Introduction to Aerospace Engineering

Lecture slides

Introduction to Aerospace Engineering

9 & 10. Structural concepts

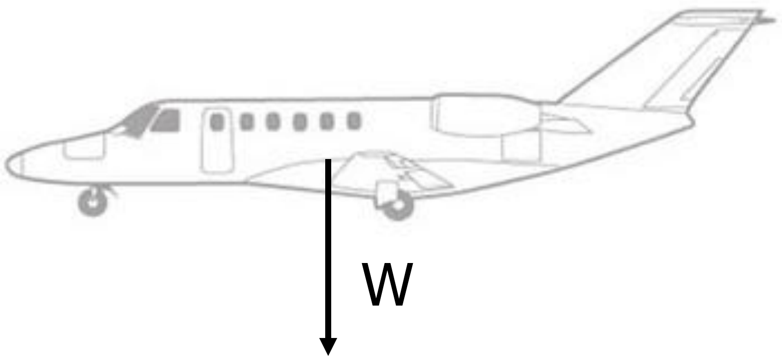
J. Sinke

9&10

Structural concepts

Lecture Notes: ***Special Handout****; See Black Board*

Do you Remember
Weight



- Aircraft Empty Weight
  - Structure: Wing - Horizontal Tail - Vertical Tail – Fuselage - Landing Gear - Surface Controls - Propulsion System – APU
  - Systems: Instruments and Navigation - Hydraulics and Pneumatics - Electrical System – Electronics – Furnishings - Air Conditioning and Anti-Ice
  - Crew and Flight Attendants
  - Operating Items
- Payload
- Fuel

→ One should minimize the weight of *aircraft structures* & systems, and Fuel, in order to maximize Payload

Contents

What is a structure?

How does it perform?

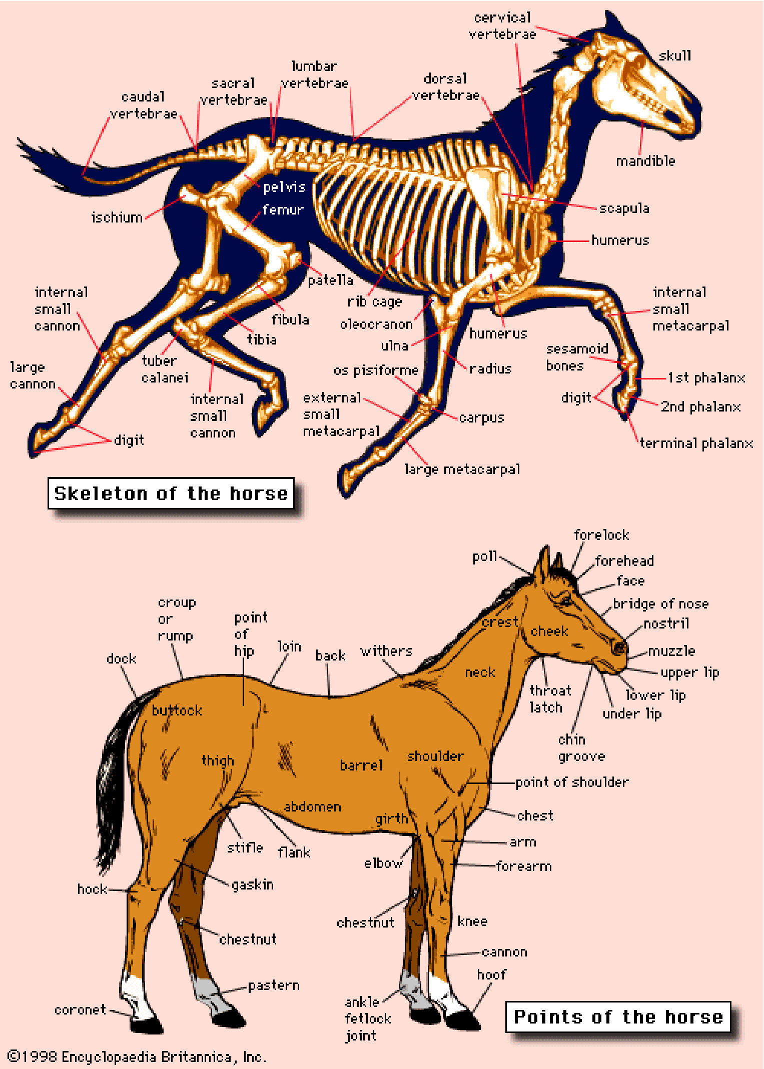
The beam as simple principle structural element ("From truss to beam")

Some loads on aircraft structures

What is a structure?

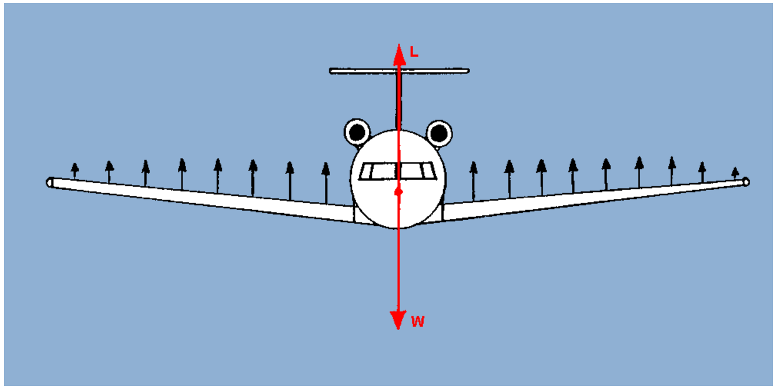
Like a skeleton – features:

- Many elements (bones)
- Several functions
- Coherence
- Joints
- Different materials



What are the functions of a structure?

- ✓ Carrying of the LOADS (dominant)
- ✓ Protection
- ✓ Framework to attach other systems

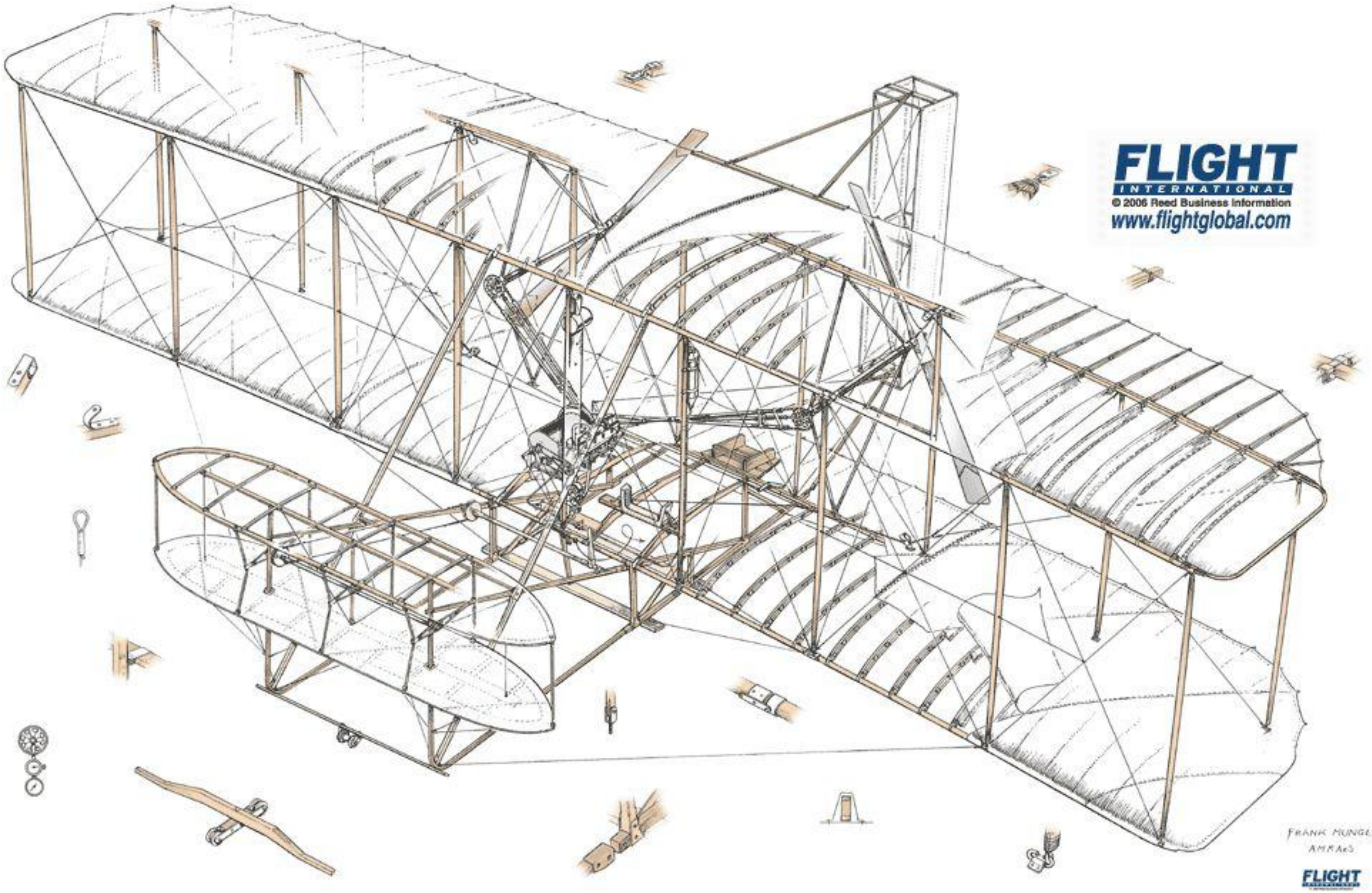


Historical development of structures

Relationship between type of structure and material

Period	*Type structure*	*Materials*
1903-1910	*Cables, lath, fabric*	Steel, wood, linen
1910-1920	*Truss, spars ribs, fabric*	Steel rods, tubes
1920-1940	*Load carrying wooden wings*	wood: triplex
1932-today	Stiffened shell structures	Aluminum
1948-today	Pressure cabin	Improved Al-alloys
±1980-today	Composite structures	Carbon fibers

What were the first composite applications? When?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Biplane vs. Monoplane

Most aircraft in early years of aviation were ***Biplanes***

+ structural → ***wings connected***
  box girder by wires & struts
+ maneuverability → more direct control (thin light weight wings)
  - wings affect each other
  - higher drag
  - limited increase in lift (20%) w.r.t. monoplane

Monoplane vs. Biplane

In first years: limited models

Louis Bleriot (1909) – Channel

→ Wing structure: single spar/tube

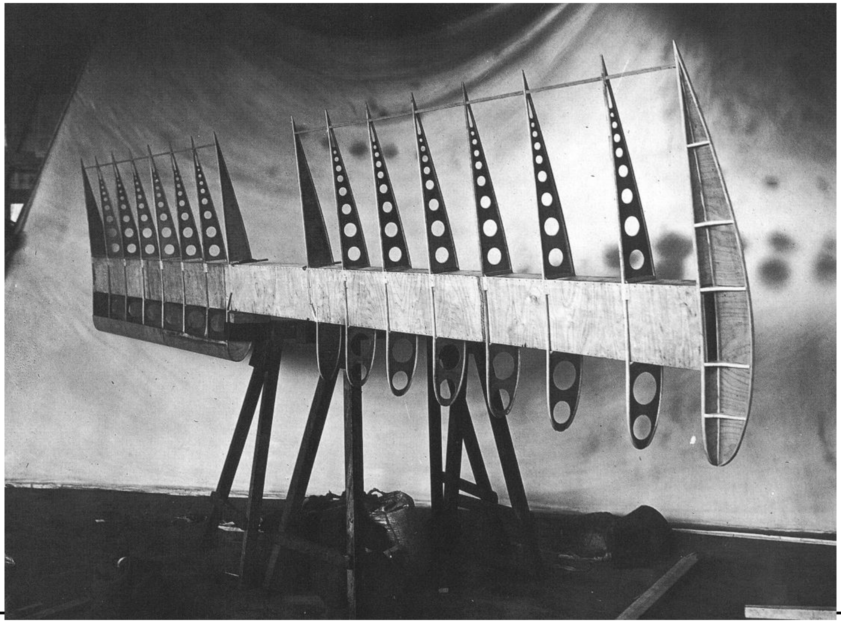
→ ***Skin not loaded!***

→ Later cantilever beam/metal structure

Wing position: low, center, high, parasol

What loads?

