Light Aircraft Structures
Definitions

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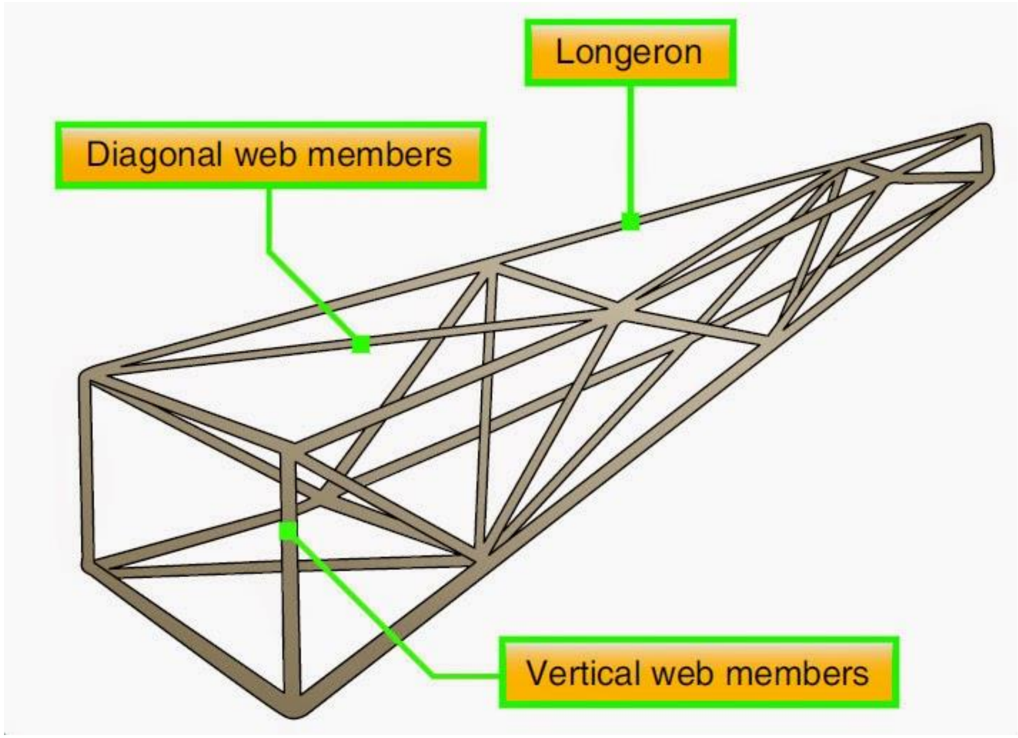
Airframe Types – Space Frame

- Space frame = strut framework + wireframe



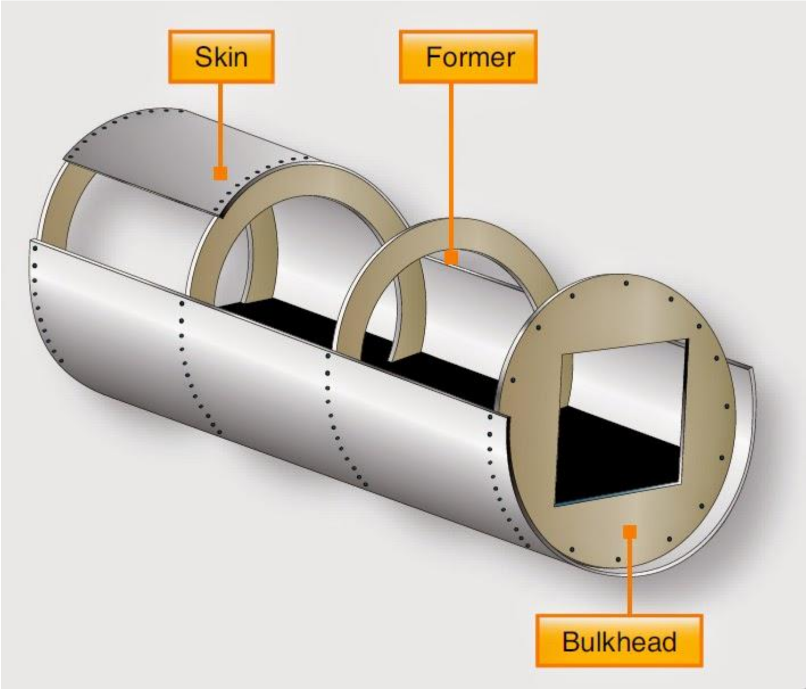
WWI designs:
Spaceframe & canvas

Sopwith
Camel (1916)

Fokker
Dr.I (1917)

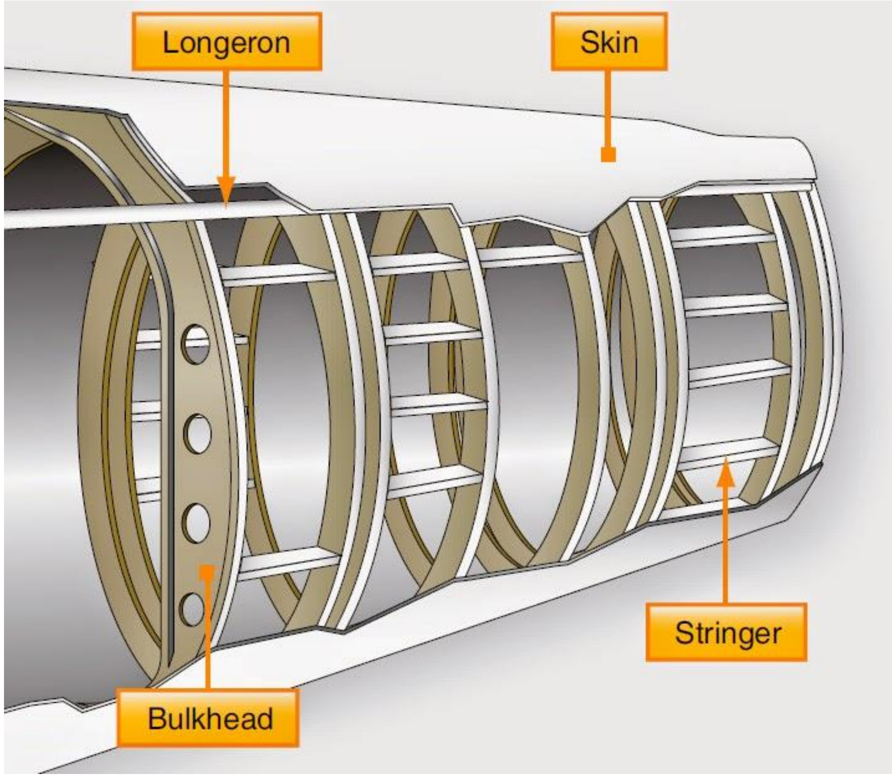
Airframe Types – Monocoque

- Monocoque = ‘single shell’
  - ‘Pure’ stressed skin construction



Airframe Types – Semi-Monocoque

- Combination of monocoque + space frame



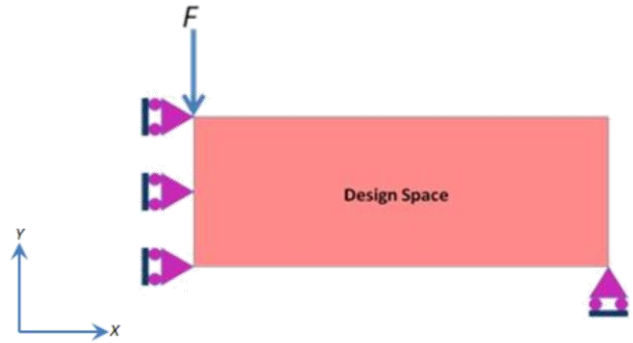
WWII designs:
Metallic 'stressed-skin'

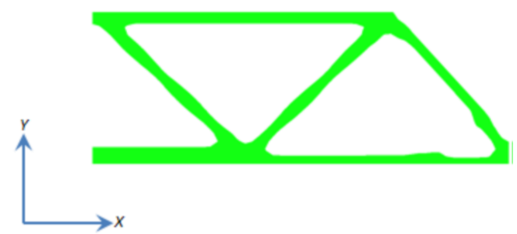
Boeing
247D (1933)

