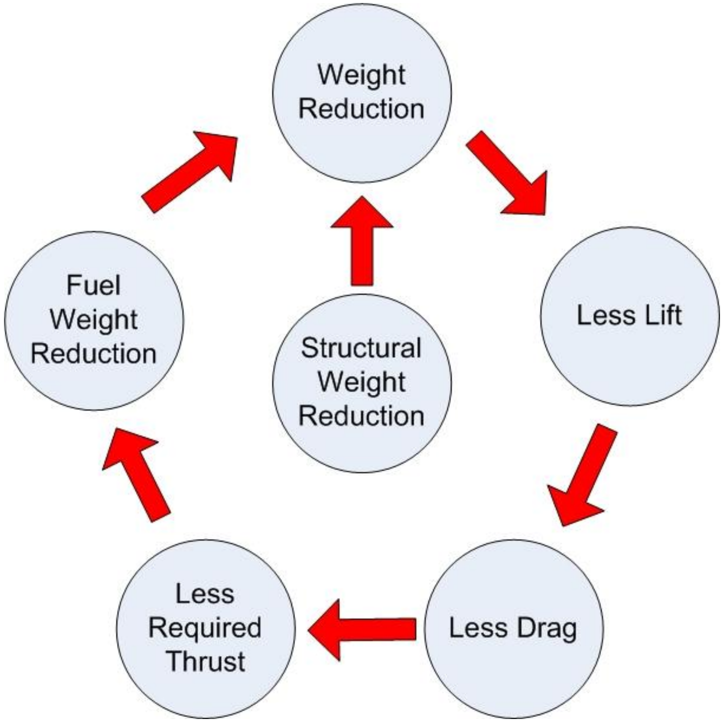
Snowball Effect of Weight Reduction

- Any reduction in aircraft structural weight results in …
  - For a typical passenger aircraft with MTOW about 60,000 kg:

$$\frac{\partial MTOW}{\partial OEW} \approx 2$$

  - Reducing OEW by 1 kg …
    reduces MTOW by 2 kg

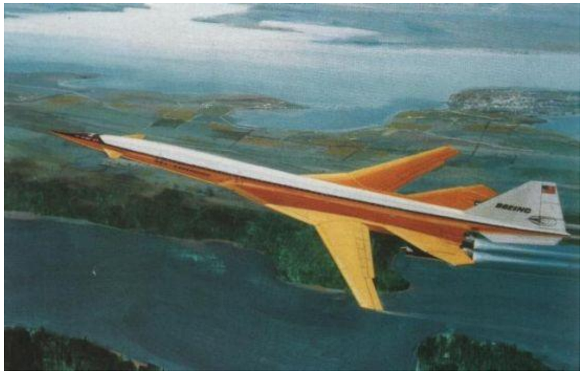


Weight Control. What is that?

A process to derive the lightest feasible aircraft within the constraints defined by the design requirements and the airworthiness regulations.

Weight Control needs *Weight Estimation*

Case Studies

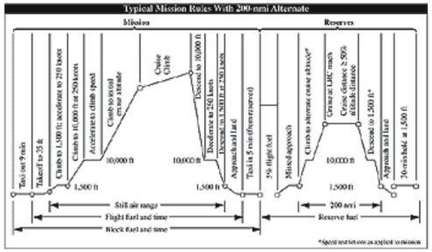


- Boeing SST
  - Optimistic weight estimation
  - The designed aircraft could meet all requirements without a payload!
  - In other words … *they really did not have an airplane!*

- Canadair Challenger
  - First prototype: MTOW 33000 lb
  - Disappointing range performance
    - New Engine
    - MTOW increased to 41500 lb
  - Selling price increased from 7.0m US $ to 10.2m US $

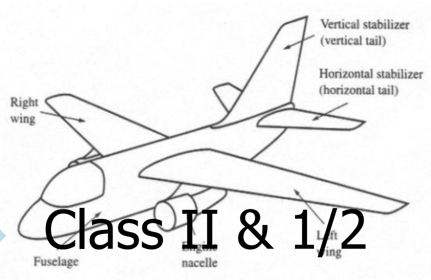
Weight Estimation Methods

- Class I
  - Early stages of design
  - *Fraction* method based on existing aircraft



Assumptions: L/D, Cj, ...