Wing Spar
with ribs



1924: The Fokker F VII

F.VIIb/3m Specifations

Length:	14.60 m
Wing span:	21.70 m
Height:	3.90 m
Empty weight:	3,050 kg
Max take-off weight:	5,200 kg
Cruise speed:	170 km/h
Engines:	300 hp Wright J-5 Whirlwind (3x)
Accommodation:	8 passengers.

Fokker F VII

Period 1924 (F VII) till early 1930's
Decline started in America:
- crash in TWA in 1931 (football coach)
- first metal aircraft

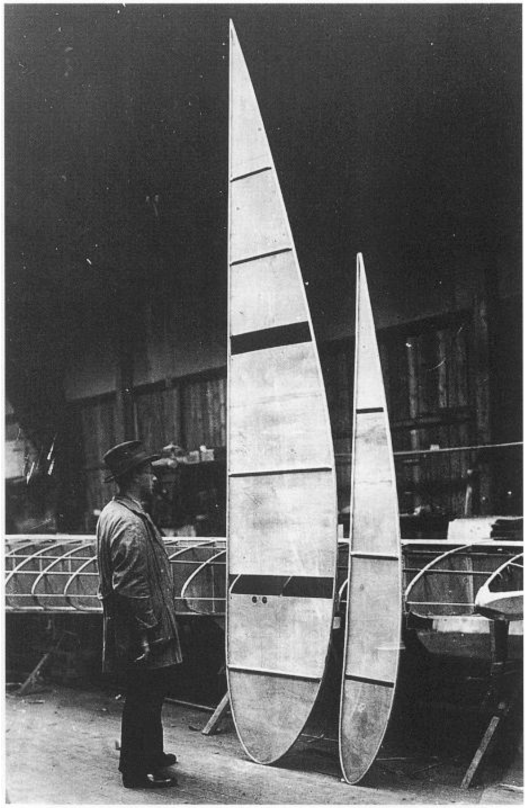
Large number
In use with many airlines

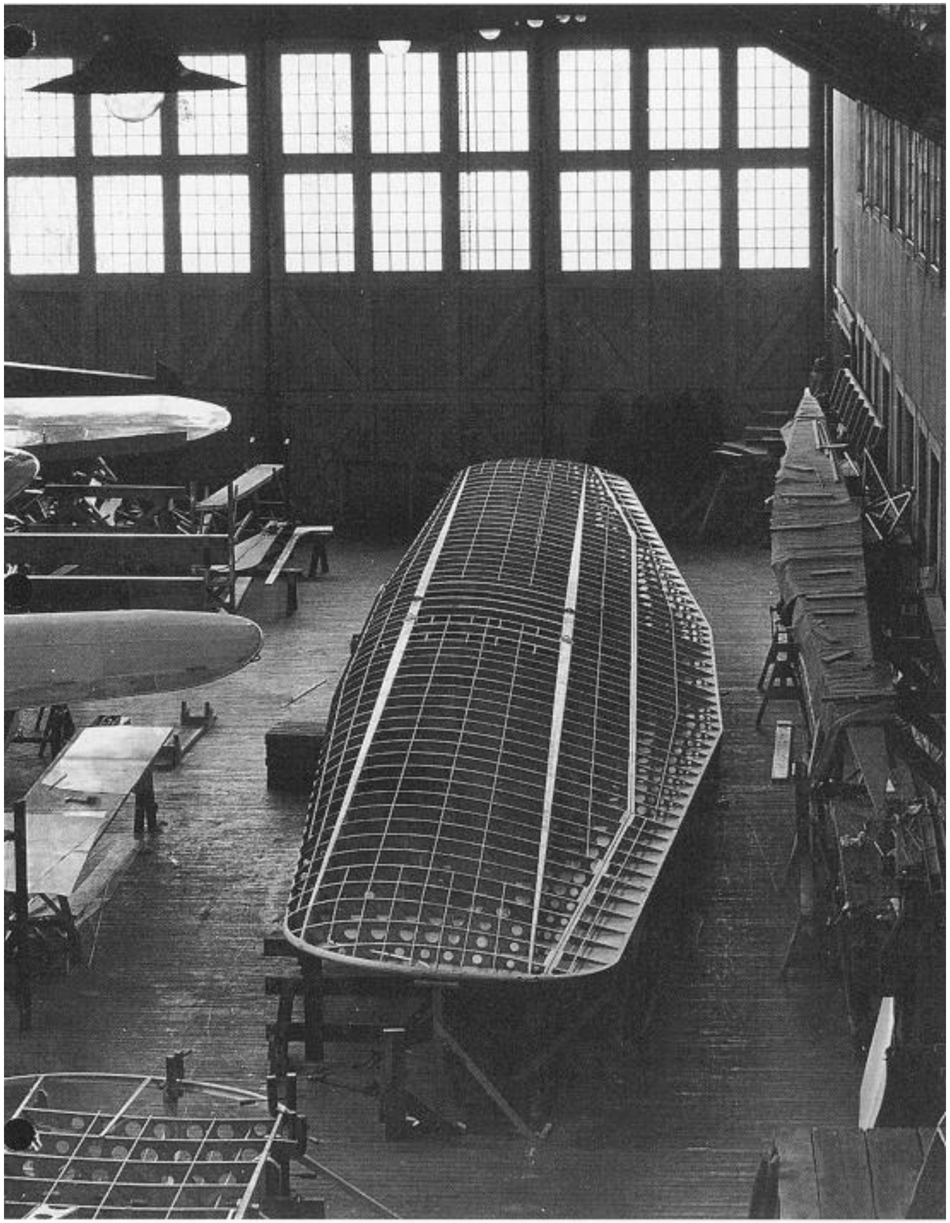
Features:

- ***monoplane***
- ***wooden wing structure***
- ***truss structure + canvas "skin"***