Douglas
DC-3 (1935)

Airframe Types – Topology Optimisation

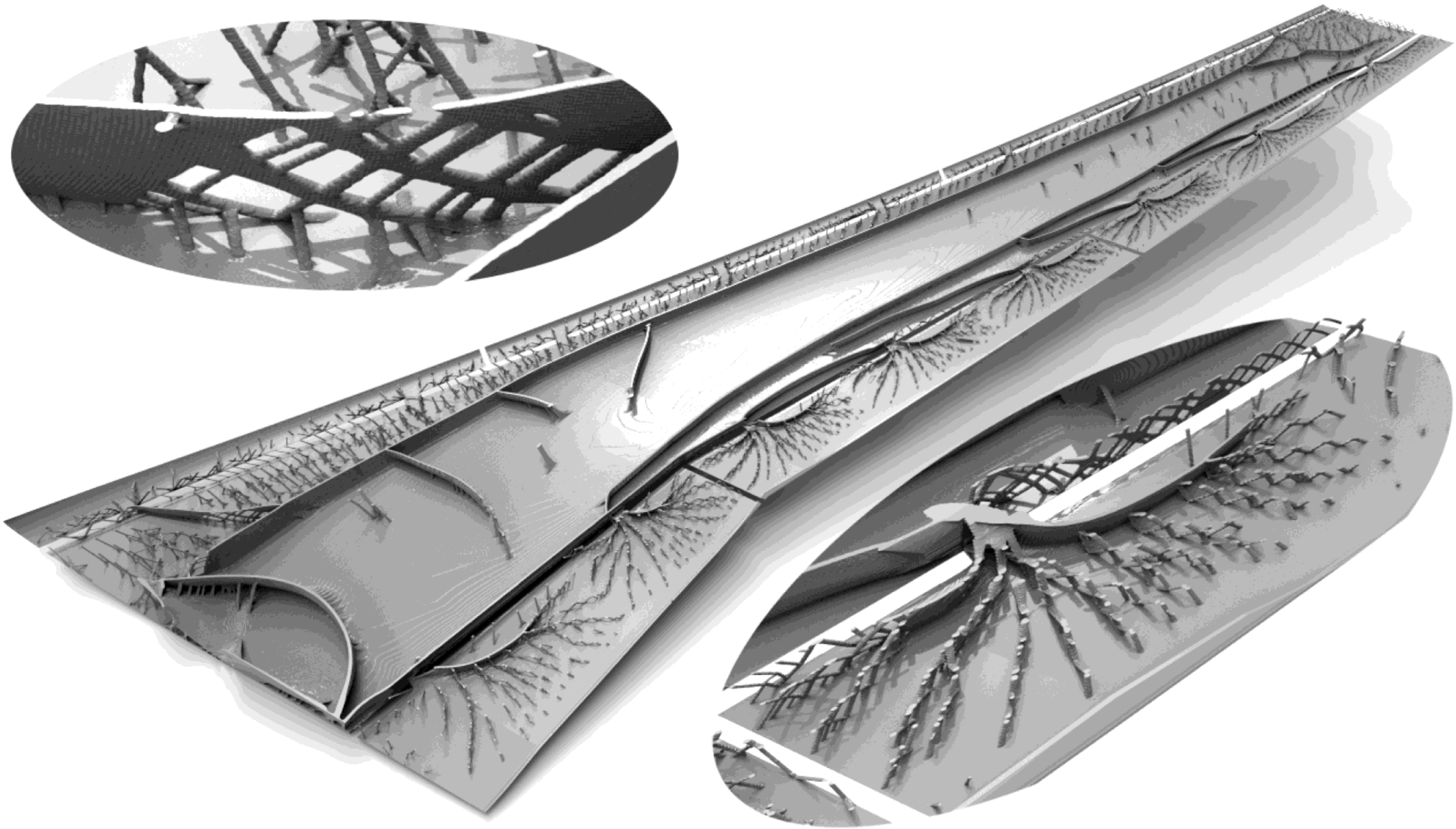
- Topology optimisation:
  - Objective: minimise mass
  - Constraints:
    - Provide minimum stiffness for given load conditions
    - Stresses must be below allowable values
  - Start with monolithic structure
  - Analyse stresses, *e.g.* maximum principal stresses
  - Remove material (or reduce density) where unloaded
  - Iterate





Walker DL: *Topology Optimization of an Aircraft Wing*; PhD Thesis, Air Force Institute of Technology (2015)

Topology Optimisation - Examples



Aage *et al.*, *Giga-voxel computational morphogenesis for structural design*; Nature Letters (2017)

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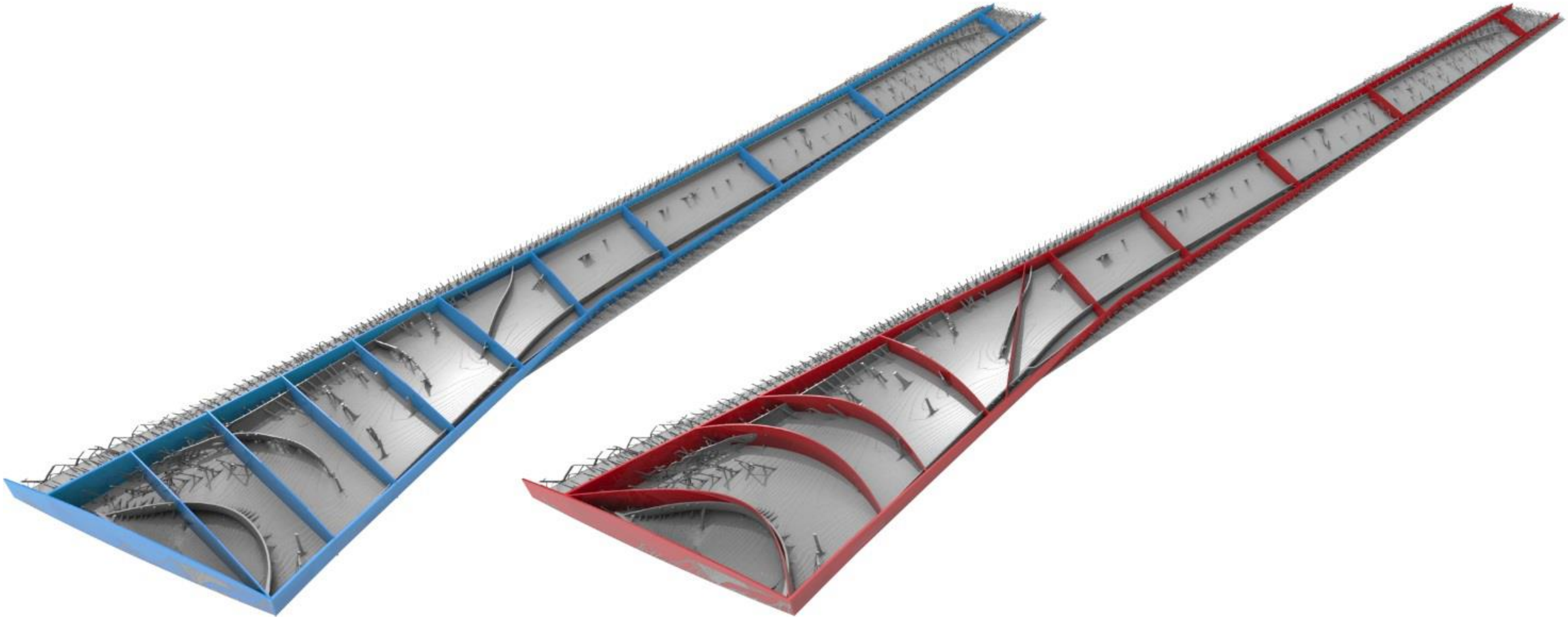

