

AS3020: Aerospace Structures

Module 1: Design of Aircrafts

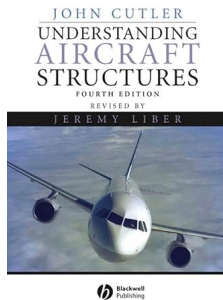
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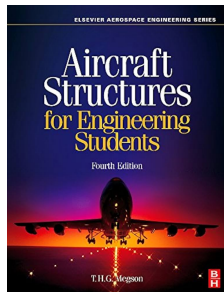
August 6, 2024

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 - Bolted and Riveted Joints
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*Chapters 1-5, 7, 9
in Cutler [1]*



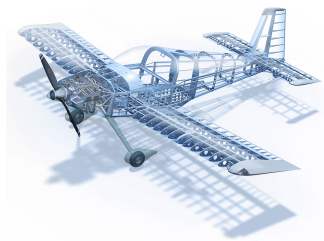
*Chapters 12-15
in Megson [2]*

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?



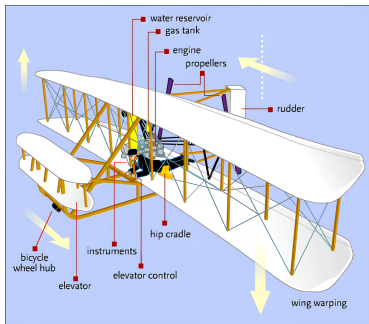
RV-14 Airframe [3]

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.

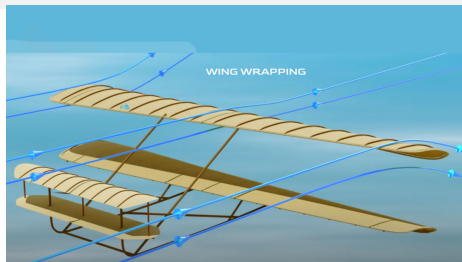
1.1. Wired Brace Construction: The Wright Flyer

Historical Overview

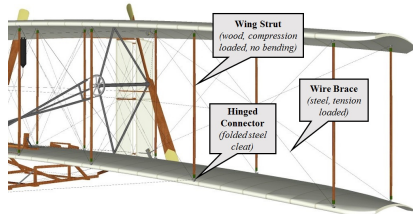


The Wright Flyer, 1903 [4]

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



The warping wing [5].



Wired brace construction [6]

1.2. Braced Fuselage Design

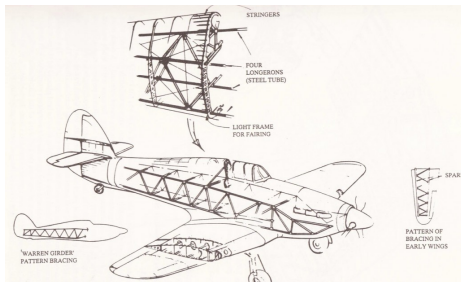
Historical Overview

- 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

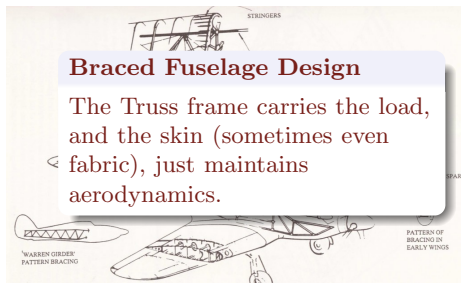
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Frame of the 1917 Sopwith Camel [7]

- **Warren trusses** replaced wire braces (“Warren-girder” design)



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

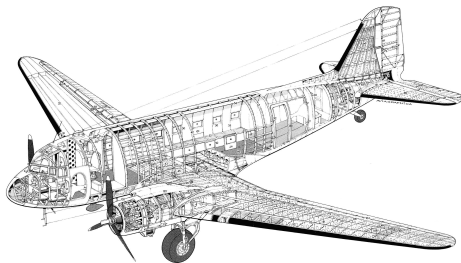
Historical Overview

- 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

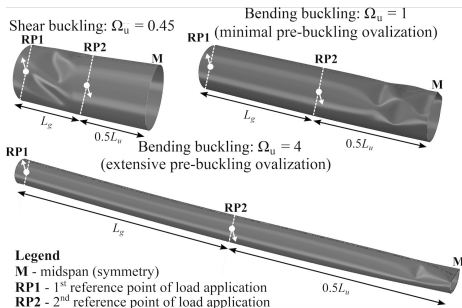


Douglas DC-3 (1933) [10]

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.