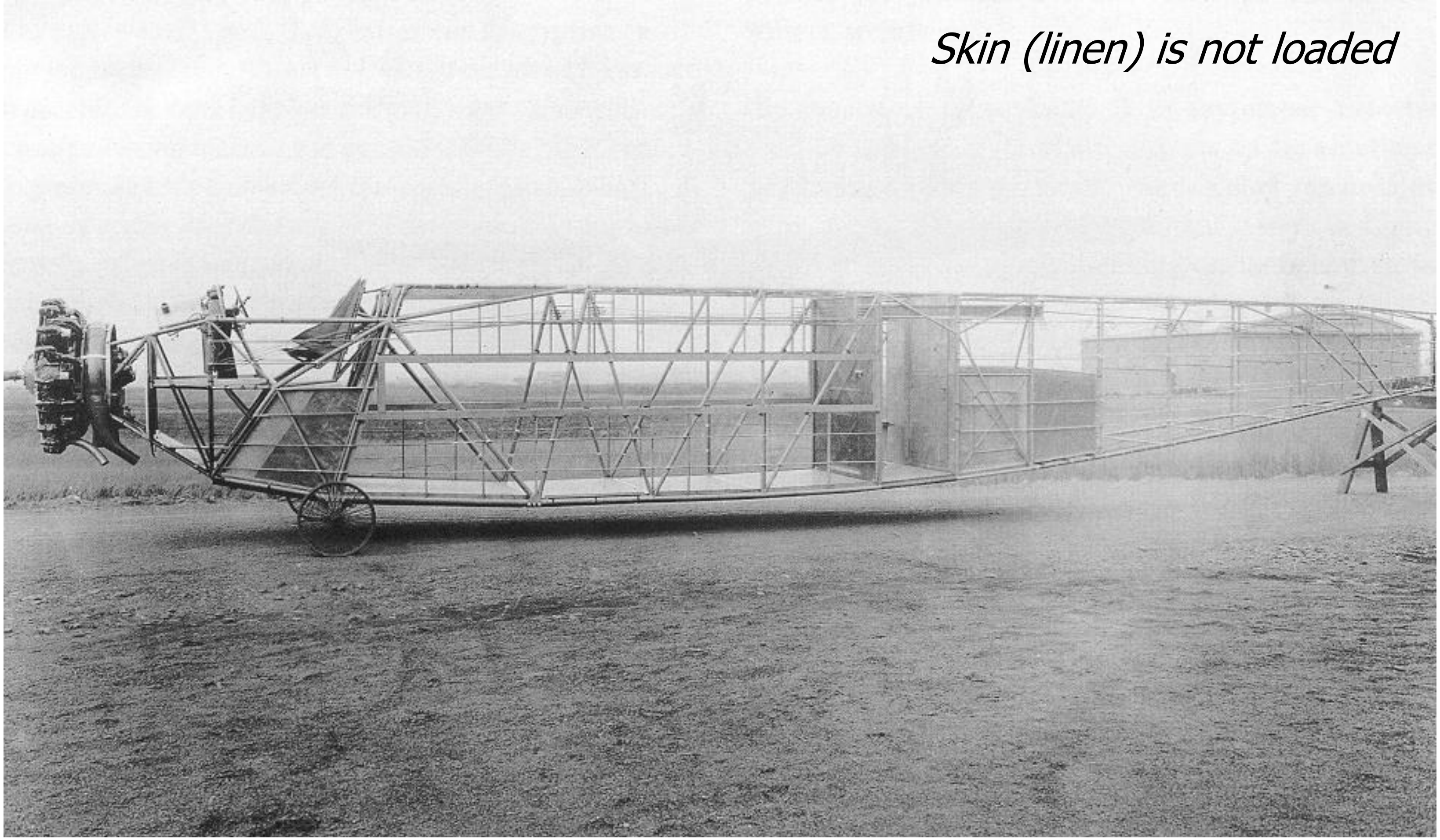
Wooden wing structure

Craftsmanship (carpenters)
Loaded triplex (wood) skin





Fuselage: Truss structure

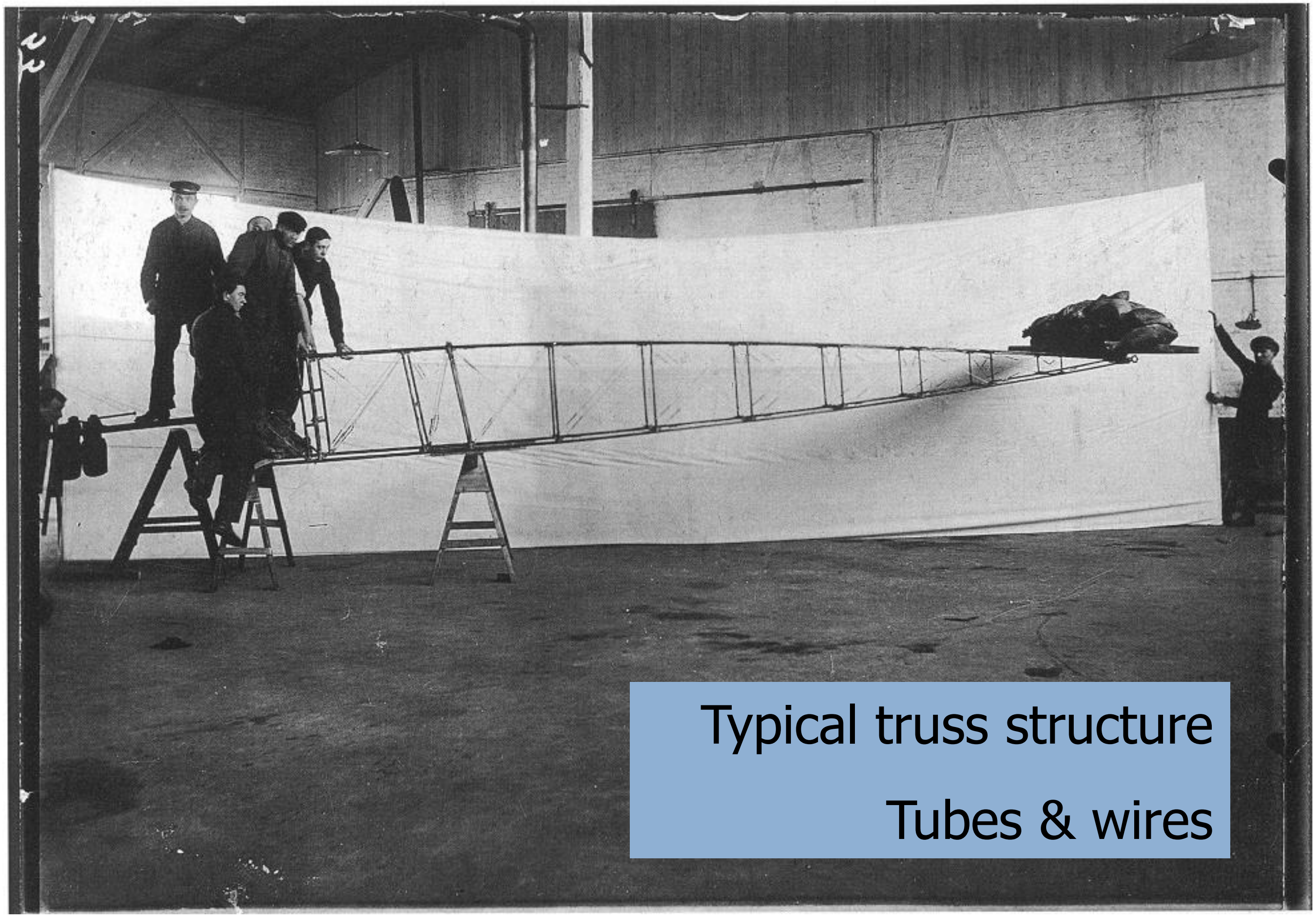


Skin (linen) is not loaded

Wooden structures – testing a spar

What kind of test is this? What property is determined?

Truss structure – testing



Typical truss structure

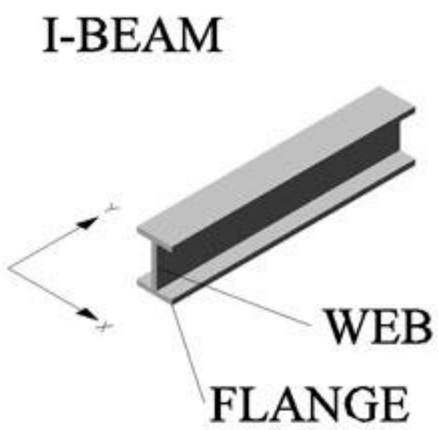
Tubes & wires

Testing a wing structure (Bombardier Cseries)

Anatomy of a structure

- A structure is an Assembly of Structural Elements
- Each element participates in (some of) the functions of the structure
- Structure has coherence
- Structural elements are joined together

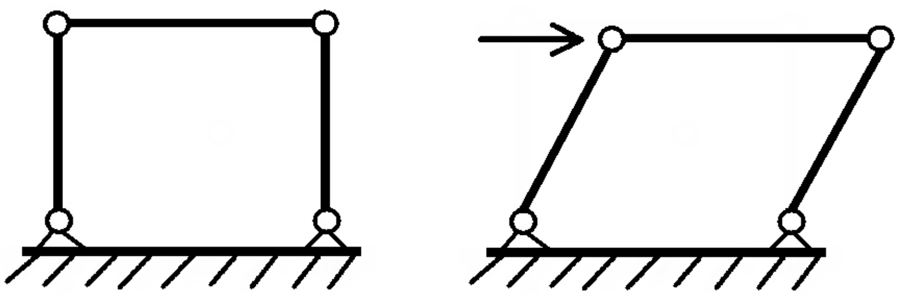
- Most structural elements are ***derivatives*** of a beam

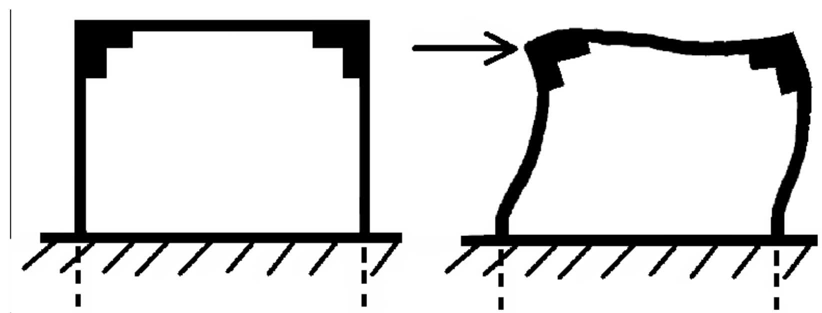


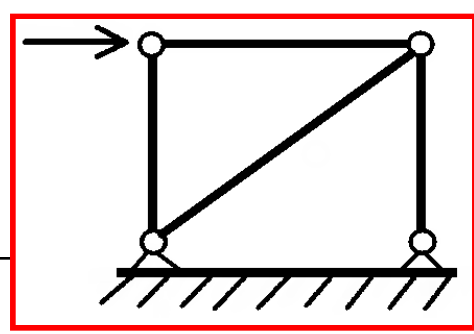
From Truss to Beam

In the beginning of flight, aircraft structures were truss structures.
For aerodynamic reasons they were closed with fabric.

The basic truss is very simple, elegant and light weight

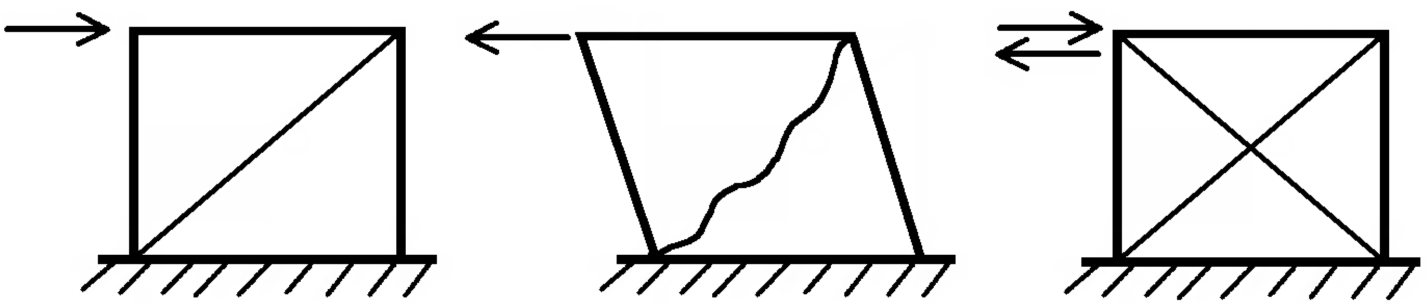




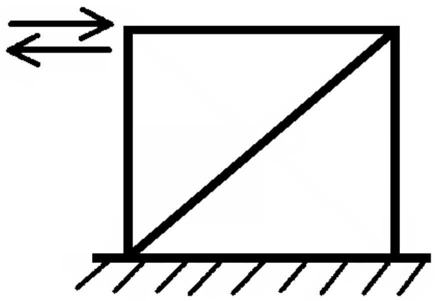


From Truss to Beam

The diagonal element can also be a ***cable***.
A cable can not be loaded in compression.
So two cables are necessary.

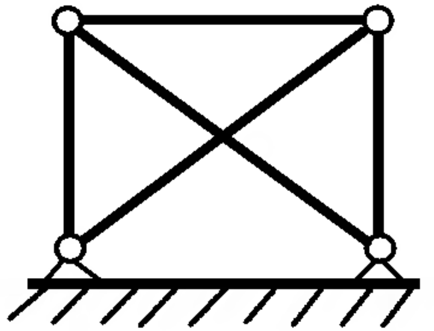


One cable can be replaced by one ***rod***.
Rods can be loaded both in
tension and compression.

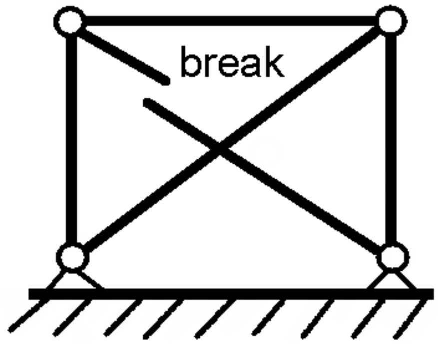


From Truss to Beam

What happens when two diagonal rods are used?
The structure becomes:
- more difficult to assemble (no hinge at crossing),
- more difficult to calculate,
- heavier ? (see next slide)



