AS3020: Aerospace Structures

Module 1: Design of Aircrafts

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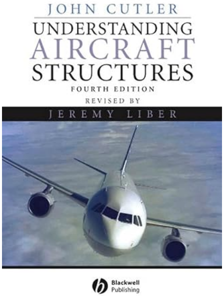
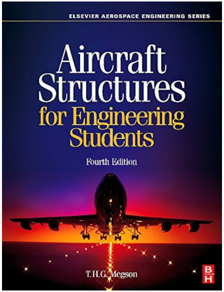


Chapters 1-5,7,9 in Cutler [1]



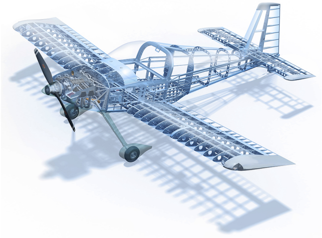
Chapters 12-15 in Megson [2]

Introduction

In this module we seek to gain an *executive understanding* of,

- the evolution of the structural design of aircrafts;
- the balance of the different loads on an aircraft;
- joining processes used in aircrafts.

Why do aircrafts look the way they do?



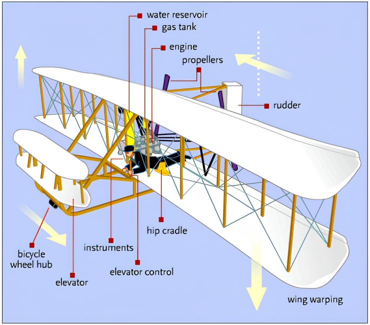
RV-14 Airframe [3]

Textbook References

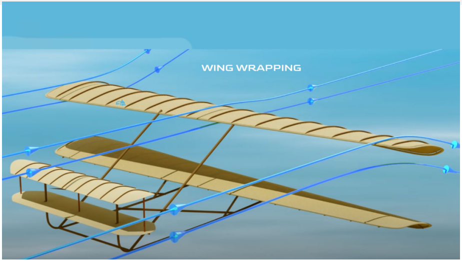
- Chapters 1-5,7,9 in J. Cutler. Understanding Aircraft Structures, Wiley, 2005. ISBN: 978-1-4051-2032-6
- Chapters 12-15 in T. H. G. Megson. Aircraft Structures for Engineering Students, Elsevier, 2013. ISBN: 978-0-08-096905-3.

1.1. Wired Brace Construction: The Wright Flyer

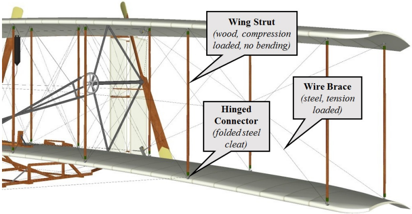
Historical Overview



The Wright Flyer, 1903 [4]



The warping wing [5].



Wired brace construction [6]

- The bi-wing construction for structural integrity
- Light-weight wired-brace construction

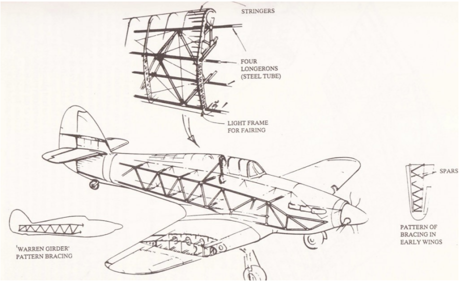
1.2. Braced Fuselage Design

Historical Overview

- The wired-braced, box-strut design approach persisted for a couple decades or so (∼1930s)
- Wooden struts/longerons replaced by steel-tubes in this time

Frame of the 1917 Sopwith Camel [7]

- **Warren trusses** replaced wire braces ("Warren-girder" design)



Hawker Hurricane frame, 1935 [1]

Warren Truss [8]

Patented truss (∼1840s) formed by equilateral triangles

1.2. Braced Fuselage Design

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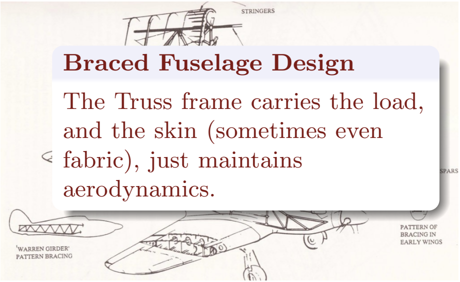


Braced Fuselage Design

The Truss frame carries the load, and the skin (sometimes even fabric), just maintains aerodynamics.