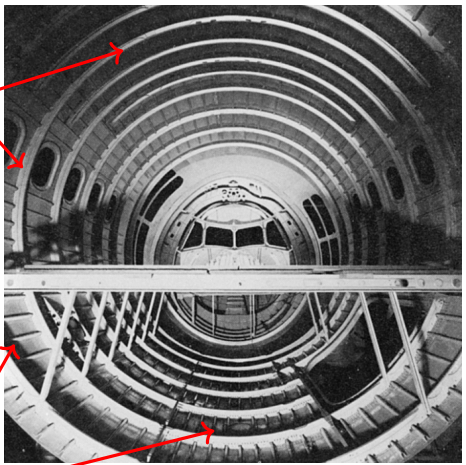
Shear buckling [12]

1.3. Semi-Monocoque Design

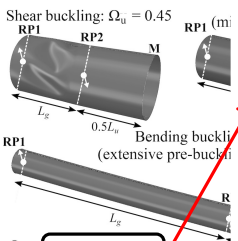
Historical Overview

- Thin-walled str
- Buckling becom
- under compress

Frames/Rings



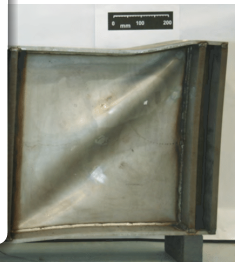
...ensical thing to do
 ...the skin into
 ...ler elements
 ...means of
 ...olding the
 ...ndicular to section
 ...longitudinally.



Stringers

Legend:
 M - moment
 RP1 - 1st reference point of load application
 RP2 - 2nd reference point of load application

Insides of a fuselage [2]

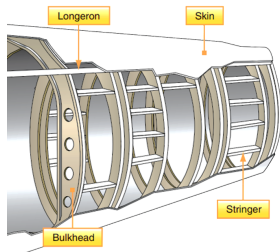


Thin-walled cylinder [11]

Shear buckling [12]

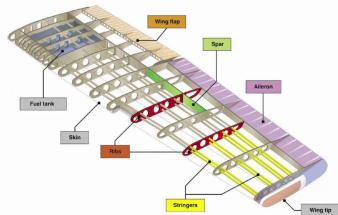
1.3. Semi-Monocoque Design

The Fuselage



Structural members in a fuselage [13]

The Wing



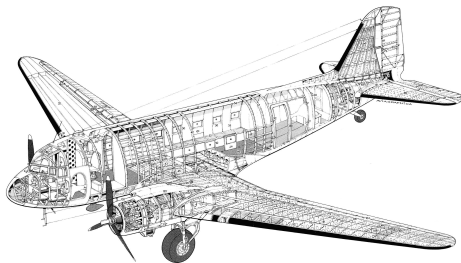
Structural members in a wing-box [14]

- 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]

1.3. Semi-Monocoque Design

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Sandwich structures

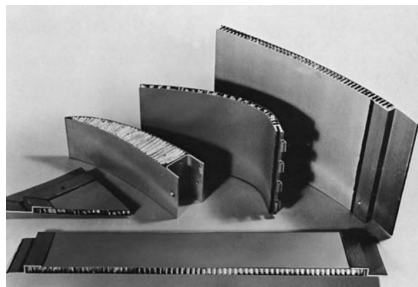


Figure from [1]

1.3. Semi-Monocoque Design

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Composite Materials

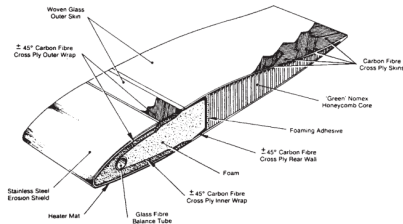


Figure from [2]