- Class II
  - Component weight
  - Empirical methods

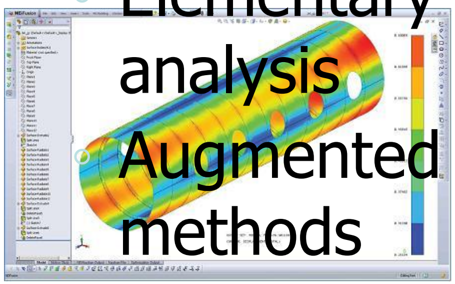


Speed

Accuracy

- Class III
  - Finite Element analysis

- Class II & 1/2
  - Elementary structural analysis
  - Augmented by empirical methods



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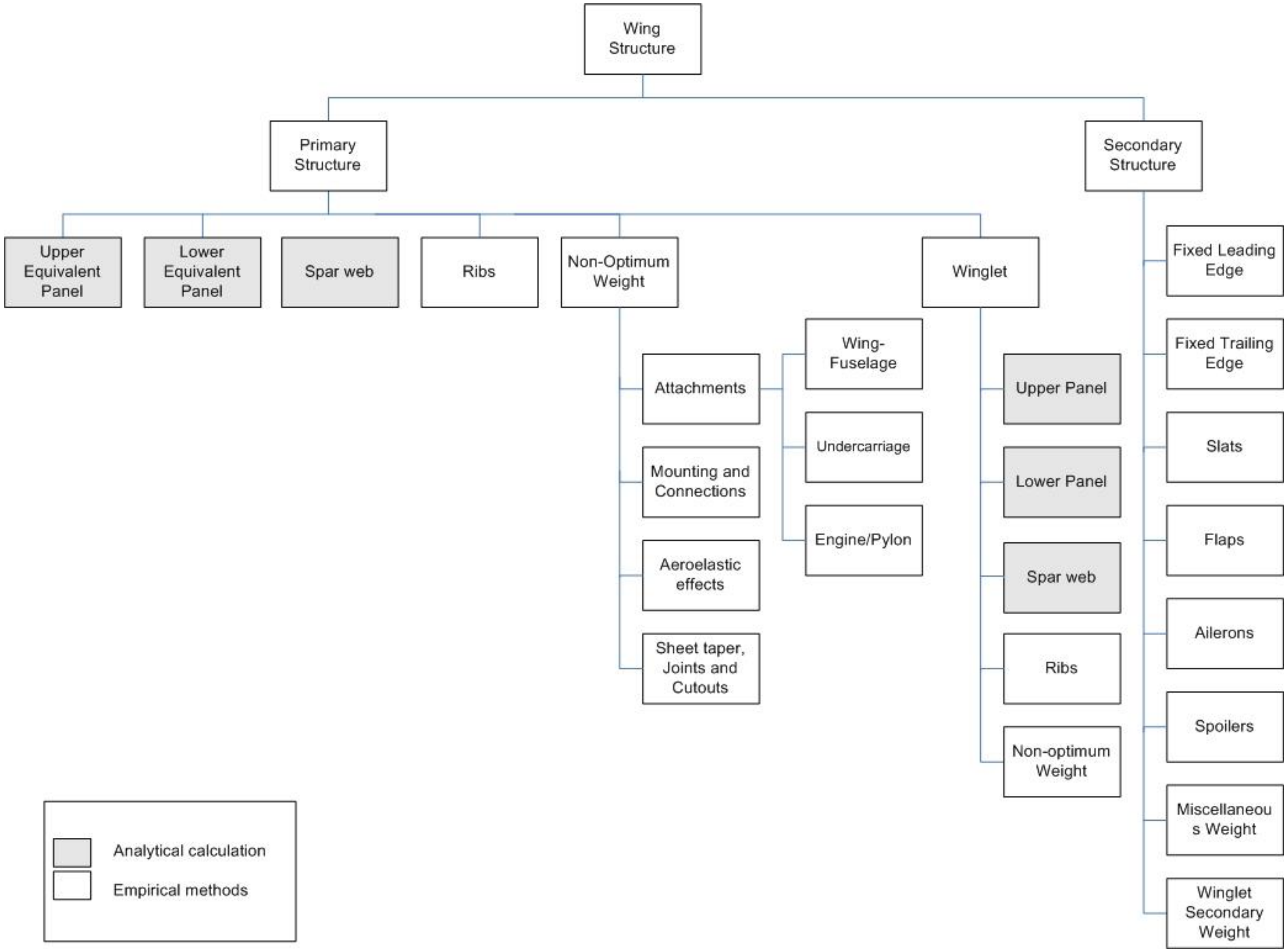
Lifting surfaces Weight Decomposition