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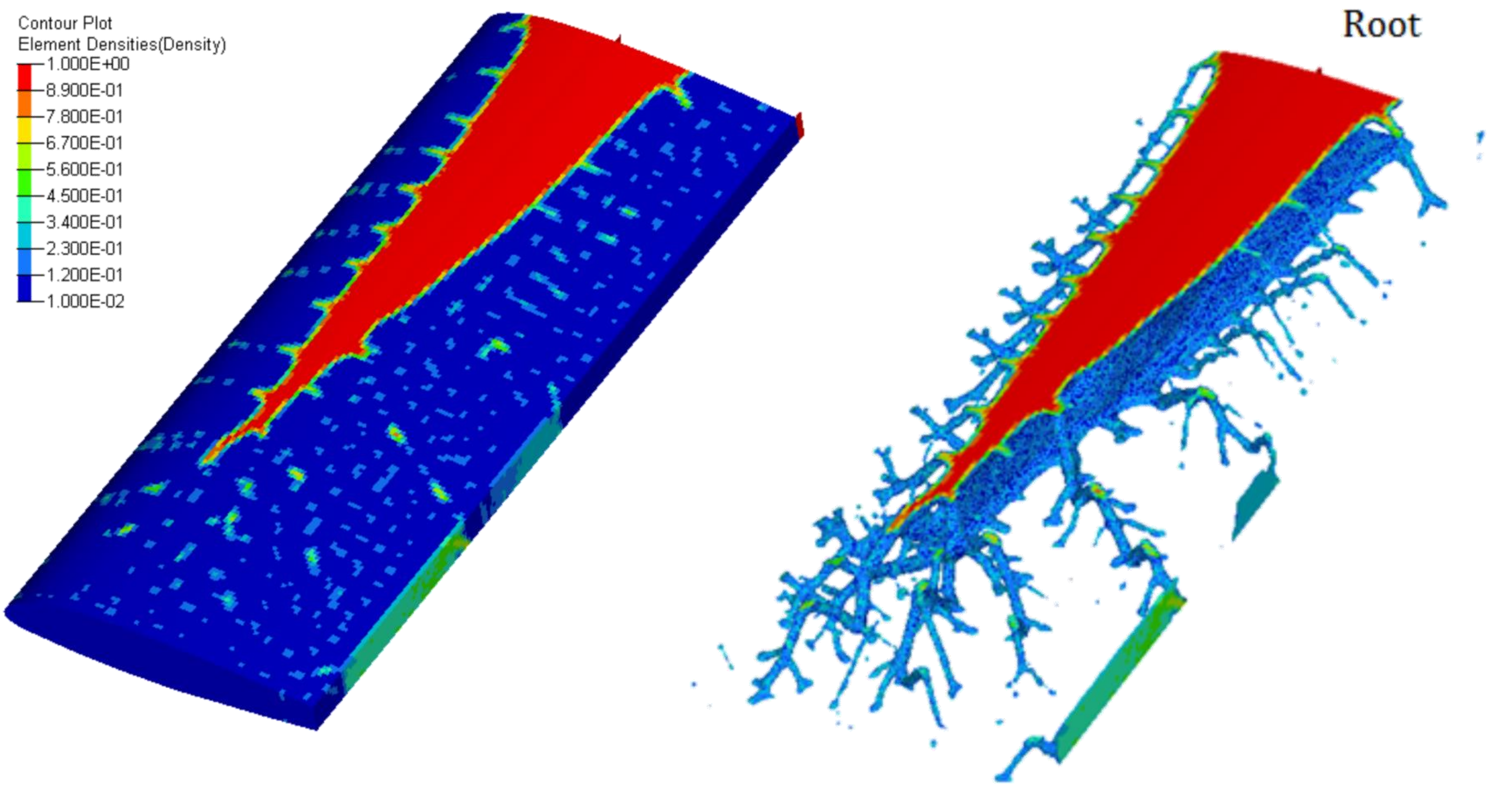

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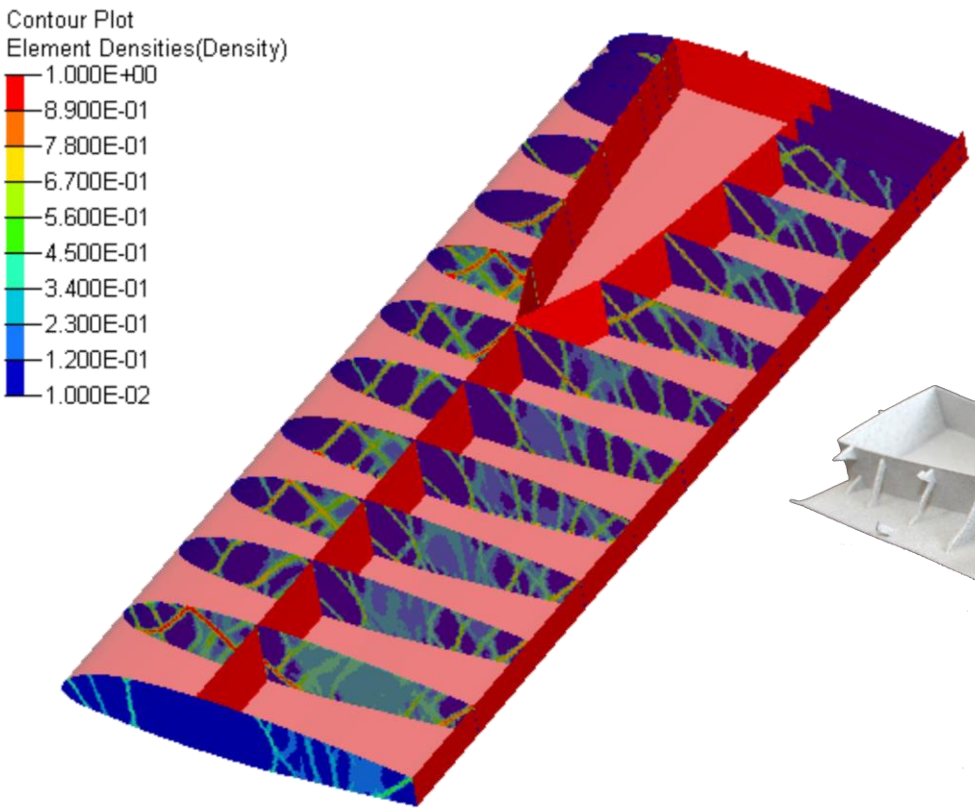
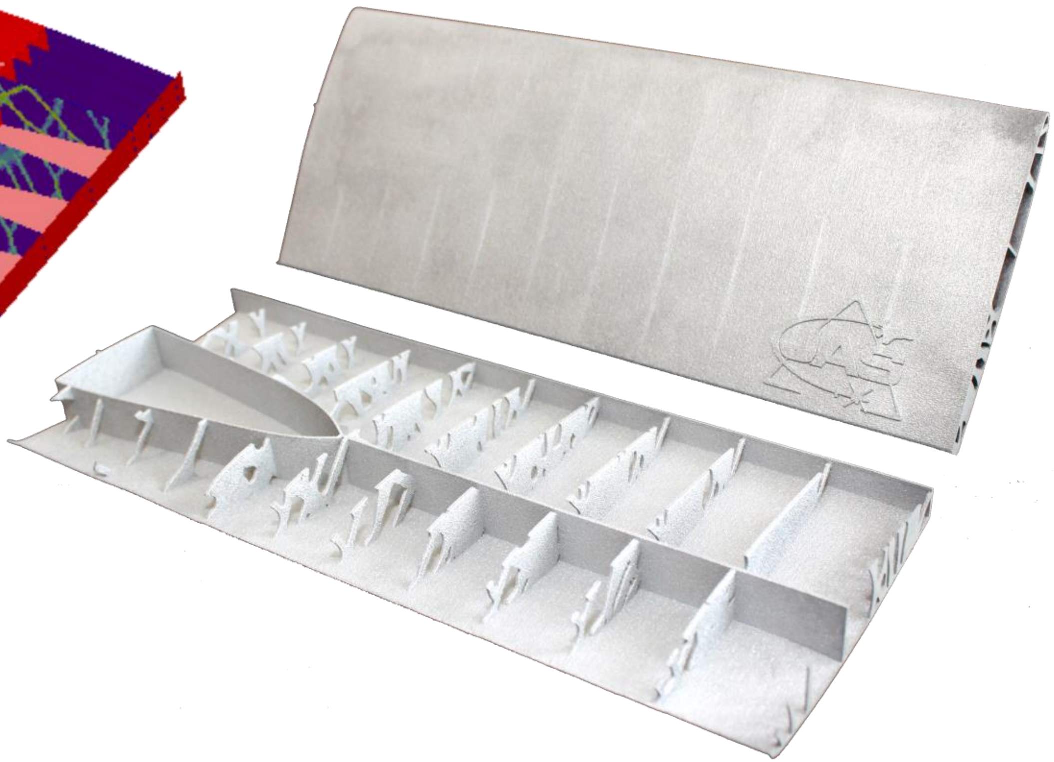
Topology Optimisation - Examples