Hawker Hurricane frame, 1935 [1]

Warren Truss [8]

Patented truss (∼1840s) formed by equilateral triangles

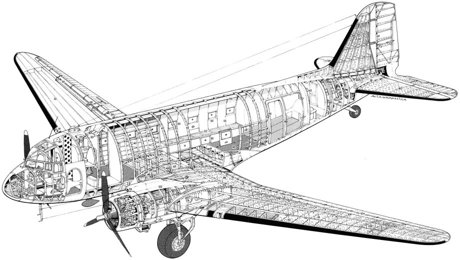
1.3. Semi-Monocoque Design

Historical Overview

- Ships have always had to maximize volume while maintaining a shape
- Bent wooden frames used to maintain the hull shape

A wooden ship hull [9]

- The skin is now load-bearing: **stressed skin construction**, aka, **semi-monocoque construction**
- Since skins also carry load, the structure is at a generally lower stress level

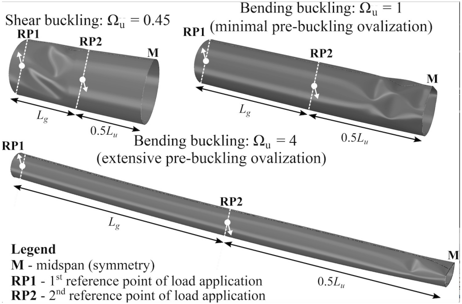


Douglas DC-3 (1933) [10]

1.3. Semi-Monocoque Design

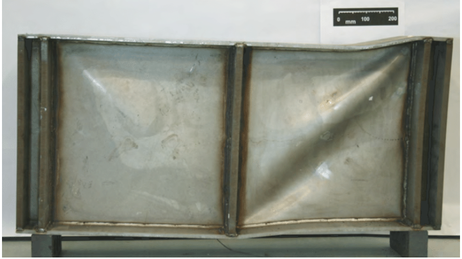
Historical Overview

- Thin-walled structures can carry tension much better than compression
- Buckling becomes a major issue under compression



Thin-walled cylinder [11]

- The common-sensical thing to do is to **split up the skin into multiple smaller elements**
- We do this by means of **ribs/frames** holding the structure perpendicular to section and **stringers**, longitudinally.



Shear buckling [12]

1.3. Semi-Monocoque Design

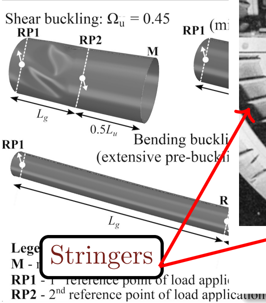
Historical Overview

- Thin-walled str… t… h b… …omp…
- Buckling becon… under compress…

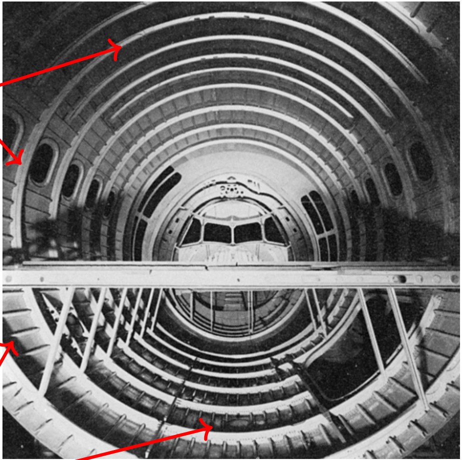
…ensical thing to do … **the skin into …ller elements** …means of …olding the …ndicular to section … longitudinally.