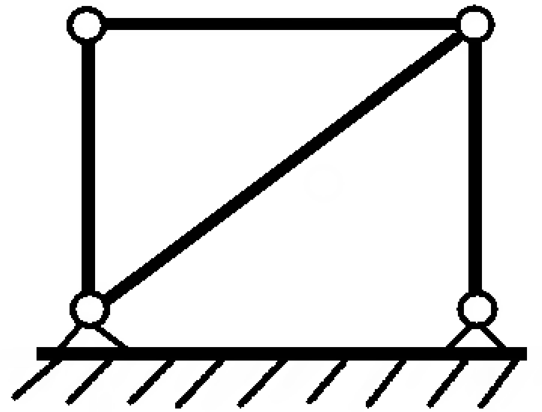
There is one advantage however…



The structure has some "reserve".
One rod may fail - ***fail safe structure***

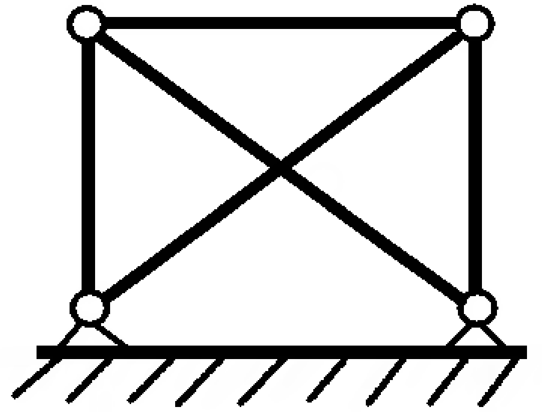
From Truss to Beam

Safe Life



Each element strong enough to stay intact for the entire life cycle

Fail Safe

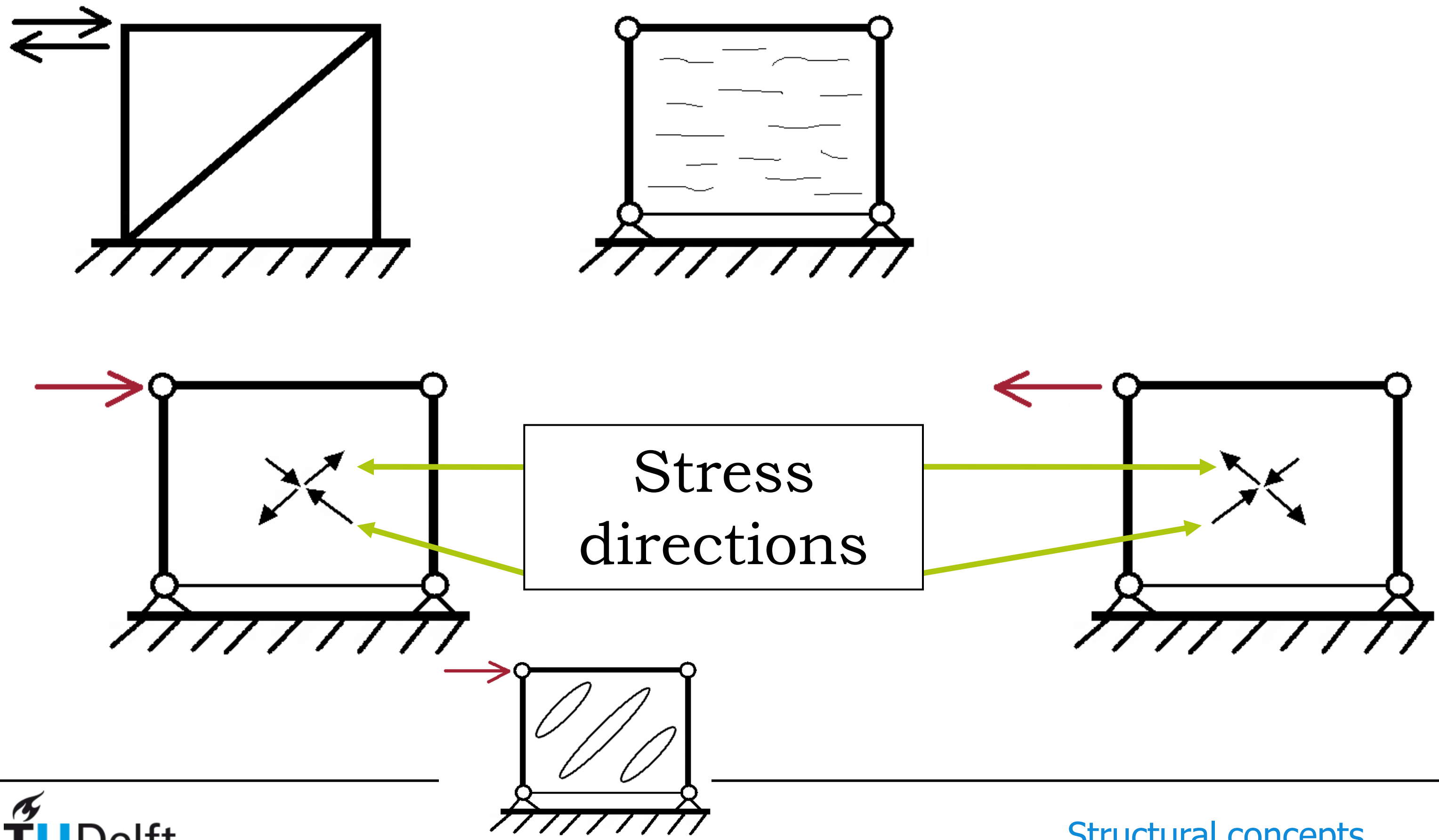


One element may fail: other elements strong enough to stay intact for limited time; inspection required!!

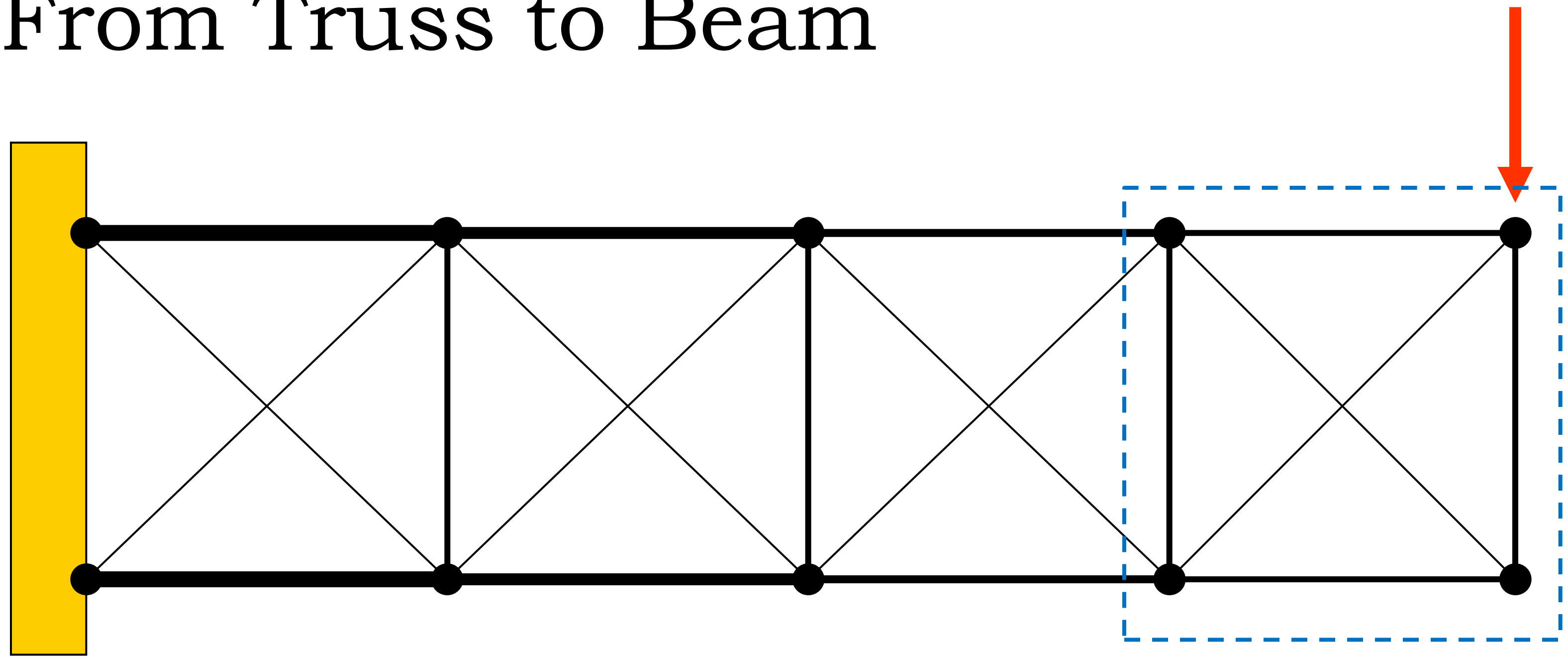
Which option is lighter??

From Truss to Beam

The rod can be replaced by a thin sheet or skin.



From Truss to Beam



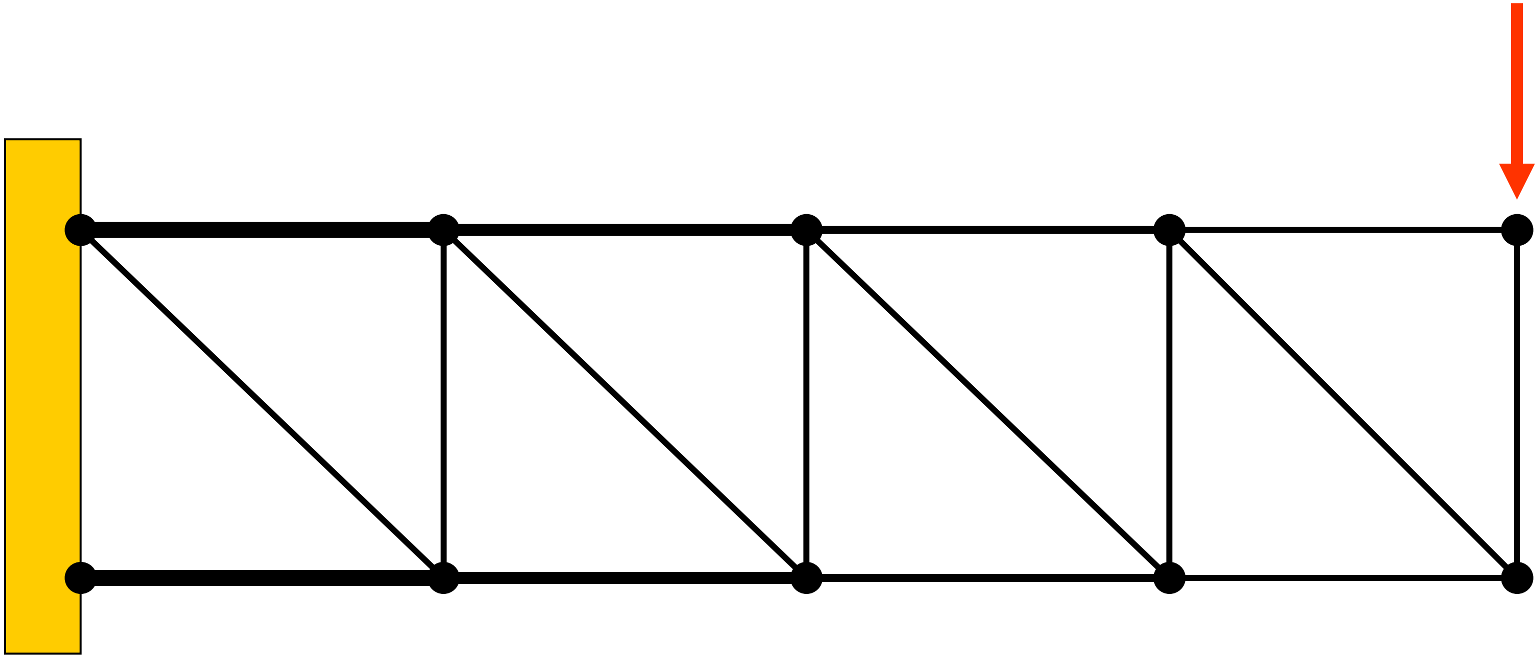
"Wire-braced" structure

Combination of rods and wires

Increasing thickness of the rods to the left – *Why?*

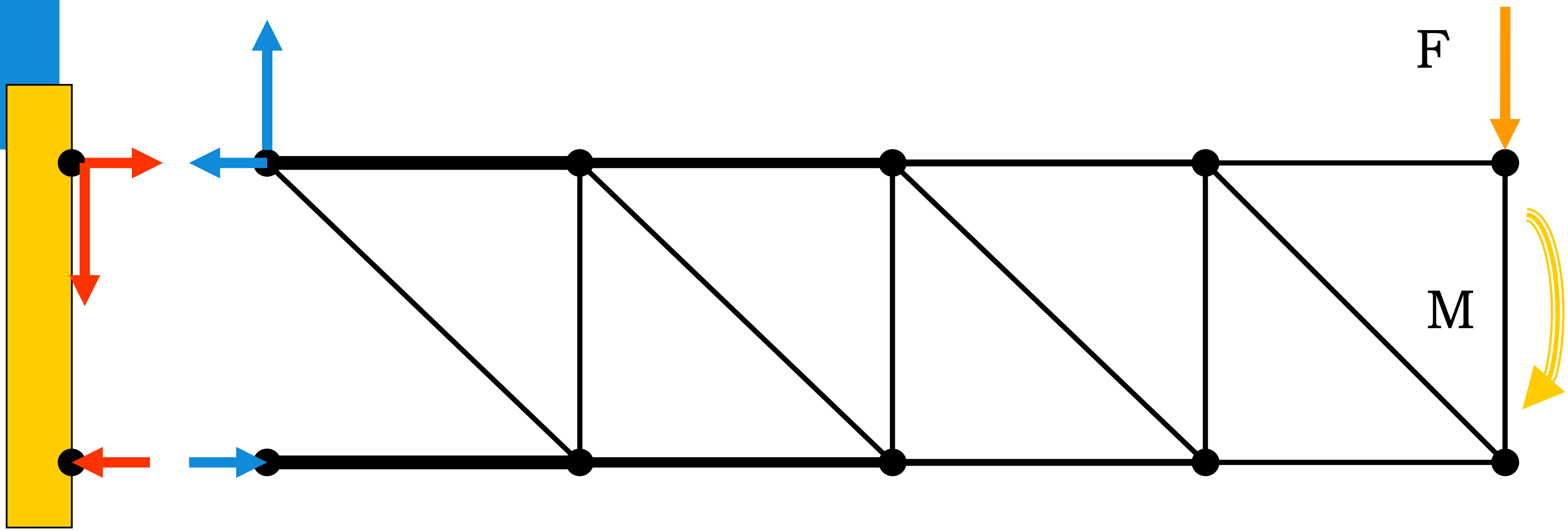
This is not true for the vertical rods and wires – *Why not?*