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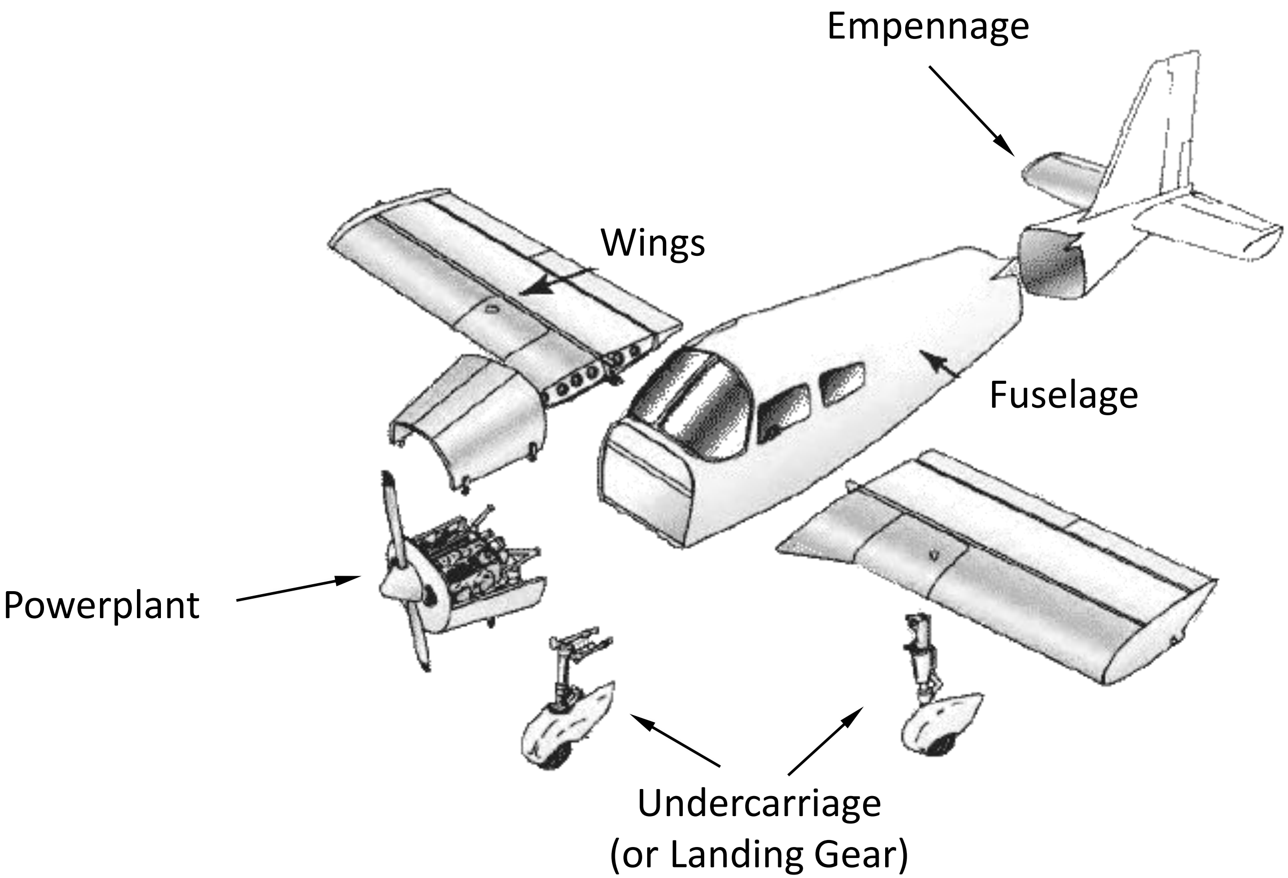
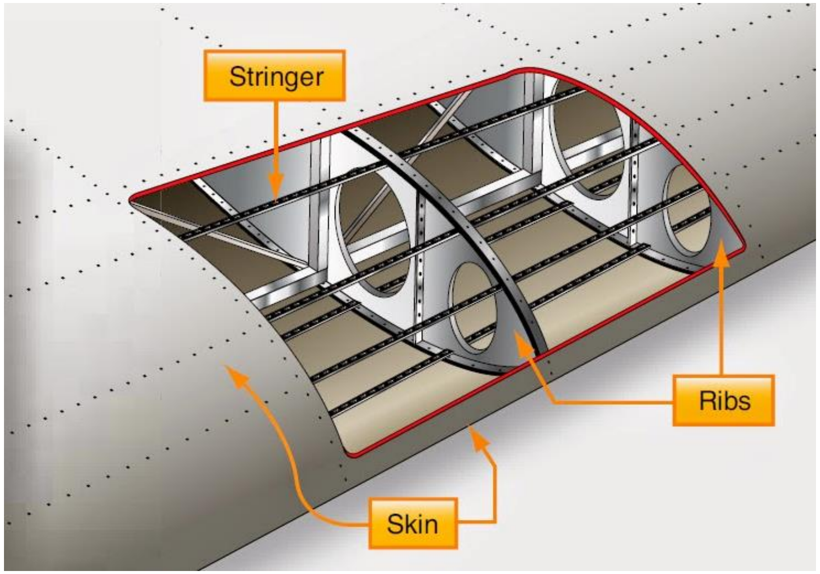
- Light aircraft can be split into different 'parts' or sub-systems:

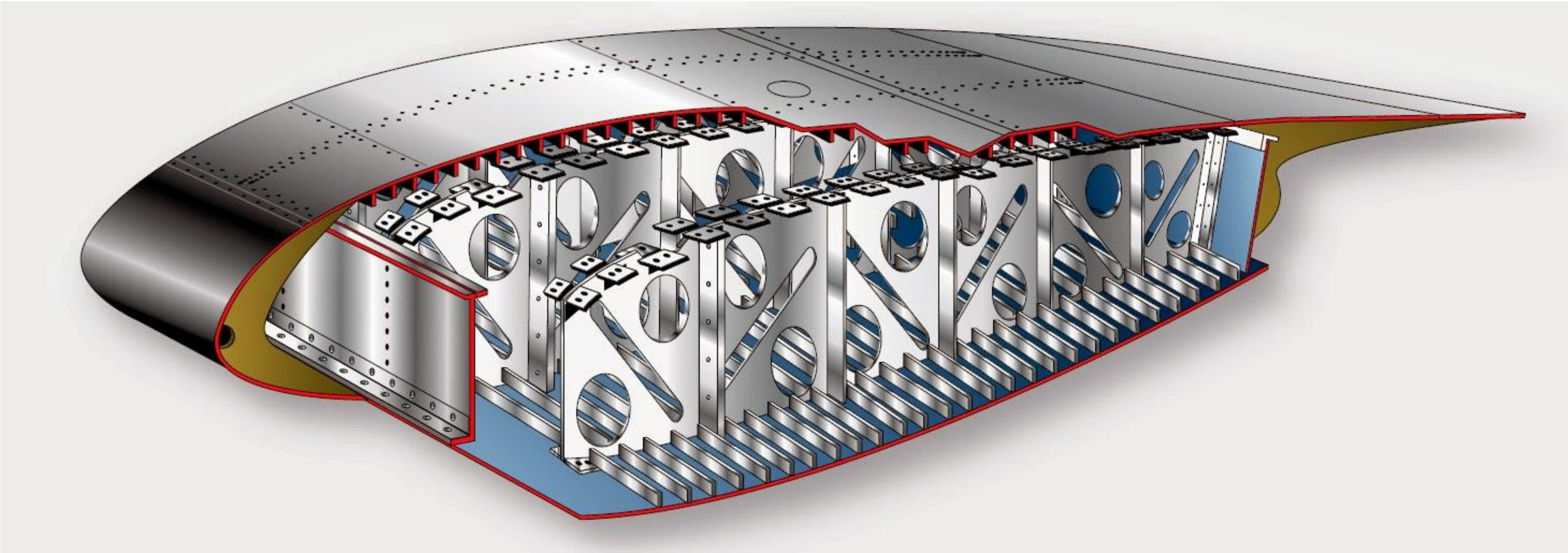


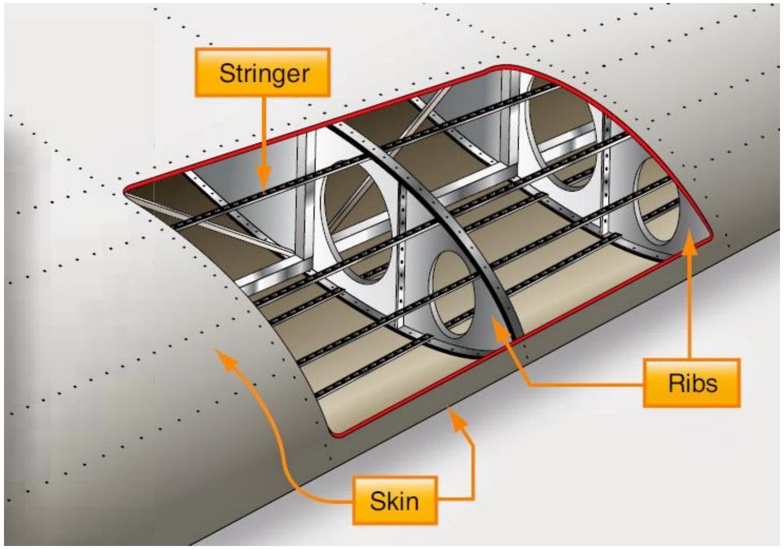
Wing Structures

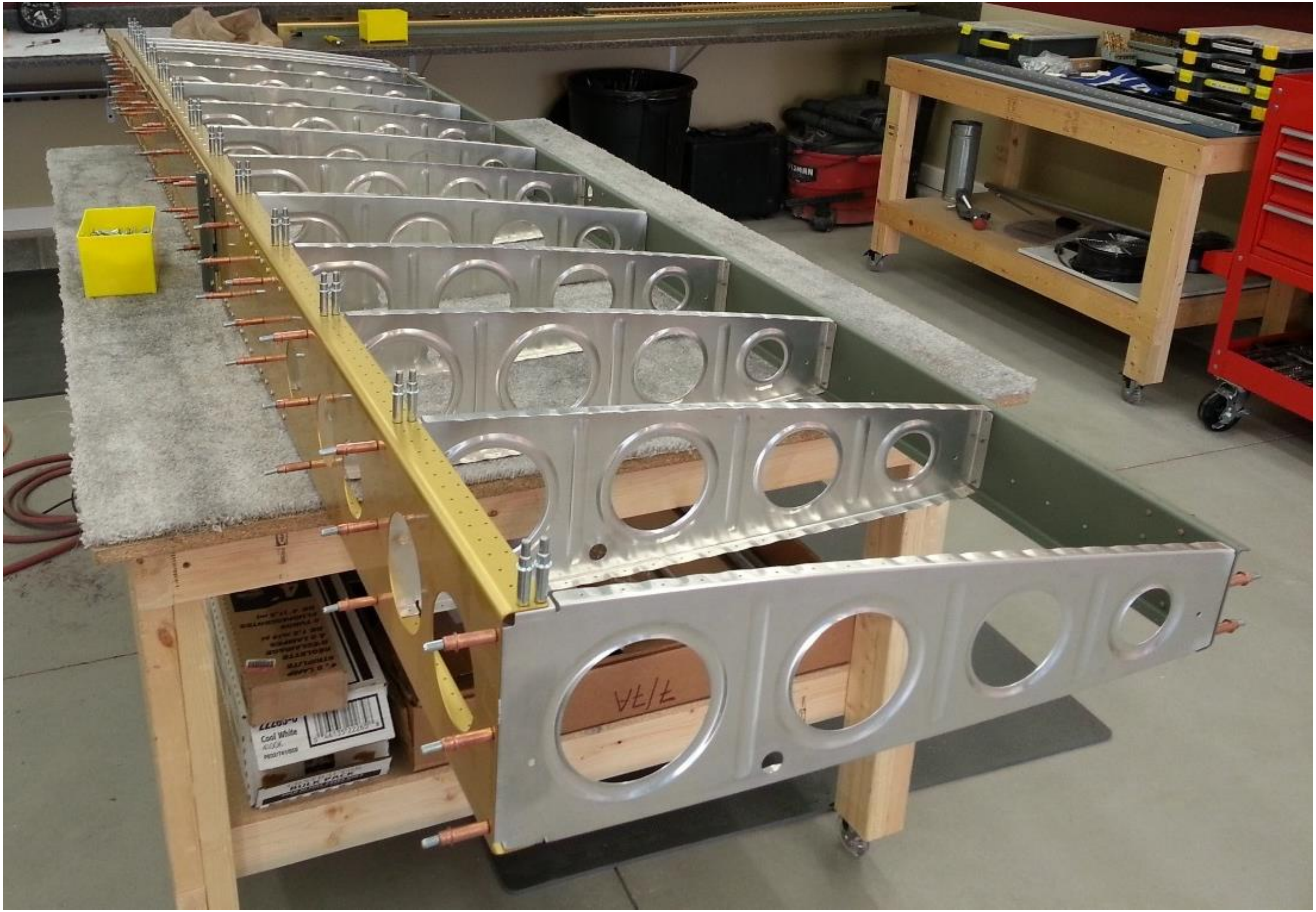


- Skins
  - Provide the aerodynamic surface
  - Usually made from rolled flat sheets
  - Riveted to rib, spar flanges and stringers
- Spars
  - Resist bending
  - Classic design uses two spars
  - ‘Spar webs’ are usually thin flat sheets
  - ‘Spar caps’ are usually the web folded or riveted/bolted
- Ribs
  - Maintain aerofoil shape
  - Carry local load inputs, *e.g.* engines or gear
  - Flat sheets with flanges around edges, riveted to skins
  - Cut-outs for passage of continuous spanwise stringers, ‘lightness holes’ and system openings
- Stringers
  - Resist bending
  - Stabilise skin (*i.e.* prevent buckling)
  - Smaller section than spar caps