Frames/Rings

Stringers



Thin-walled cylinder [11]

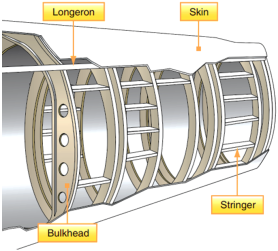


Insides of a fuselage [2]

Shear buckling [12]

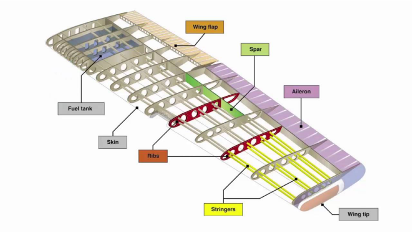
1.3. Semi-Monocoque Design

The Fuselage



Structural members in a fuselage [13]

The Wing



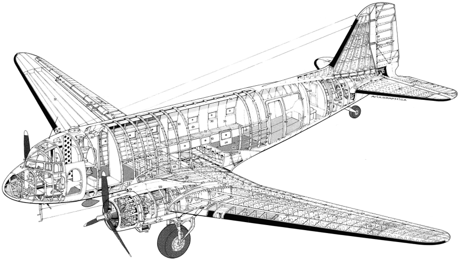
Structural members in a wing-box [14]

- The basic premises of the designs are identical, **but loads on the members vary**

1.3. Semi-Monocoque Design

Historical Overview

- Through experience, the industry has converged onto the following numbers:
  - Frame-spacing: ~ 500 mm
  - Frame-sections: $\sim 75 - 150$ mm
- A few more considerations:
  - The skins need to be **fastened onto the frames**
  - Moving to more and more lightweight structures, thin walls are very prone to **Sheet-buckling/wrinkling** (even "thermal" buckling)



Douglas DC-3 (1933) [10]

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Sandwich structures

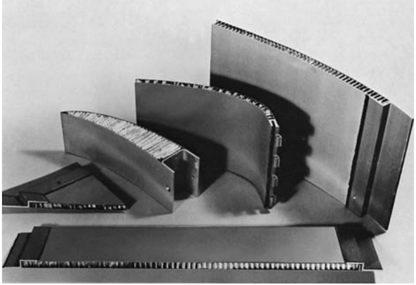

Figure from [1]

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Composite Materials

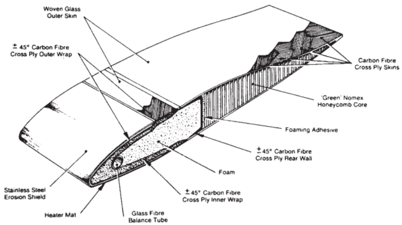

Figure from [2]

1. Historical Overview

Design Overview

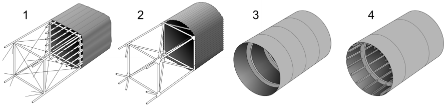

Figure from [3]

The "converged" aircraft

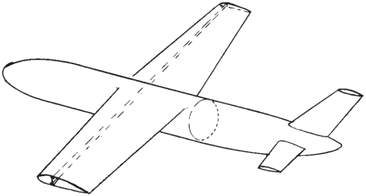

Figure from [1]

Parts of an aircraft

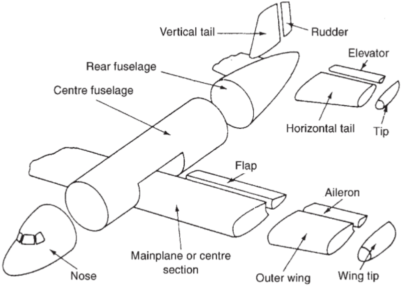

Figure from [2]

1. Historical Overview

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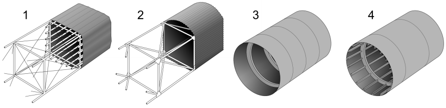

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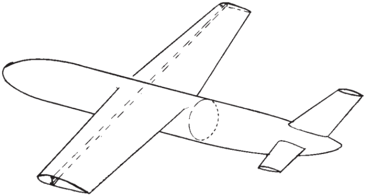

Figure from [1]