From Truss to Beam



Truss made of rods only

From Truss to Beam



External Force F

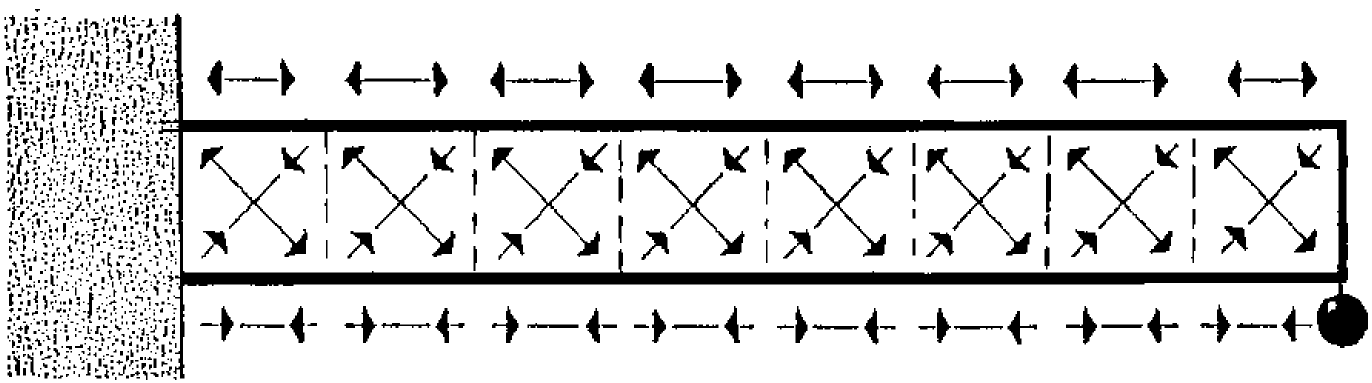
Induces Bending moment M

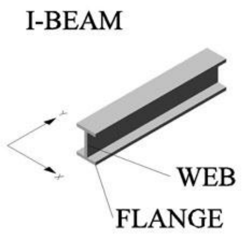
Truss applies force to the supports (red arrows)

Support reacts on Truss for equilibrium (blue arrows)

From Truss to Beam

- Truss can be replaced by sheet metal
- Web plate instead of diagonal tubes
  - Web plate – shear forces; girders – tension and compression forces

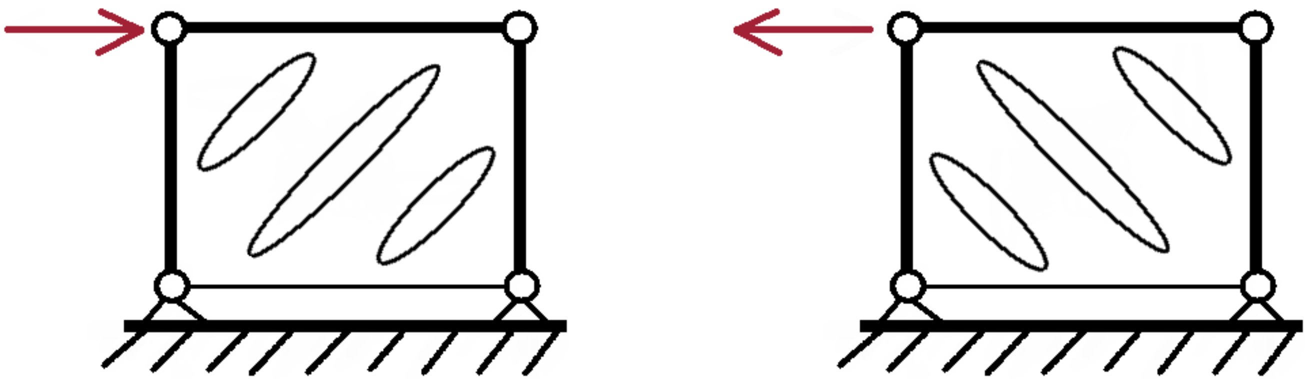




- Simplified:

From Truss to Beam

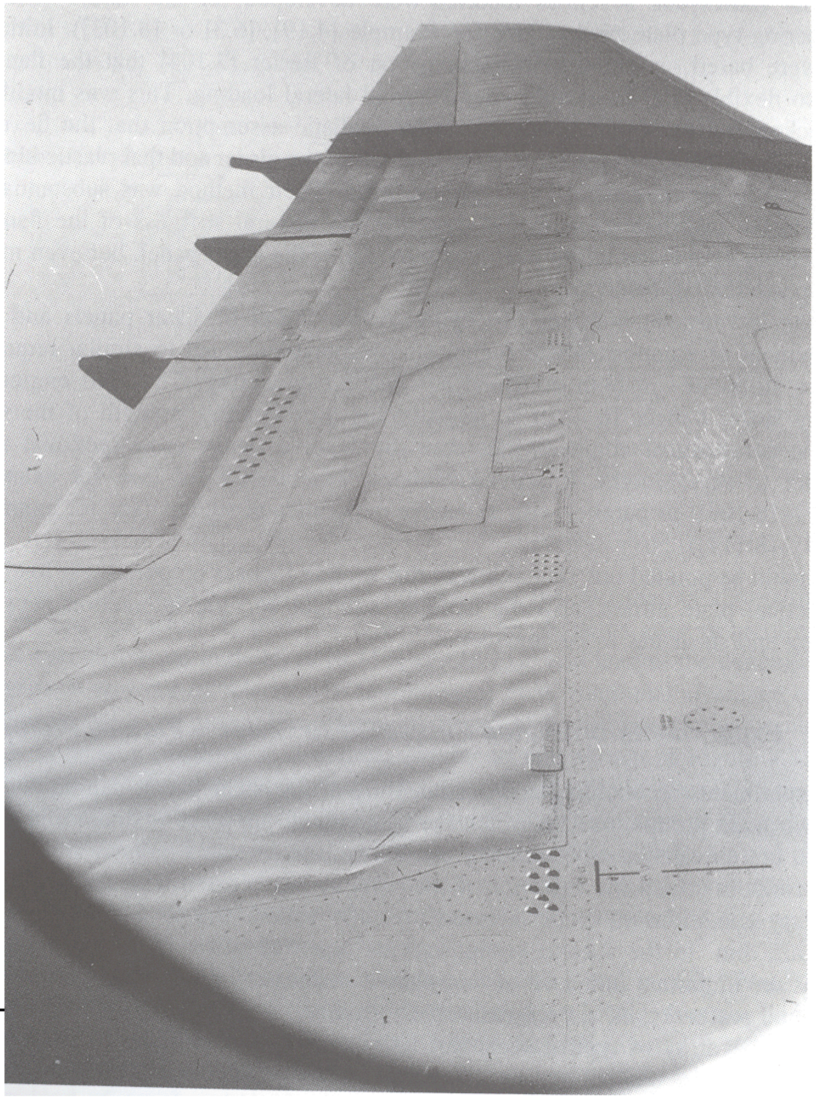
When applying high forces on the structure, buckling starts.
Compression forces cause local buckling of sheet



Elastic buckling is no Failure!

Only reduced compression load carrying capabilities.
Tensile forces are fully carried.

From Truss to Beam

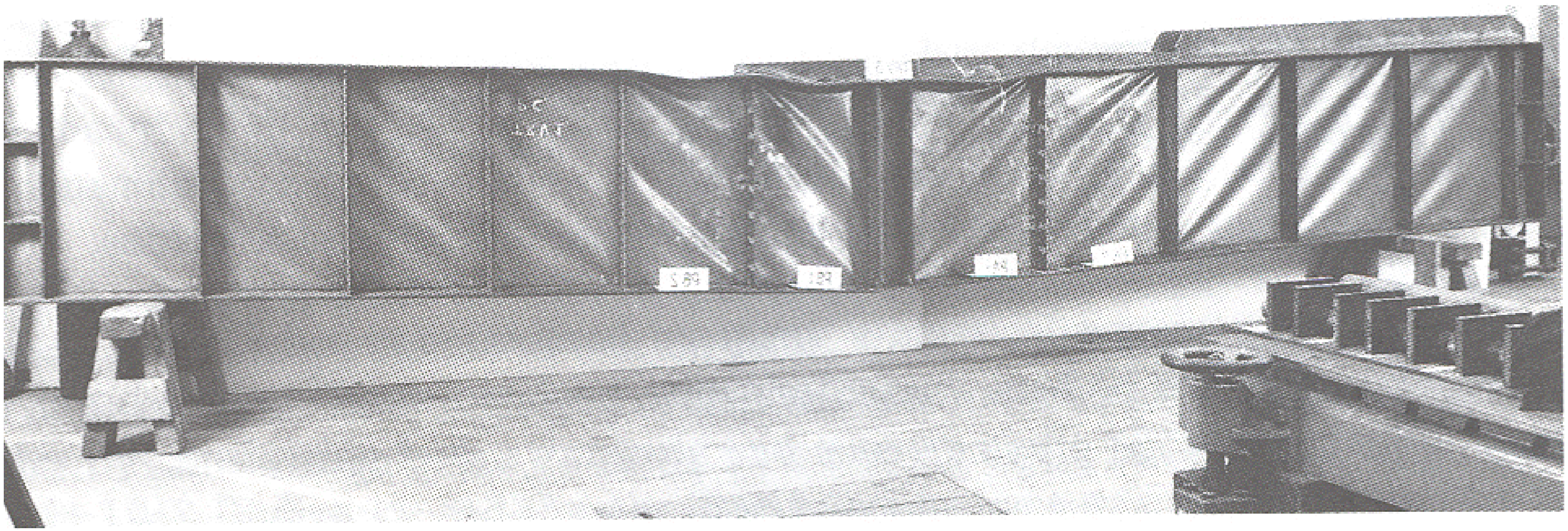


Skin buckling
due to
shear
loads

From Truss to Beam

This is an example of ***plastic*** buckling = Failure!!