Wing Structures







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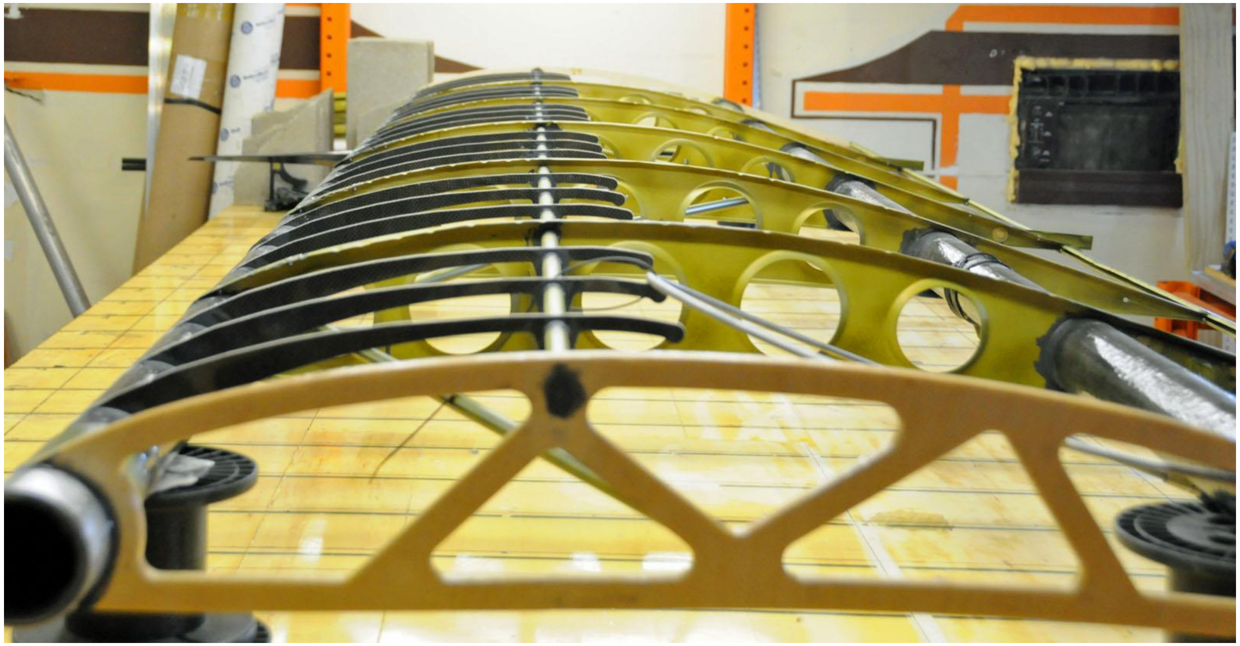
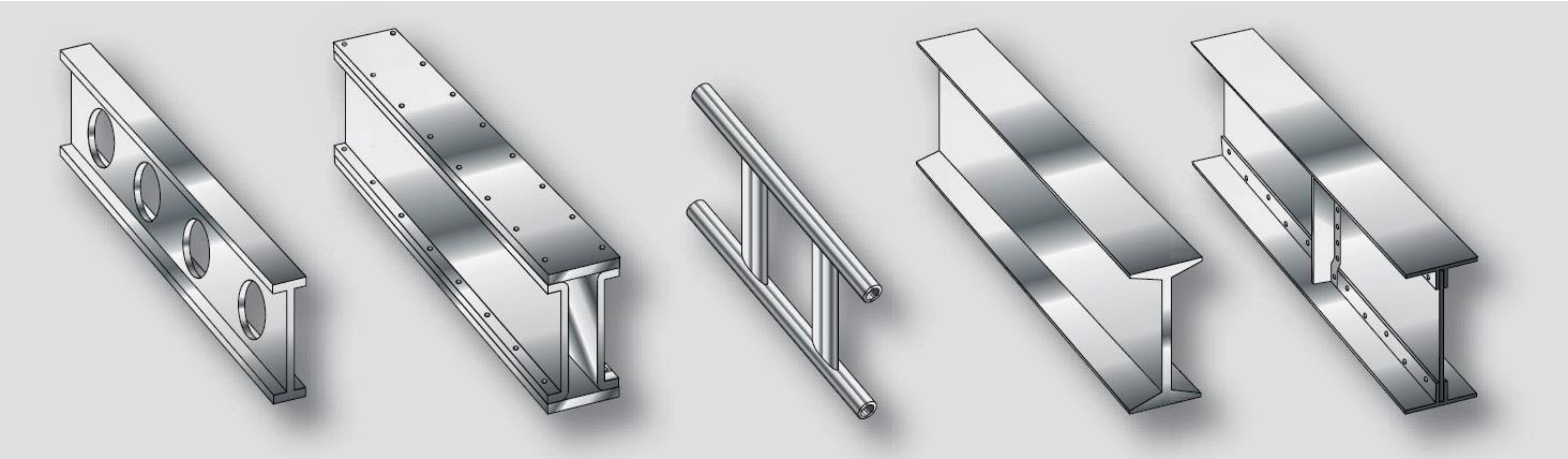
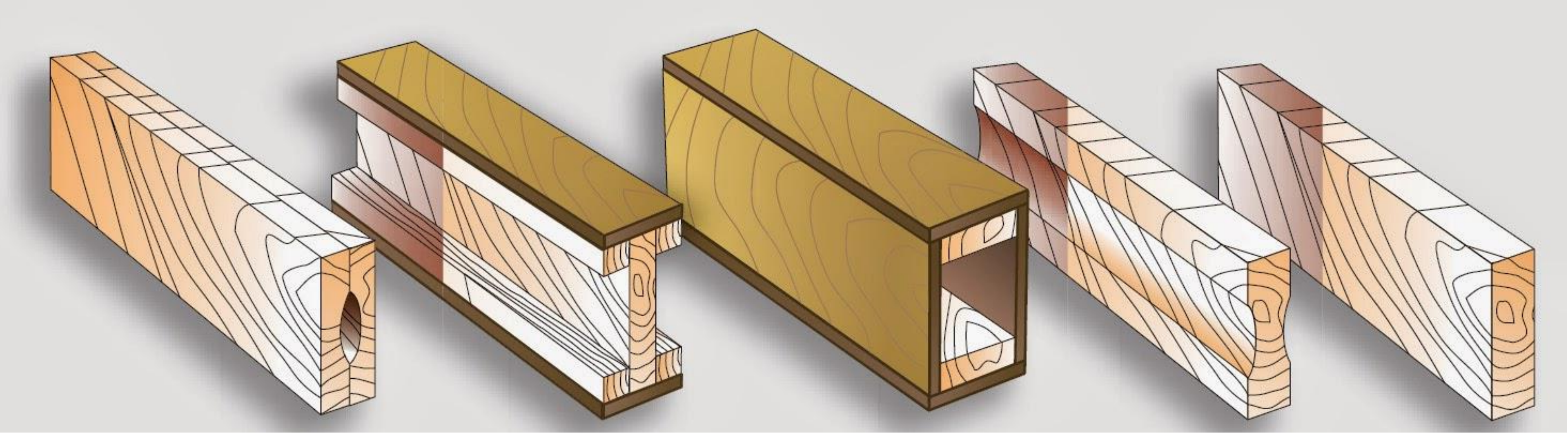