1. Historical Overview

Design Overview

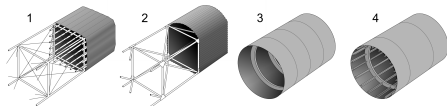


Figure from [3]

The “converged” aircraft

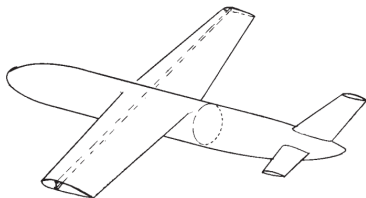


Figure from [1]

Parts of an aircraft

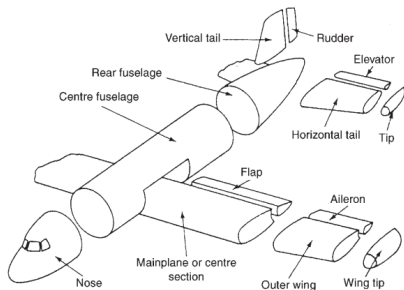


Figure from [2]

1. Historical Overview

Design Overview

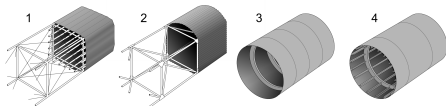


Figure from [3]

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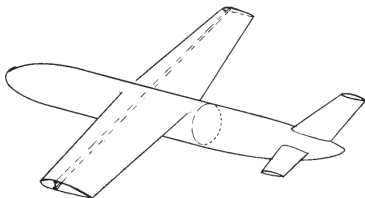


Figure from [1]

Parts of an aircraft

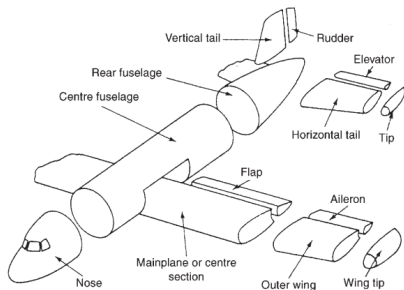


Figure from [2]

- **“Wings”**: Mainplane, tailplane

1. Historical Overview

Design Overview

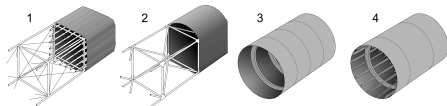


Figure from [3]

The “converged” aircraft

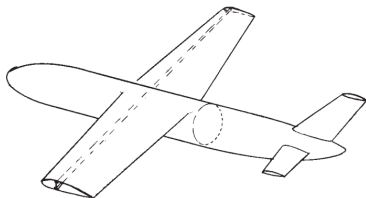


Figure from [1]

Parts of an aircraft High Lift Devices

High-lift devices

(a) Cruising

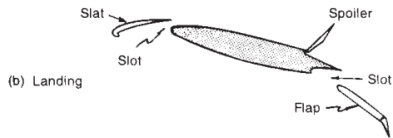


Figure from [1]

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

1. Historical Overview

Design Overview Dimensions of an Aircraft

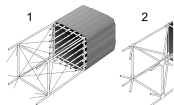
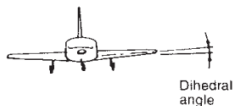
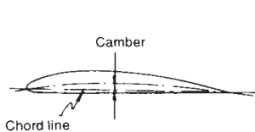


Fig 1.1



The “convergence”



Fig 1.2

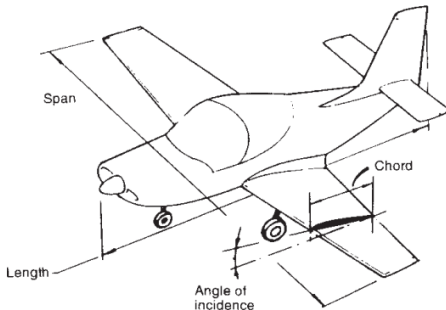
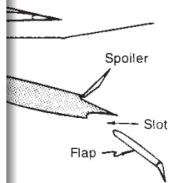


Figure from [1]



[1]