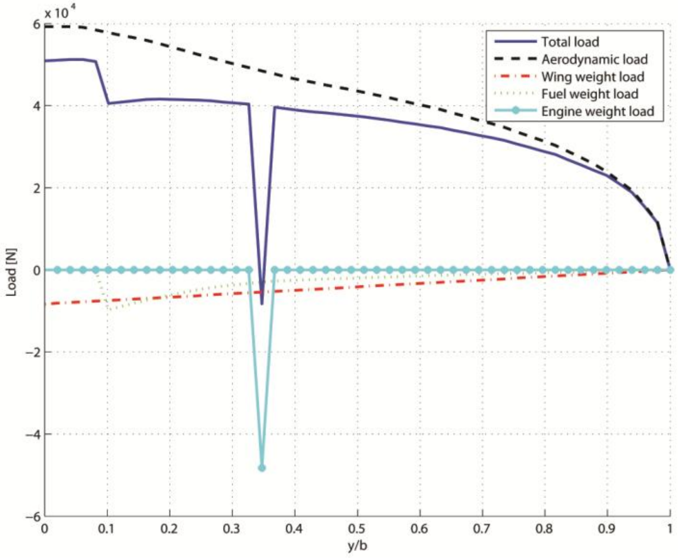
Load Calculation

- Aerodynamic loads based on airworthiness regulations
  - Vortex Lattice Method as the aerodynamic solver (Q3D AeroSolver should be used)
  - Effect of tail load and CG position on wing load can be ignored.
  - Scenarios to determine the critical loads for sizing the structure:

    Wing:
    - Symmetric maneuver load for maximum positive load factor at maximum take-off weight and maximum operating speed at cruise altitude.
    - Gust load for maximum zero-fuel weight at maximum operating speed.

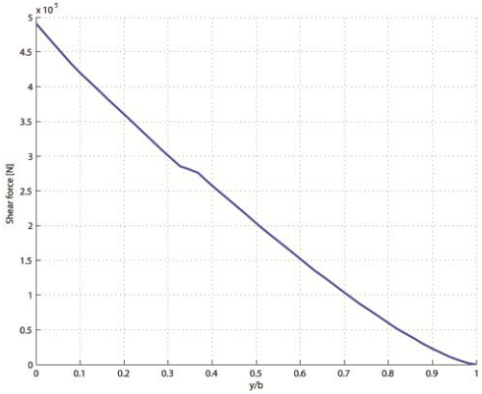
For MDO assignment the maneuver load is enough.

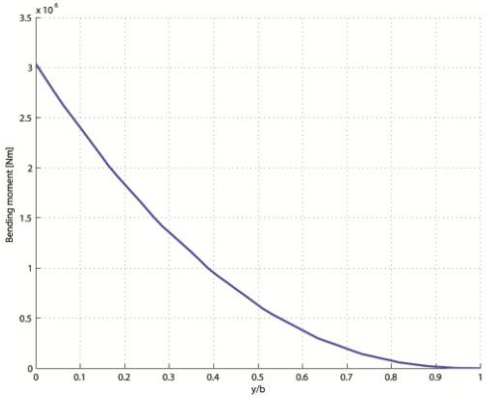
Load Calculation

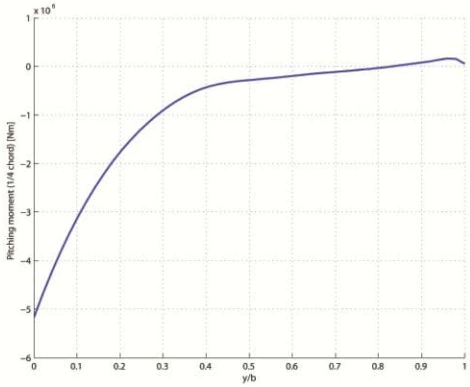


- Accounted weight relief effects:
  - Fuel weight
  - Power plant weight
  - Wing weight (iteration)

- Spanwise distribution of shear force, bending moment and torsion.