Wing Spars





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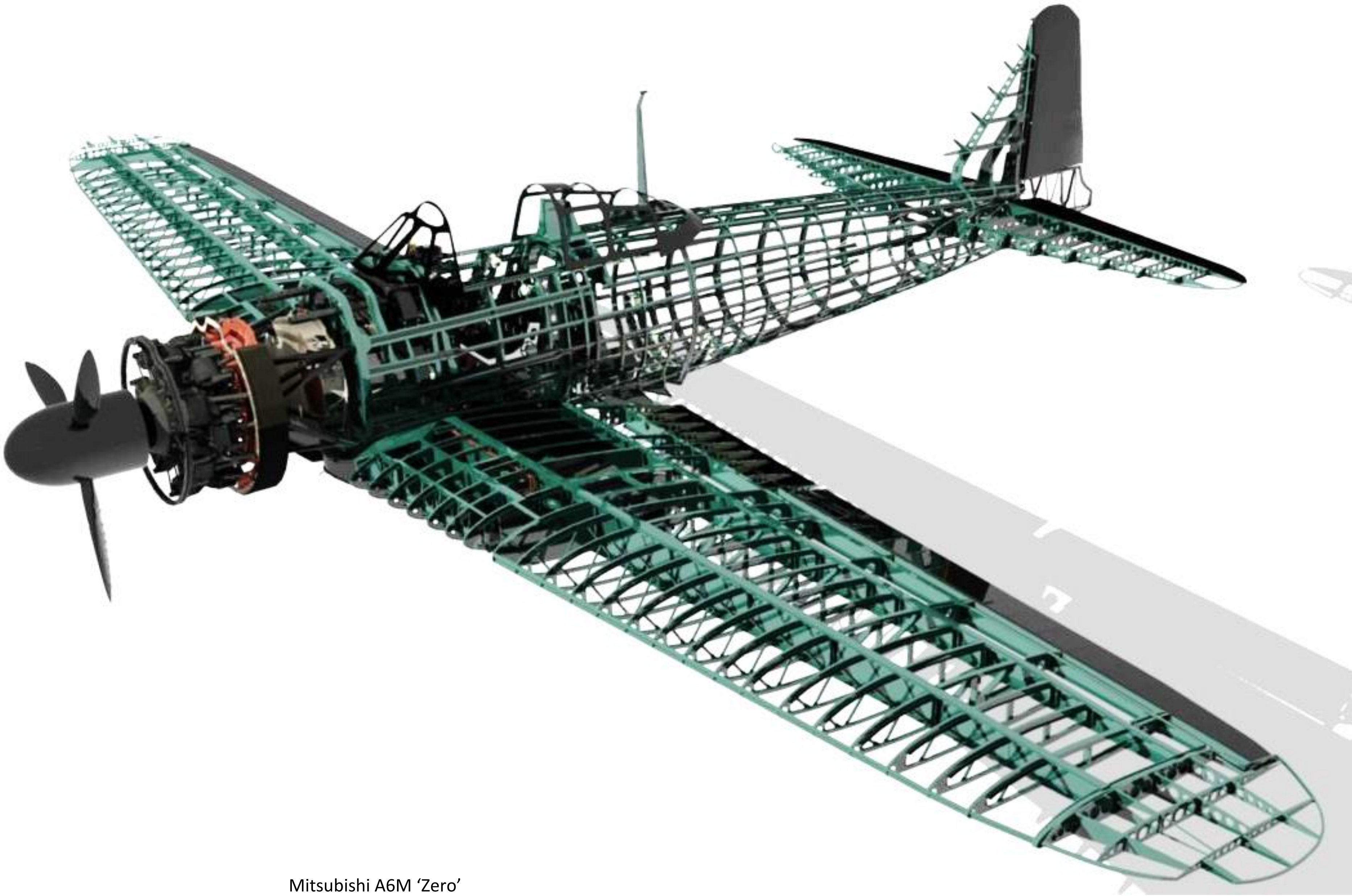
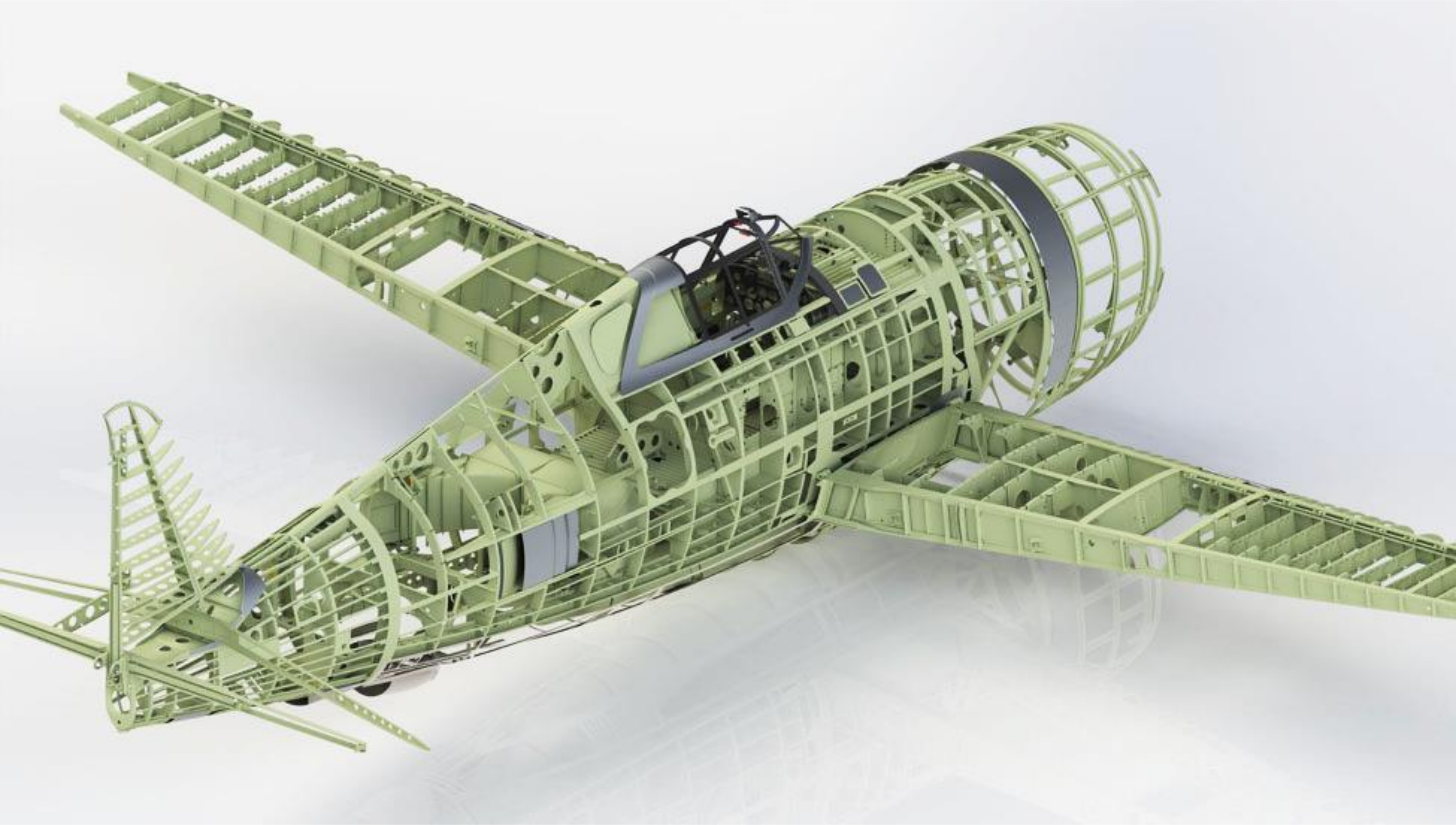


Mitsubishi A6M 'Zero'

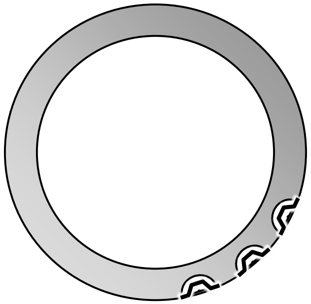
Wing Structures



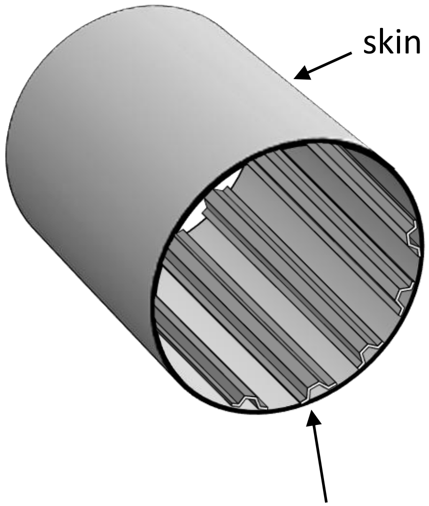
Republic P-47 Thunderbolt

Fuselage Structures

- Skins: form aero surface - formed from flat sheets, preformed by rolling. Riveted to frames, beam flanges and longerons
- Frames: maintain shape and carry local load inputs - formed from flat sheets with flanges around their edges, riveted to skins and webs. Cut-outs for passage of continuous spanwise longerons or beams, lightness holes and system openings
- Longerons: carry bending as end loading and stabilise skin (smaller section than beams)
- Beams: carry bending - thin flat sheet webs folded or bolted or riveted to flanges
- Fuselage sections are often easier to analyse than wings because they usually have an axis of symmetry and only one or two cells