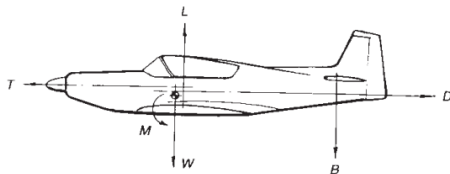
plane,

es: flaps,

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)

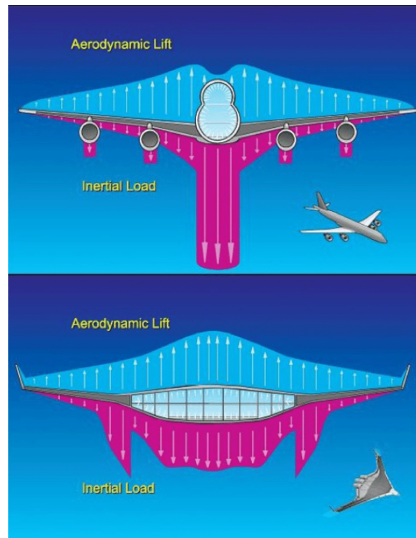
M = Moment (about the aerodynamic centre)

T = Thrust

D = Drag

B = Balancing load (from the tailplane)

Note this diagram is similar to Fig. 4.4 but shows the moment mentioned in Section 4.3



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

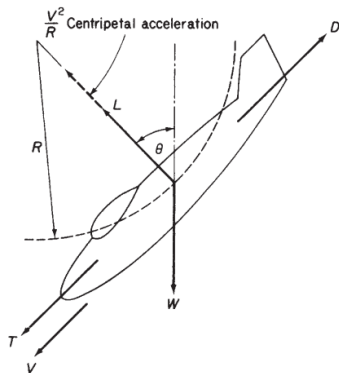


Figure from [2]

Banking

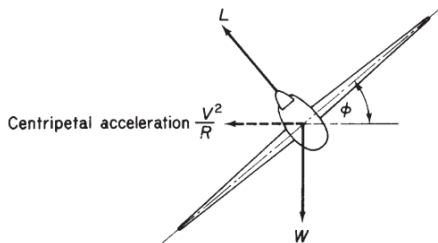
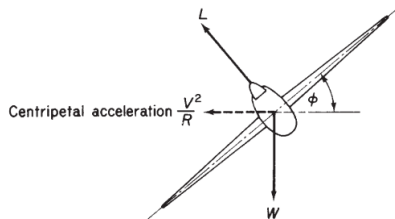
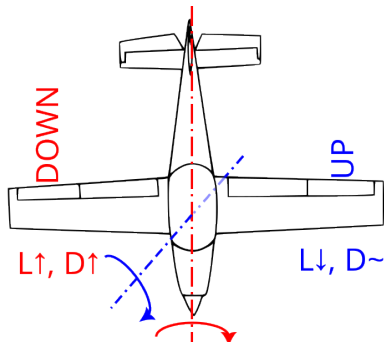


Figure from [2]

2.2. Loads During Maneuvers: “Pure Roll” Banking

2. Aircraft Loads

Let us consider the pure roll condition for banking the aircraft.



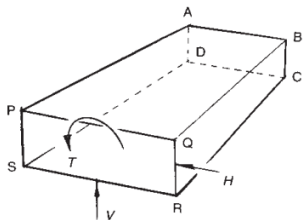
Figures from [2, 16]

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 (-)			Type of load in total
	due to V	due to H	due to T	
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

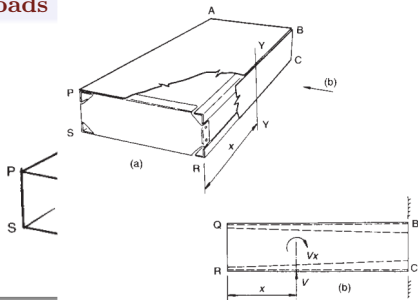
2.3. Load-based Design

2. Aircraft Loads

Content from sec. 5.6.4 in [1]

Design modifications due to shear-load V

Loads



- 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**.