Could you explain the waviness in the upper girder?



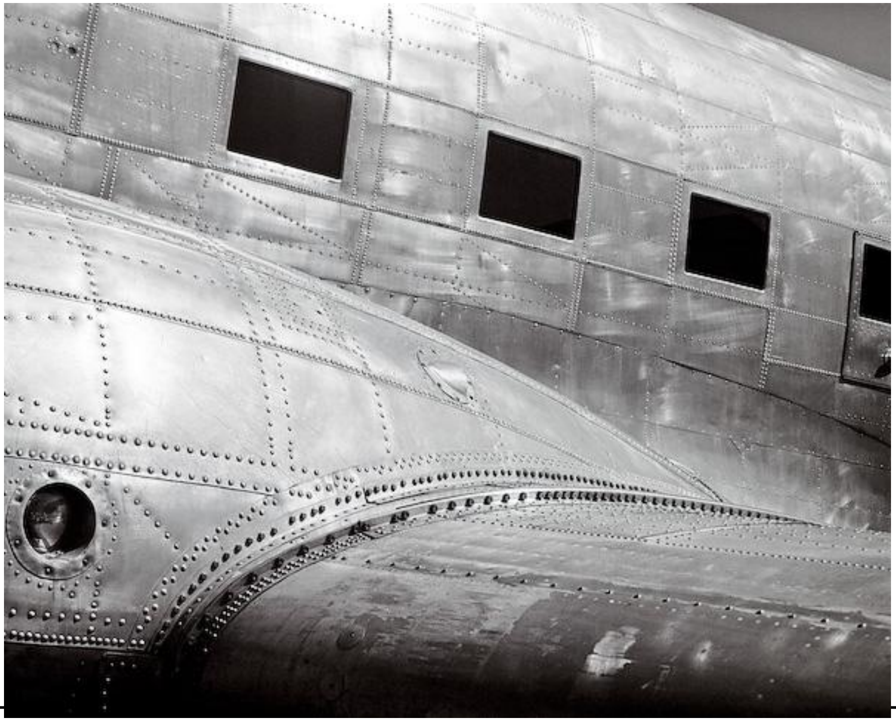
Historical development of airframes

Relationship between type of structure and material

Period	*Type structure*	*Materials*
1903-1910	Cables, lath, fabric	Steel, wood, linen
1910-1920	Truss, spars ribs, fabric	Steel rods, tubes
1920-1940	Load carrying wooden wings	wood: triplex
1932-today	*Stiffened shell structures*	Aluminum
1948-today	*Pressure cabin*	Improved Al-alloys
1988-today	*Composite primary structures*	Carbon fibers

DC-3

All metal aircraft
Aluminum in infancy
Riveting – non-countersunk rivets
No pressure cabin



Junkers 52 “Tante Ju” “Auntie Ju” (1932)

Prof. Hugo Junkers

1859-1935

Professor at Aachen

- metal cantilever wings

- all metal airplane

First steel, later Alu2024

- flying wing

- house arrest until death by nazis

Shell Structures

- Shell structure – load bearing thin sheet material (incl. ***stressed skin***), with stiffening elements
- Monocoque – structure consisting of only a load bearing skin

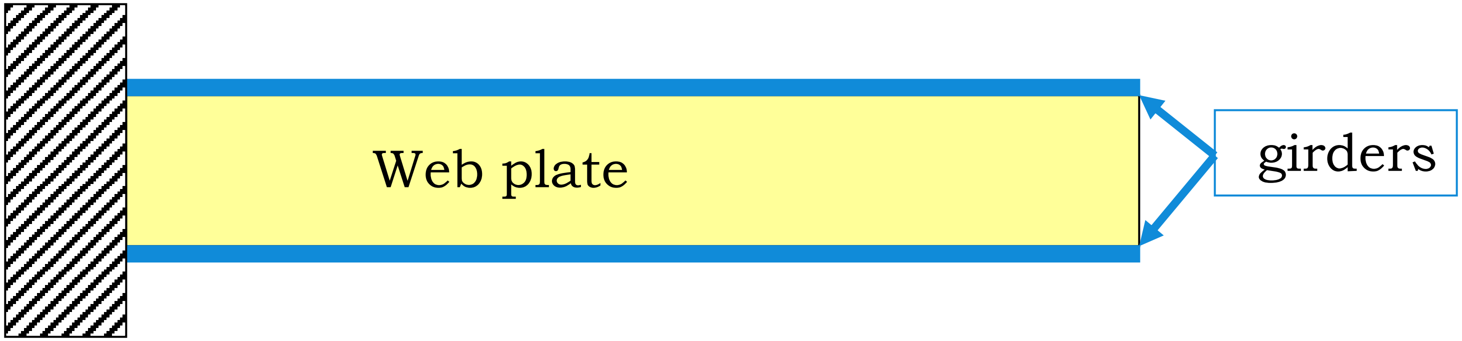
(Semi-monocoque – with some supporting elements)

Principal Structural Elements (PSE)

Principal Structural Element – primary structure – carry loads - *failure is/can be catastrophic*

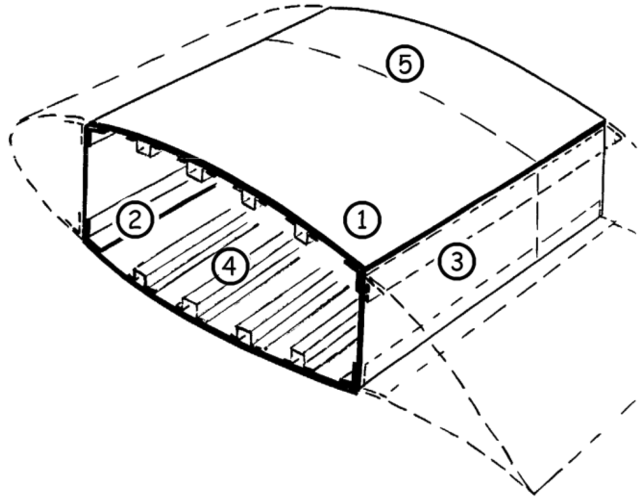
Non-principal structural elements – secondary structures *failure is not catastrophic* (e.g. fairings, some hatches)

Most Structural Elements are "beamlike" elements



PSE – metal

What Beam elements do you discover?



Spar

Stringers

Frame

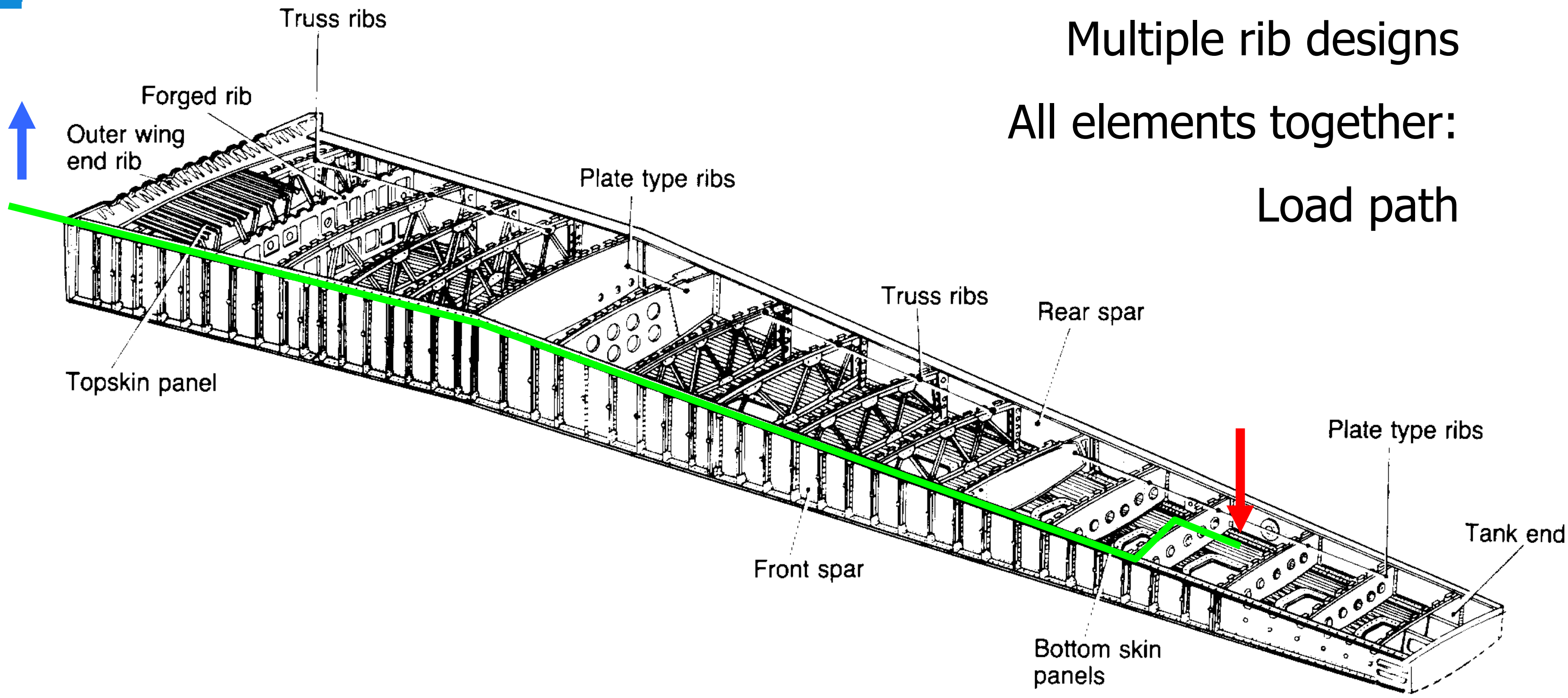
PSE – metal

Complex wingbox

Multiple rib designs

All elements together:

Load path



Structures, beams, etc.

Questions?

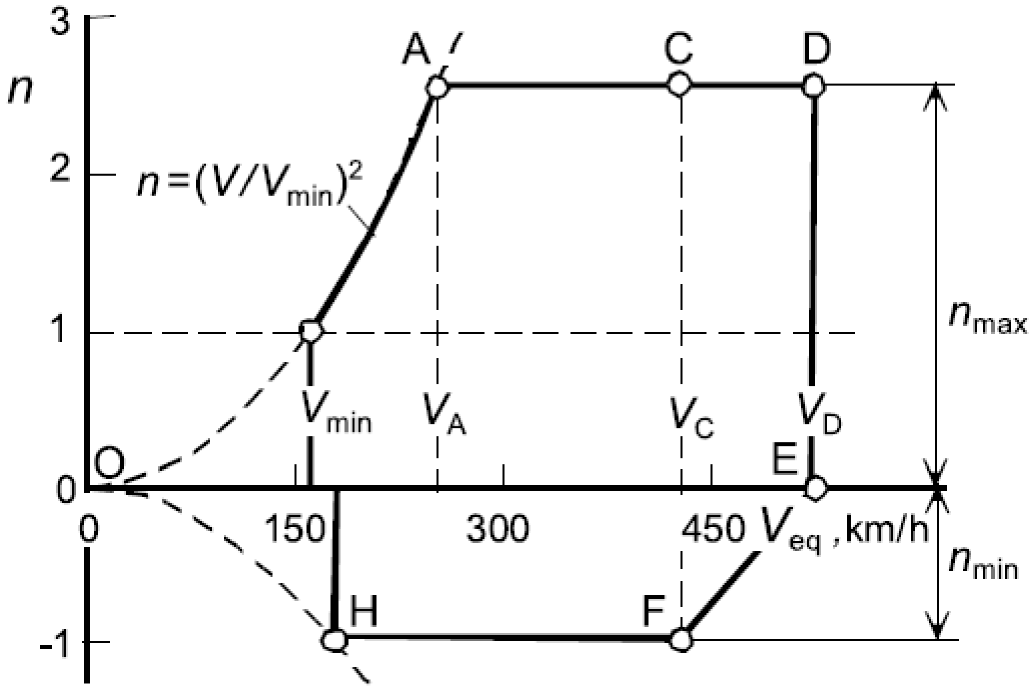
Loads – use of V-n diagram

Loads by Manoeuvre & Gusts

Load factor n

n = L / W

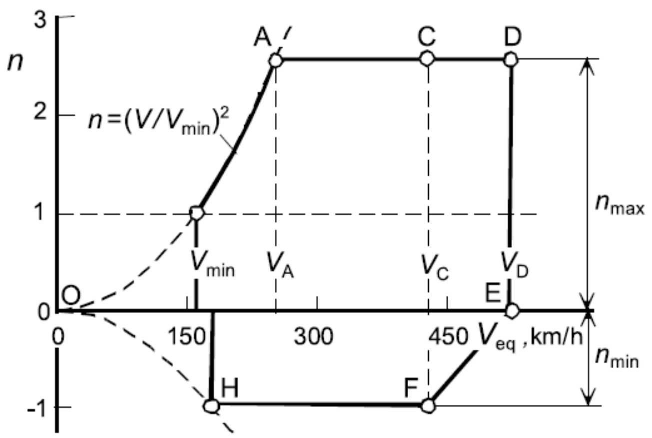
What is the load factor at cruise?