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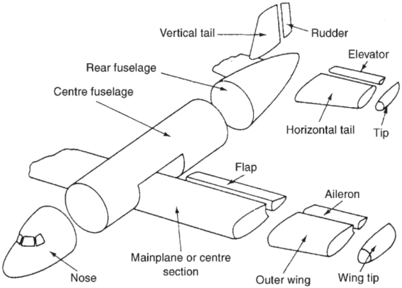


Figure from [2]

- **"Wings"**: Mainplane, tailplane

1. Historical Overview

Design Overview

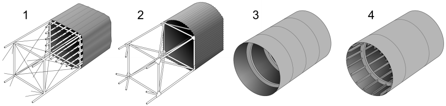


Figure from [3]

The "converged" aircraft

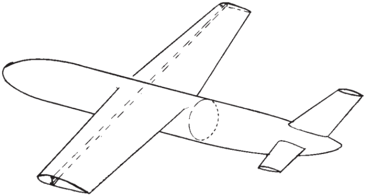


Figure from [1]

Parts of an aircraft

High Lift Devices

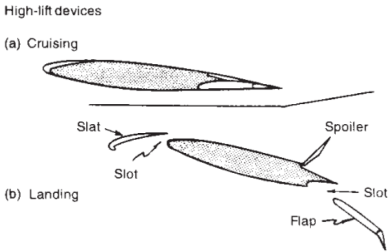
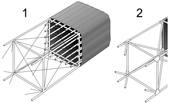


Figure from [1]

- **"Wings"**: Mainplane, tailplane
- **High lift devices**: flaps, ailerons, elevators

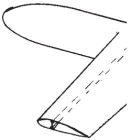
1. Historical Overview

Design Overvi



F

The “converge



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Dimensions of an Aircraft

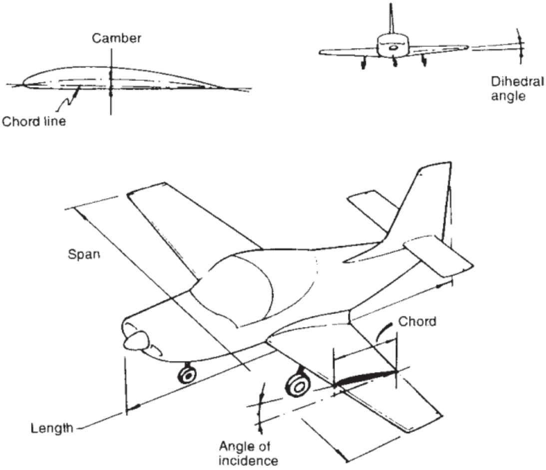
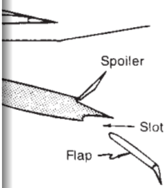


Figure from [1]



[1]

plane,

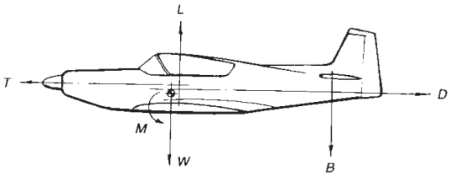
es: flaps,

s

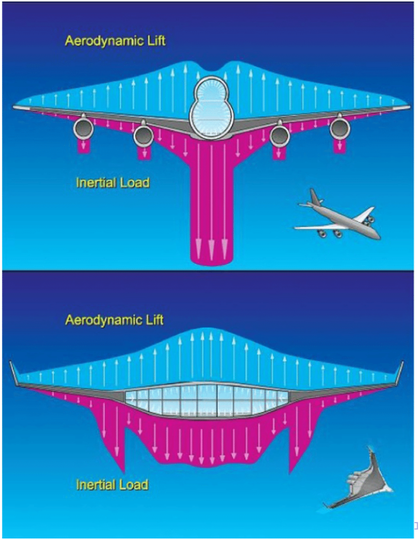
2. Aircraft Loads

2.1. Loads in Steady Level Flight

- The fuselage is being lifted up by the wing as the flight moves forward
- The load distributions are non-trivially related to flying conditions as well as design choices



W = Weight
L = Lift (at the wing aerodynamic centre)
M = Moment (about the aerodynamic centre)
T = Thrust
D = Drag
B = Balancing load (from the tailplane)
Note this diagram is similar to Fig. 4.4 but shows



2.2. Loads During Maneuvers

2. Aircraft Loads

A maneuver is any disturbance to steady-level flight.
Note: Even increasing acceleration in level flight is a maneuver.