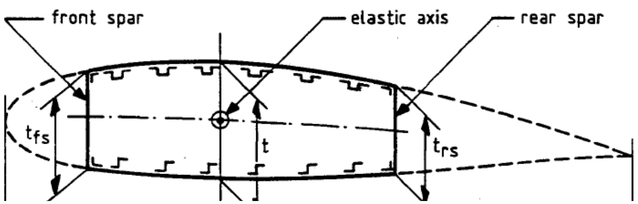


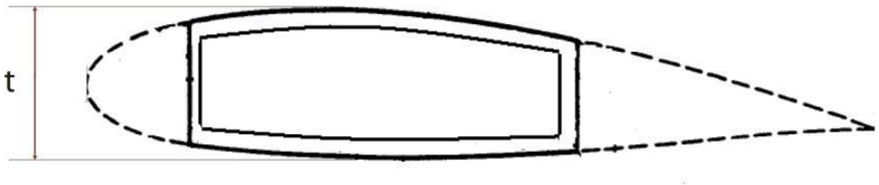


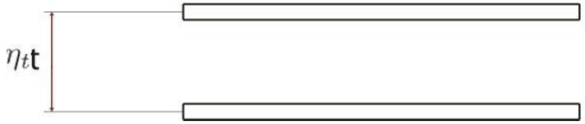


Structural Analysis

- Required elements for structural analysis of simplified wingbox:
  - equivalent panels
  - effective distance







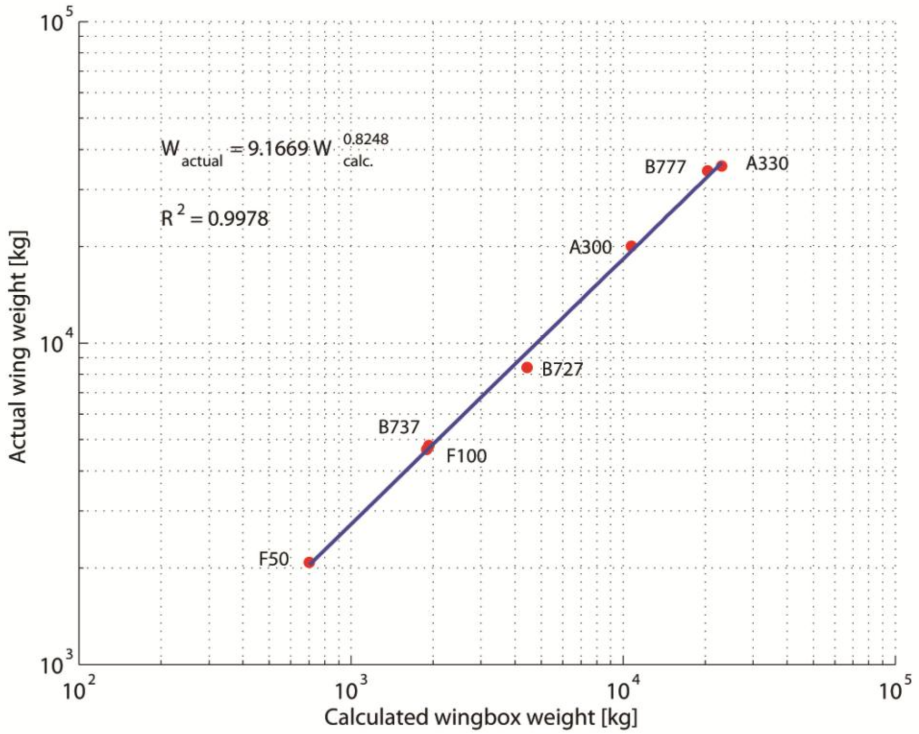
Structural Analysis

- Upper panel, lower panel and spar webs are sized for:
  - Maximum allowable tensile stress
  - Maximum allowable compressive stress
  - Buckling criteria
    - Stiffened panel efficiency method
  - Maximum allowable shear stress

TYPE		F
Plain Corrugation		1.26
Trapezoidal Corrugated, Semi Sandwich		0.83
Truss Core, Semi Sandwich		0.78
Semi Trap, Corrugated Semi Sandwich		0.85
Top Hat Stiffened		0.96
Truss Core Corrugation		1.07
Semi Circle Corrugation		0.84
Truss Core Sandwich		0.78
Zed Section Stiffners		0.96
Integral Stiffners		0.81
Integral Zed Stiffners		1.02
'y' Stiffners		1.11

Secondary Weight estimation approach

Simplified approach to account for the secondary structure and non-optimum weight: *A regression method is used to derive the wing total weight as a function of the wingbox optimum weight*



EMWET(Elham Modified Weight Estimation Technique): Student Version

- **Inputs:**
  - Wing planform geometry (coordinates of sections apex points, chord lengths) EMWET cannot handle zero leading edge sweep, an angle of at least 0.1-0.5 degree is needed
  - Wing shape (airfoil coordinates)
  - Structural parameters (location of spars, rib pitch)
  - Material properties (Young’s modulus, allowables, density)
  - Sizing Loads (spanwise distribution of lift and pitching moment)

For increasing the robustness, only use the pitching moment calculated by the VLM (Res.Wing.Cm_c4) and ignore the sections Cm (Res.Section.Cm)

- **Outputs:**
  - Wing total weight.
  - Thickness of the equivalent panels.