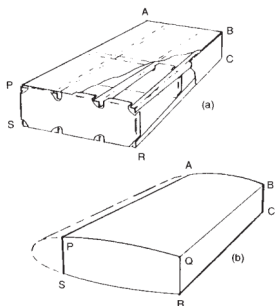
2.3. Load-based Design

2. Aircraft Loads

Design modifications due to shear H and Torsion T

Content

Loads



- 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

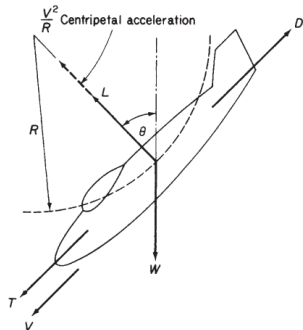
2. Aircraft Loads

- 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.

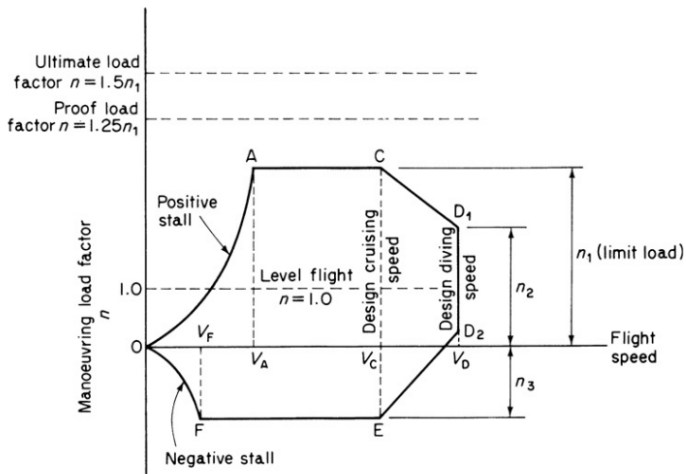


Loads During Steady Pull-Out Maneuver [2]

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



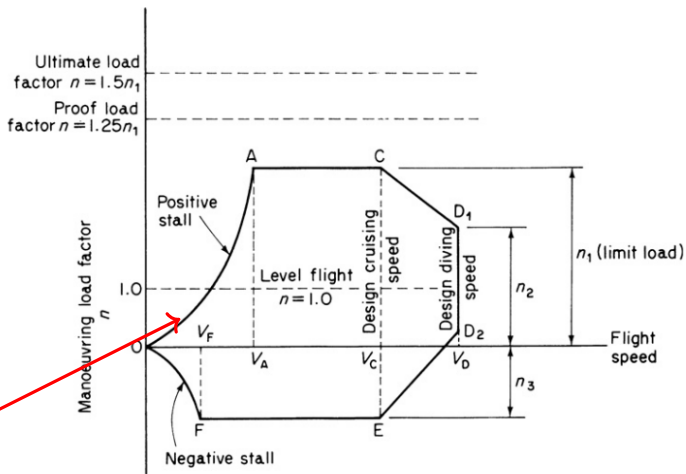
Flight Envelope from [2]

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



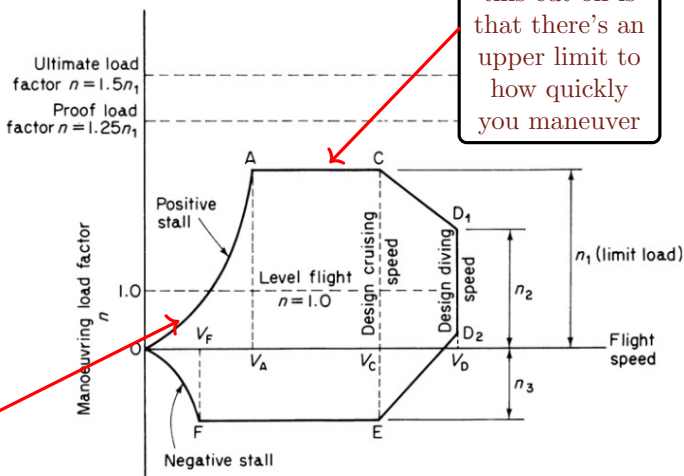
Flight Envelope from [2]