Steady Pull-out

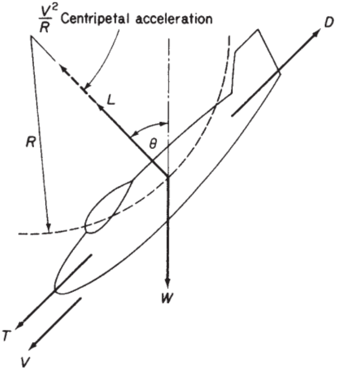


Figure from [2]

Banking

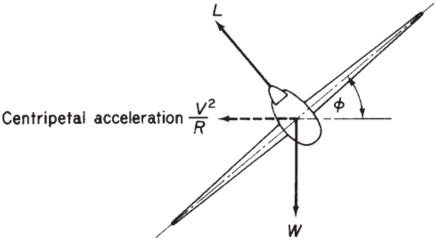


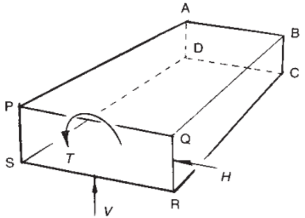
Figure from [2]

2.3. Load-based Design

2. Aircraft Loads

Content from **sec. 5.6.4** in [1].

Loads on a Box-Structure



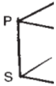
	Type of end load, i.e. tension (+) or compression (–) due to V	due to H	due to T	Type of load in total
Member PA	–	–	0	Large compressive load
QB	–	+	0	Smaller load
RC	+	+	0	Large tensile load
SD	+	–	0	Smaller load
	Type of shear load			
Skin PQBA	0	+	+	High-shear load
QRCB	+	0	+	High-shear load
SRCD	0	–	+	Lower-shear load
SPAD	–	0	+	Lower-shear load

2.3. Load-based Design

2. Aircraft Loads

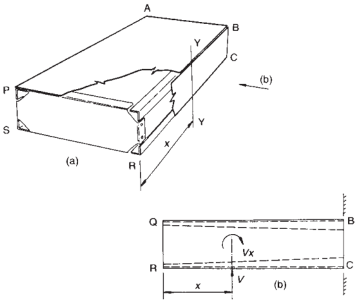
Content from sec. 5.6.4 in [1]

Loads



d in total
pressive load
d
le load
d
load
load
r load
r load

Design modifications due to shear-load V



- Flat member PQRS introduced to maintain **section-integrity**;
- Additional material added at the spar-webs (corners) to support **shearing**;
- "Corner material" increased at fixture to **support moments**.

2.3. Load-based Design

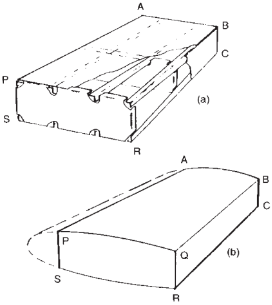
2. Aircraft Loads

Content

Loads

d in total
pressive load
d
le load
d
load
load
r load
r load

Design modifications due to shear H and Torsion T



- Longitudinal members added to prevent **torsional collapse**;
- Horizontal members added to support shear load H;
- In a real wing these will be,
  - Face PQRS: **Wing Ribs/Fuselage Frames**
  - Longitudinal members: **Stringers**
  - Face QBCR: **Wing Spars**

2.4. Flight Load Envelopes

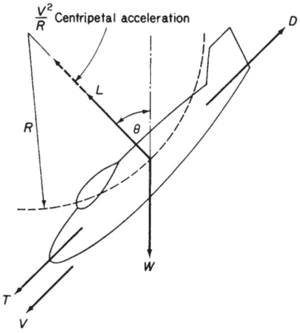
2. Aircraft Loads

- The aircraft experiences **heightened inertial loads** during maneuvers
- It has therefore become customary to specify max. permissible loads in "g's", i.e., in acceleration units

Example

In [1], it is mentioned that EASA CS-25 specifies the following for large airplanes:

- $9g$ forwards;
- $1.5g$ upwards;
- $6g$ downwards;
- $3g$ rearwards.