Frames and bulkheads



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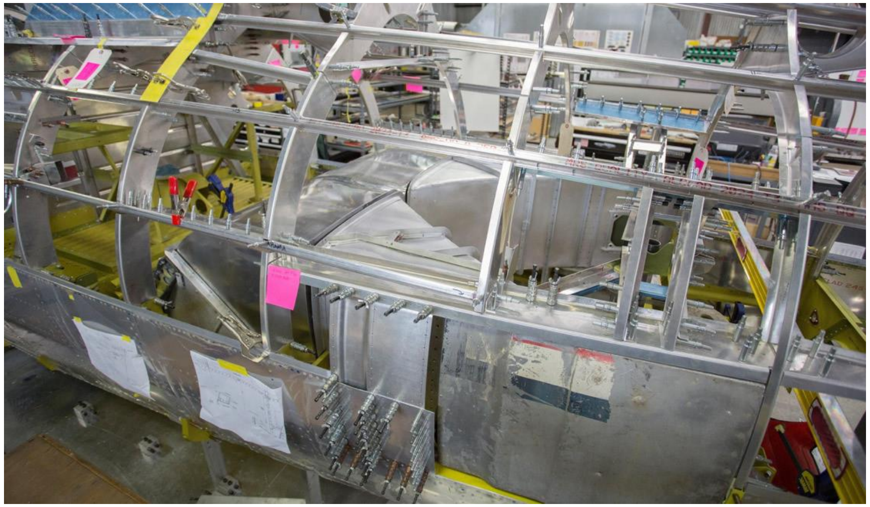
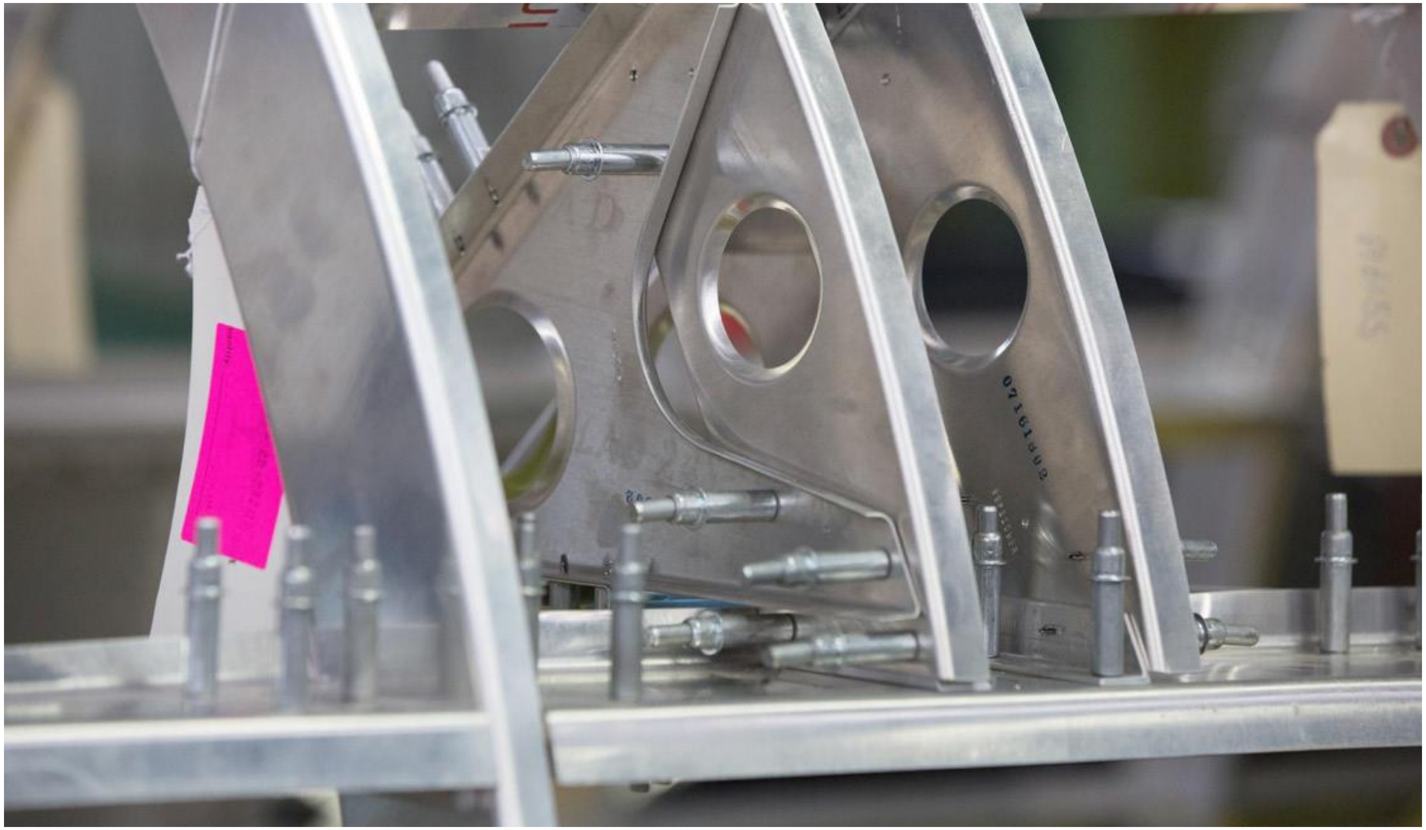
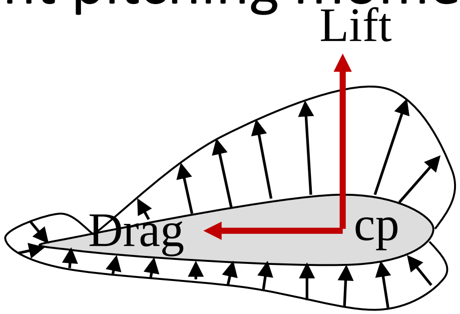
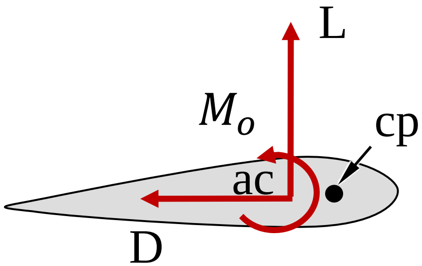




Wing Loads

- The differential pressure distribution caused by incidence and camber results in a force on an aerofoil acting at the “centre of pressure” (cp) which is resolved into perpendicular and parallel load components to the flight path as lift and drag components respectively
- However, the position of the cp changes as the pressure distribution varies with speed and incidence
- To simplify analysis we refer to a point on the aerofoil about which the moment due to lift and drag forces remains constant. This point is known as the “aerodynamic centre” (ac). Accordingly we replace the lift and drag forces acting at the cp by forces at the ac plus a constant pitching moment M_o

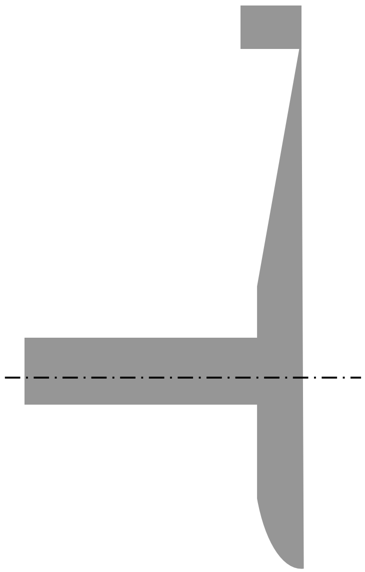




Wing Torsional Axis

- The wing torsional axis, also referred to as the 'flexural' or 'elastic' axis, represents the locus of section shear centres along the span. It is the axis about which the wing will naturally tend to twist under pure torsion

- For structural analysis the lift, drag and pitching moment at the aerodynamic centre can be replaced by equivalent loads and moments at the wing torsional axis



- Transverse loads through this axis cause only translation and no rotation whereas a pure torque applied to any section produces only rotation about this axis and no translation

- If the torsional axis is significantly offset from the aerodynamic centre then high torsional moments may be generated causing the wing to twist

Light Aircraft Structures
Structural Idealisation

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Idealisation of Semi-Monocoque Structures

- To simplify the analysis of stiffened skin structures we idealise the structure as concentrations of areas at stringers and spar caps “booms” and as thin webs “skins”
- For bending we consider the booms only and ignore the skin other than the portions accounted for in the effective boom areas
- For shear we account for the interruption of the skins by the booms which bring about step changes in the shear flow in the skins (webs) between the booms, ignoring the direct stress carried by the skins
- For torsion of a closed section we usually ignore the booms and consider the skin only and the enclosed area
- Essentially, booms carry direct stress and skins carry shear