Loads

- Limit Load: Load experienced once in a lifetime
- No remaining damage allowed

- Ultimate load: limit load x safety factor
- Failure allowed after 3 seconds



Failure behavior materials

Within the limits of load diagram, Material should not fail

- Metal should not yield
- Composite should not damage

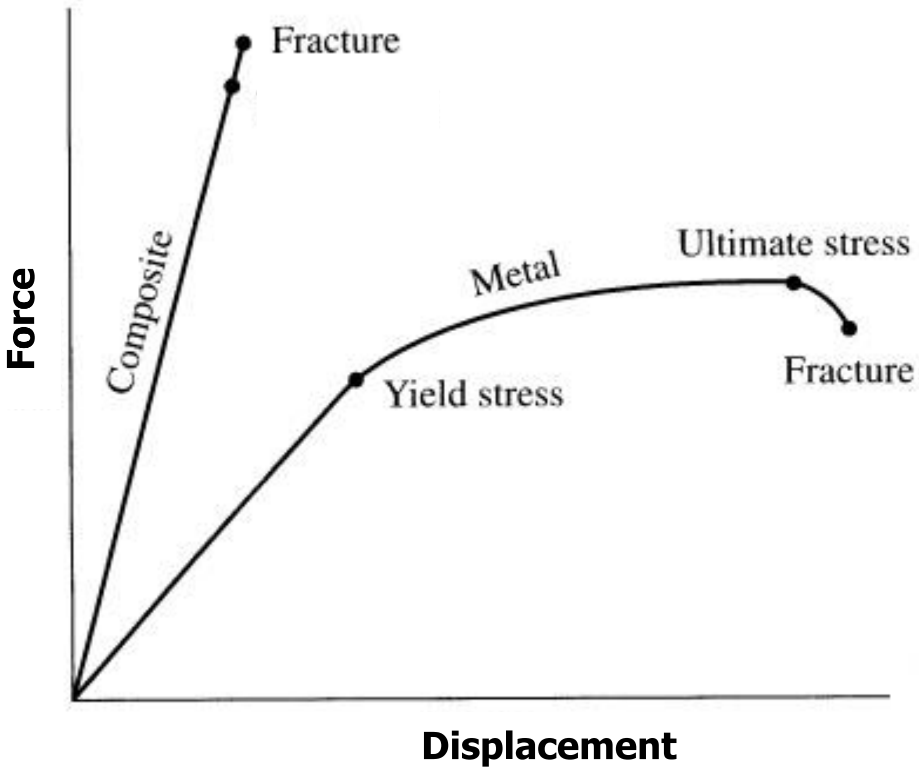
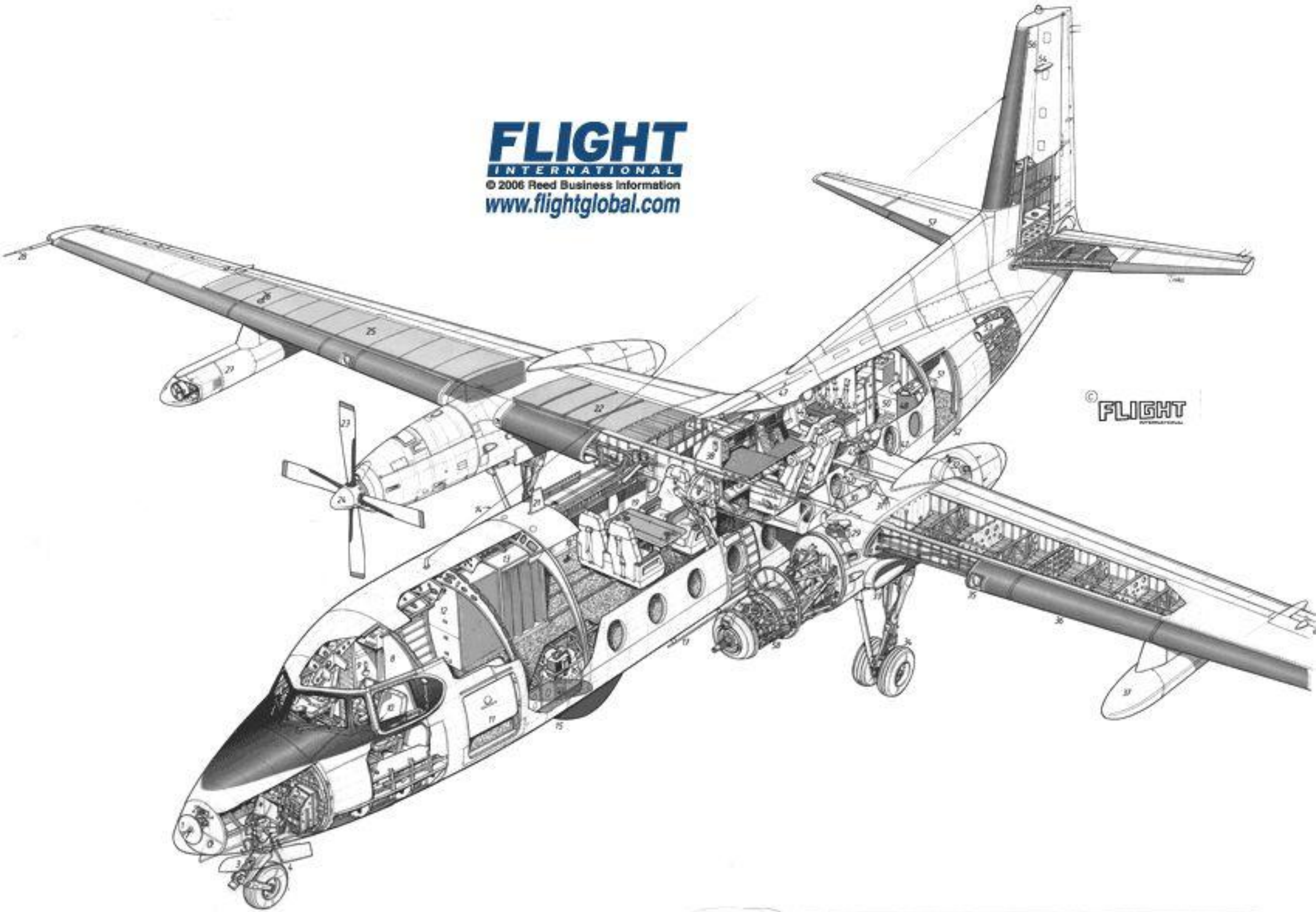


Figure 10.23 Stress–strain diagram comparing the behavior of composites with metals.

Failure could be catastrophic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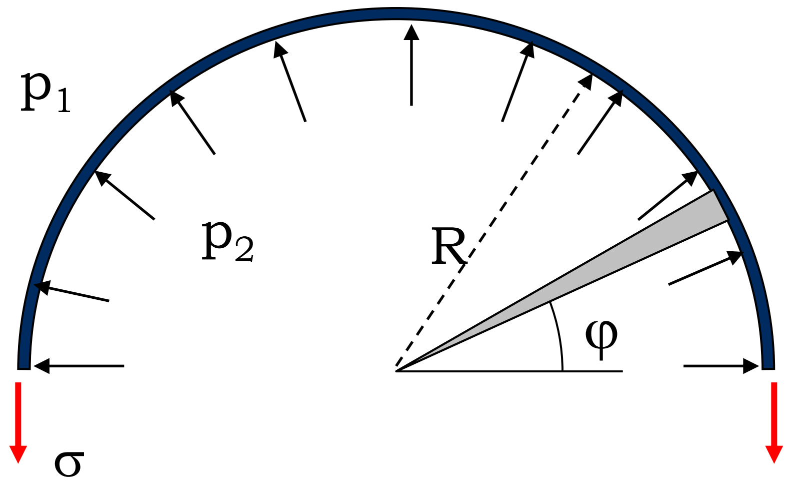
Fokker F27 - innovations

New technical features:

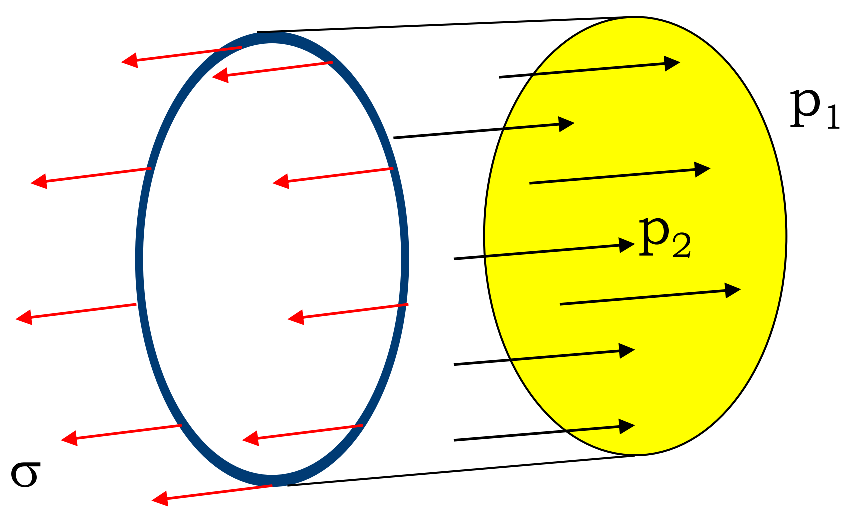
1. turboprop with advanced propeller
2. ***Bonded metal structure***
3. Significant application of ***fiber reinforced composites***
4. Pneumatic high pressure system
5. De-icing system
6. Advanced undercarriage and braking system
7. ***Pressure cabin***
8. Integral fuel tanks
9. Air-conditioning
10. Modern electronics