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 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! ;)

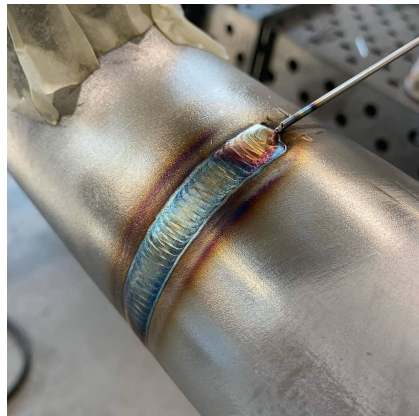
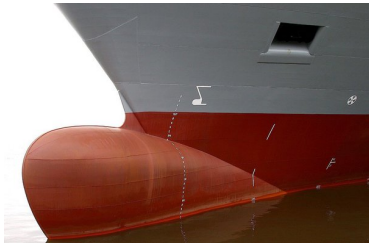
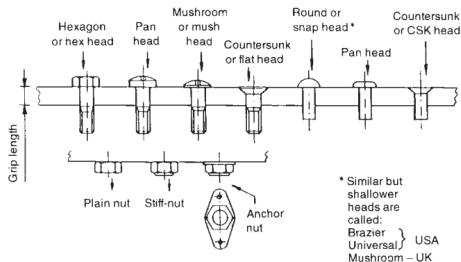


Figure from [17]

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**

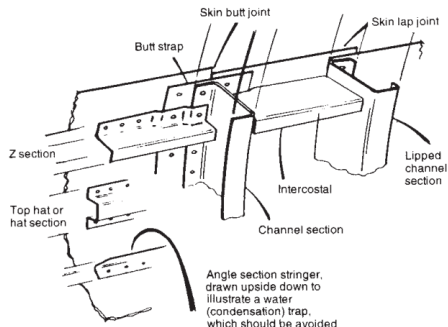


Types of fasteners [1]

3.2. Bolted and Riveted Joints

3. Joining Technology

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Detail on skin attachment to frame [1]

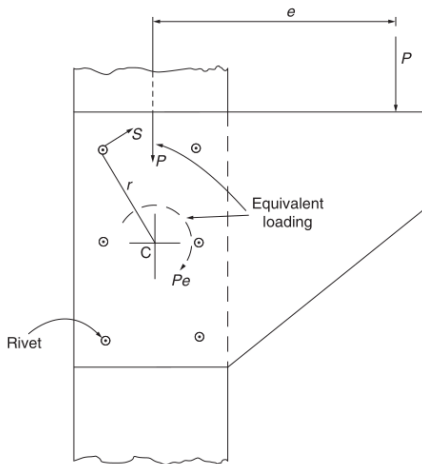
3.3. Strength of a bolted joint

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]

References I

- [1] J. Cutler. *Understanding Aircraft Structures*, Wiley, 2005. ISBN: 978-1-4051-2032-6 (cit. on pp. 2, 3, 5, 6, 11–18, 21–24, 29, 30).
- [2] T. H. G. Megson. *Aircraft Structures for Engineering Students*, Elsevier, 2013. ISBN: 978-0-08-096905-3 (cit. on pp. 2, 3, 8, 9, 11–17, 19, 20, 24–27, 31).
- [3] “Airframe”. *Wikipedia*, (June 2024). URL: <https://en.wikipedia.org/w/index.php?title=Airframe&oldid=1228362623> (visited on 08/05/2024) (cit. on pp. 3, 14–17).
- [4] *NOVA | Wright Brothers' Flying Machine | Pilot the 1903 Flyer (Non-Interactive) | PBS*. URL: <https://www.pbs.org/wgbh/nova/wright/flye-nf.html> (visited on 08/05/2024) (cit. on p. 4).
- [5] *History of First Flight*. URL: <https://www.lesics.com/history-of-first-flight.html> (visited on 08/05/2024) (cit. on p. 4).
- [6] *Flyer Fatality – Solution*. URL: <http://niquette.com/puzzles/flyerfts.html> (visited on 08/05/2024) (cit. on p. 4).

References II

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