Exercise 1: Running EMWET from Matlab

- Download EMWET from the blackboard.
- Use the example input files.
- Run EMWET from Matlab workspace.

- Change the Display option from “on” to “off” and run the tool again.

Exercise 2: Creating EMWET Input File xxx.init

- Matlab code for writing a text file:

```
fid = fopen(‘xxx.init', 'wt');
        fprintf(fid,'%g %g\n', MTOW,ZFW);
        fprintf(fid,'%g \n',n_max);
        .
        .
        .
fclose(fid);
```

- See Matlab helps for “fopen” and “fprint”

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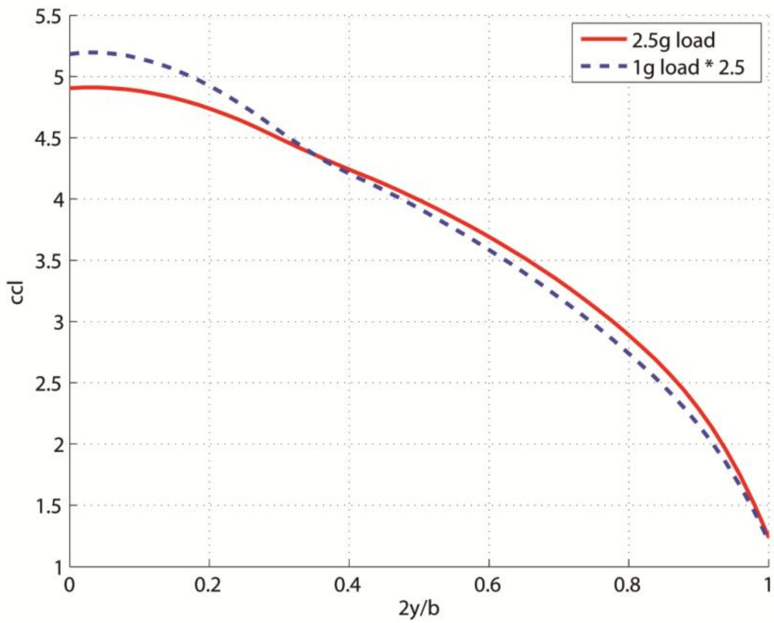
Create test.init file for the following wing (Fokker 50)

- MTOW = 20820 kg
- MZF = 18600 kg
- n_max = 2,5 (This factor is only used for adjusting the inertial loads not the aerodynamic loads, so make sure to apply the loads computed with Q3dSolver at 2.5, MTOW, maximum operative speed, cruise altitude)

- Wing span = 28m
- Root chord = 3,5 m
- Taper ratio = 0,25
- Leading edge sweep = 5 deg
- Front spar at 20% and rear spar at 80% of local chord
- Fuel tank from 10% to 70% of the semi-span
- One engine in each wing located at 2y/b = 0,25. Engine weight = 1200 kg
- Aluminum alloy 7075-T6 in all panels with following properties:
  - E = 7,1e10 N/m2, Rho = 2800 kg/m3,   Ft = 4,8e8 N/m2,   Fc = 4,6e8 N/m2
- Z type stringer
- Rib pich = 0,5m
- Eppler E553 airfoil at root and tip

Effect of Load Factor on the Aerodynamic Loads

- Loads should be calculated for a 2.5g pull up manoeuvre
- Do NOT multiply 1g load with 2.5: the result is not the same as a load calculated for a load factor of 2.5



Exercise 3: Creating EMWET Input File xxx.load

- Run Q3D AeroSolver for the previous wing at the following flight conditions:
  - M = 0,55
  - V = 170 m/s
  - H = 6000 m
  - Rho = 0,5505 kg/m3
  - μ= 1,54e-5
  - Re = 1,64e7
  - *CL = to be determined*

$$L = C \times C_l \times q$$

$$M = C \times MAC \times C_m \times q$$

- Create test.load using the lift and moment distribution from ***Q3D***

  Use INVISCID analysis mode of the Q3D solver to save time
- Run EMWET for the new Wing

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Exercise 4: Reading EMWET Output File xxx.weight

- Open the output file from Matlab using the following codes:

```
fid     = fopen('test.weight', 'r');
Res = textscan(fid, ??);
fclose(fid);
```

Write the proper Matlab code. Use Matlab help for "textscan".

Read the wing weight from the output file.