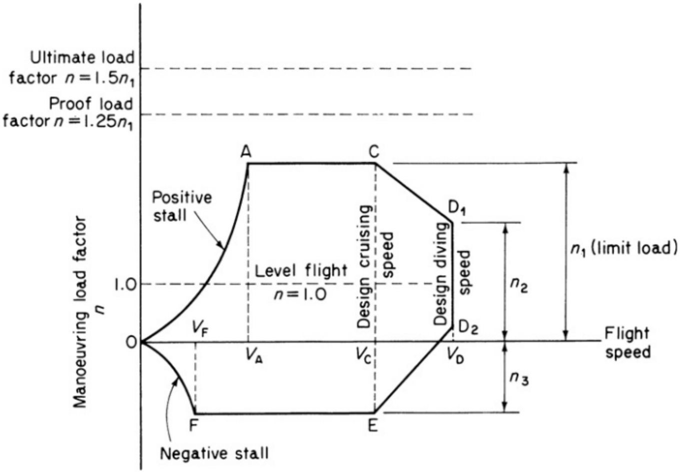


Loads During Steady Pull-Out Maneuver [2]

2.4. Flight Load Envelopes: The V-n Diagram

2. Aircraft Loads

At any given flight speed, the envelope specifies the **load that the flight must be able to withstand**



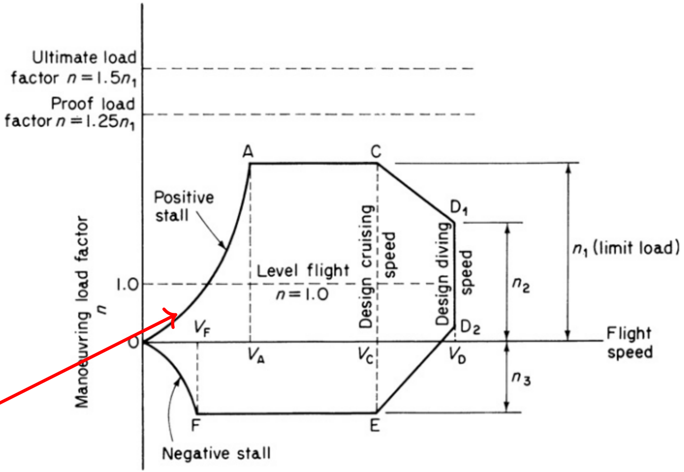
Flight Envelope from [2]

2.4. Flight Load Envelopes: The V-n Diagram

2. Aircraft Loads

At any given flight speed, the envelope specifies the **load that the flight must be able to withstand**

The wings can't carry the aircraft to the left of here



Flight Envelope from [2]

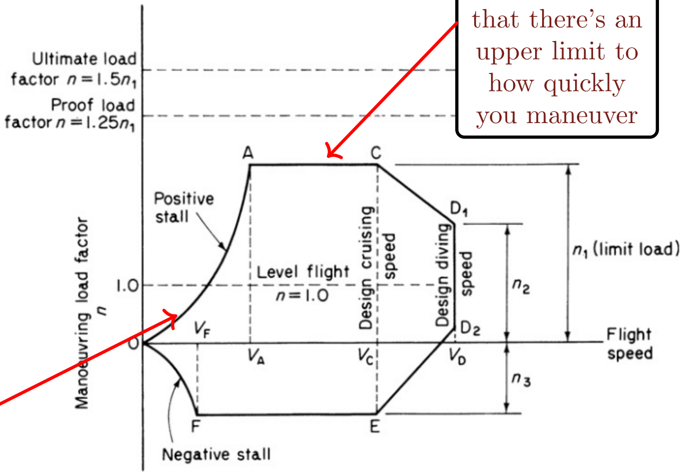
2.4. Flight Load Envelopes: The V-n Diagram

2. Aircraft Loads

At any given flight speed, the envelope specifies the **load that the flight must be able to withstand**

The logic for this cut-off is that there's an upper limit to how quickly you maneuver

The wings can't carry the aircraft to the left of here

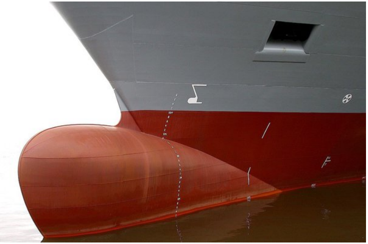


Flight Envelope from [2]

3. Joining Technology

3.1. Welding

- Welding is an "easy road out" for a designer but quite non-ideal in practice
  - Requires high skill;
  - Difficult to inspect for defects;
  - Poor fatigue strength.
- Extensively used in ship-hulls but not so much in aircraft skin
  - Listing out reasons will be part of your first assignment! ;)



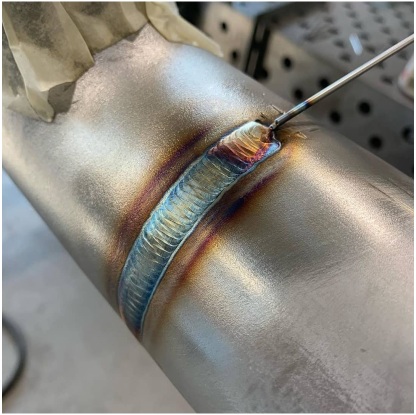
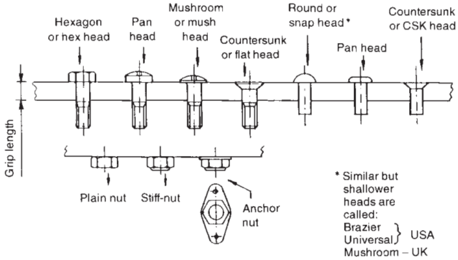


Figure from [16]

3.2. Bolted and Riveted Joints

3. Joining Technology

- Bolts, screws, rivets
- Riveting process:
  - Pop riveting: https://www.youtube.com/watch?v=u9EnPAgo8p4
  - Hot riveting: https://www.youtube.com/watch?v=5aTL0Jvrf4I
- Attaching thin plates to the frames, riveting/bolting (fastening in general) is the most appropriate
- An important consideration for fastening in general is **maintenance**



Types of fasteners [1]

3.2. Bolted and Riveted Joints

3. Joining Technology

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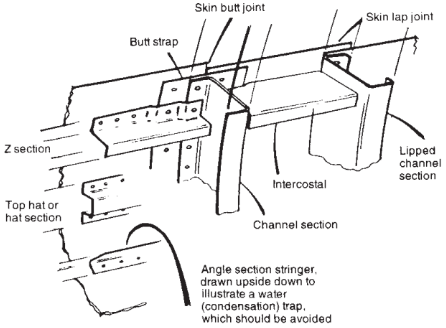


Detail on skin attachment to frame [1]

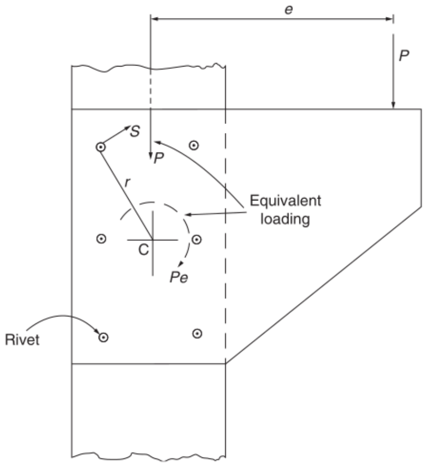
3.3. Strength of a bolted joint

3. Joining Technology

- Considering the strength of a loaded jointed system, we have to **compute the loads on each fastener individually and check for failure**

Bolt-Load Distribution

$$S = \frac{Pe}{\sum r^2} r$$



Eccentrically loaded joint [2]

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