Pressure cabin



$\Delta p = p_2 - p_1$

$$2.\sigma.t = \int \Delta p.\ \sin(\varphi).Rd\varphi$$
$$= \Delta p.2R$$
$$\sigma_{circ} = \Delta p.R/t$$



$$\sigma.2\pi R.t = \Delta p.\pi R^2$$

$$\sigma_{long} = \Delta p.R/2t$$

Ratio: $\sigma_{circ}/\sigma_{long} = 2$

Example

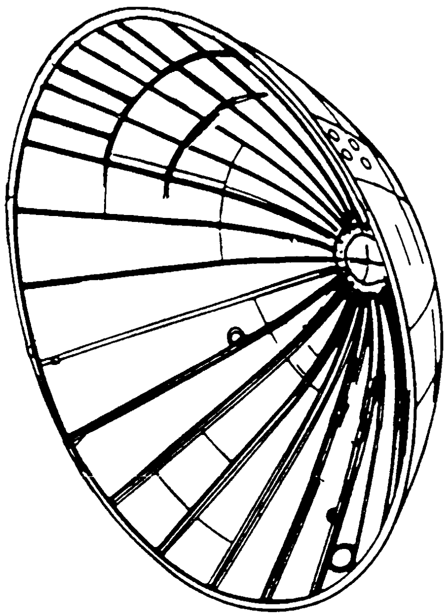
Radius $R = 2$ m
Pressure at high altitude (11.000m) $p_1 = 22620$ Pa (Pa = N/m^2)
Pressure in the aircraft p = 70928 Pa (70% of sea level)

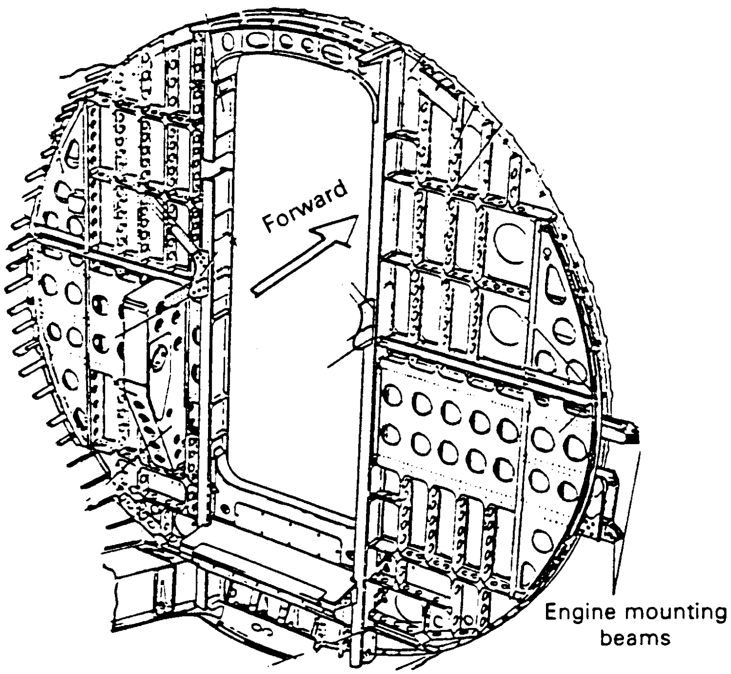
So $\sigma_{circ} = \Delta p.R/t$
or $\sigma.t = \Delta p.R =$ 96616 N/m

And $\sigma_{long} = ½\, \sigma_{circ} =$ 48308 N/m

for $t = 1$ mm $\sigma_{circ} = 96.6$ MPa (=N/mm^2)
$t = 2$ mm $\sigma_{circ} = 48.3$ MPa
etc.

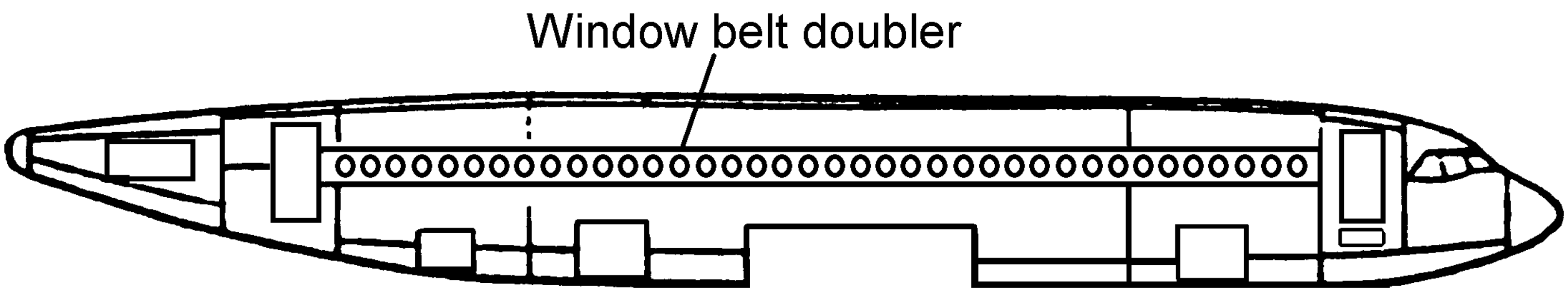
Pressure cabin - bulkheads





Pressure Bulkhead are used to close the pressurized are of the fuselage.

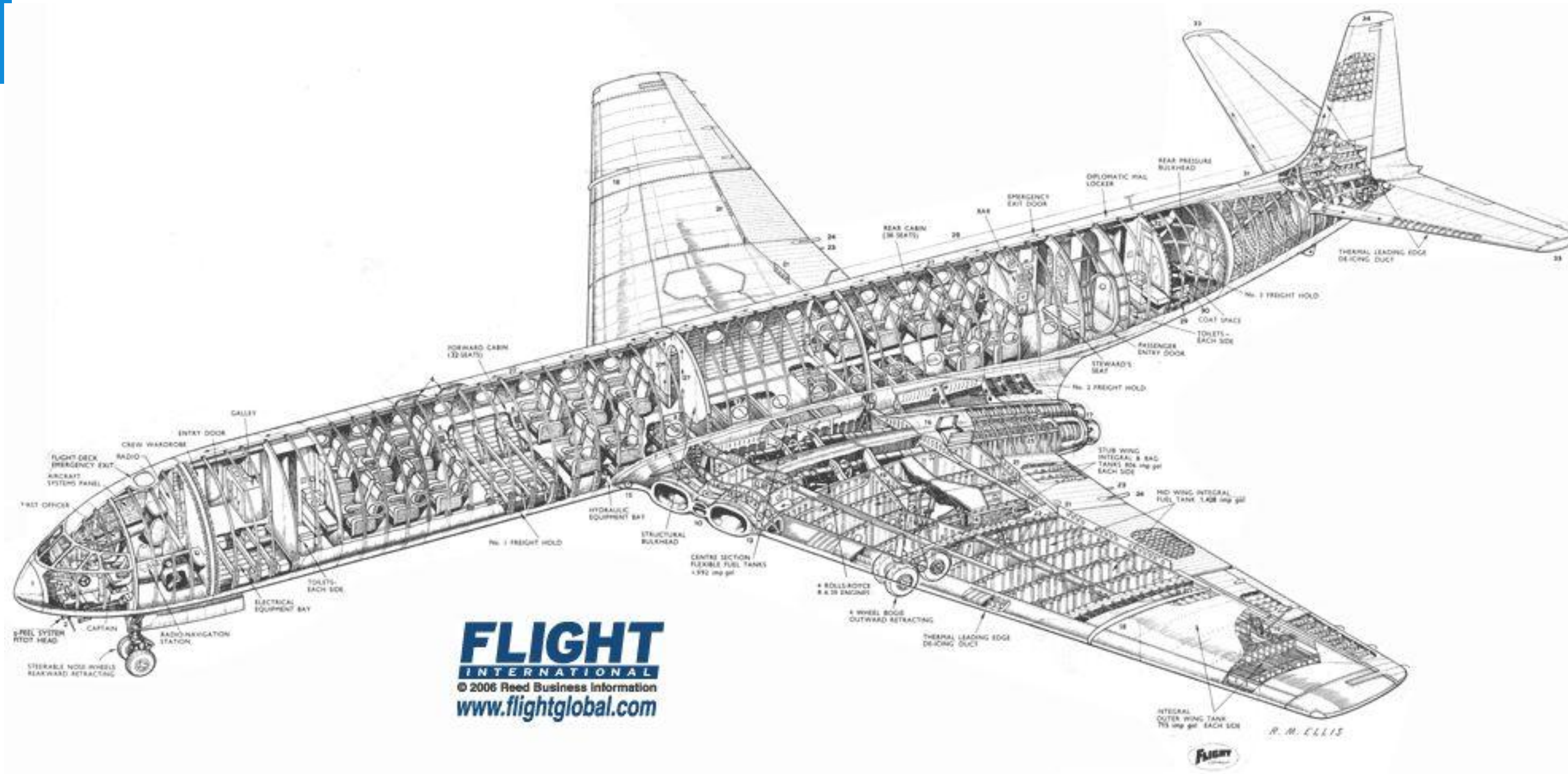
Pressure cabin - cutouts



Fuselages are not perfectly closed cylinders:
Due to practical use, the ideal cylinder is disturbed by cut outs for:

- Windows
- Passenger Doors
- Cargo doors
- Landing Gear doors

Comet: first passenger jet aircraft with pressure cabin



Comet

First jet aircraft – Lead of British industry
Thin aluminum skin
Pressurized cabin – flying altitude (10 km +)
Stress concentration around windows/doors
Rectangular shapes
Squeezed in rivets (tiny cracks)

http://www.youtube.com/watch?v=JBcCv2UaiPo

End Result: Americans bypassed British (Boeing 707/DC-8)

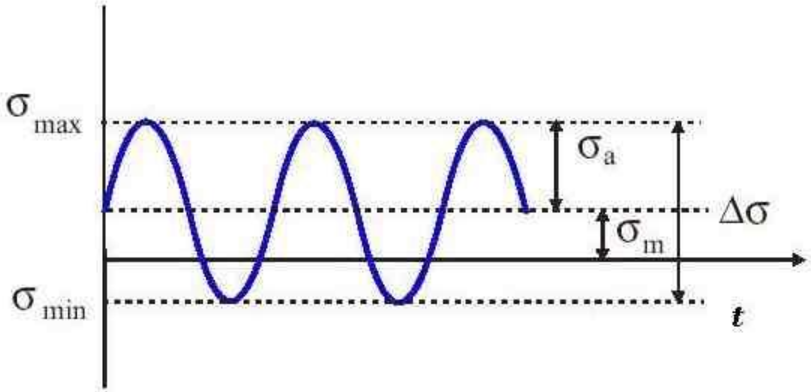
Fatigue

Dynamic loading – repetitive

Example: Paperclip - try to break one!
One can with bending/unbending

(Repetitive) force smaller than breaking force destroys the part!!
See next slide – SN-curve

Constant Amplitude (CA) fatigue



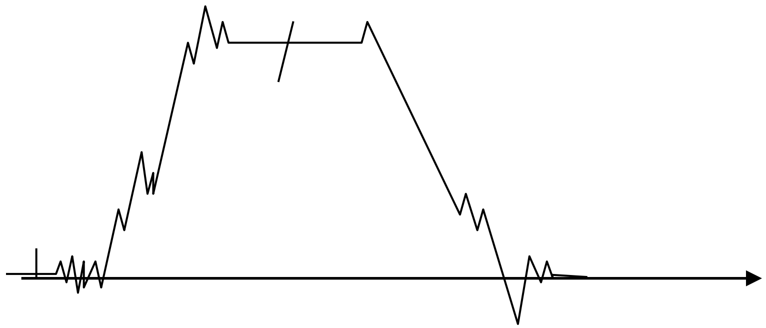
Fatigue

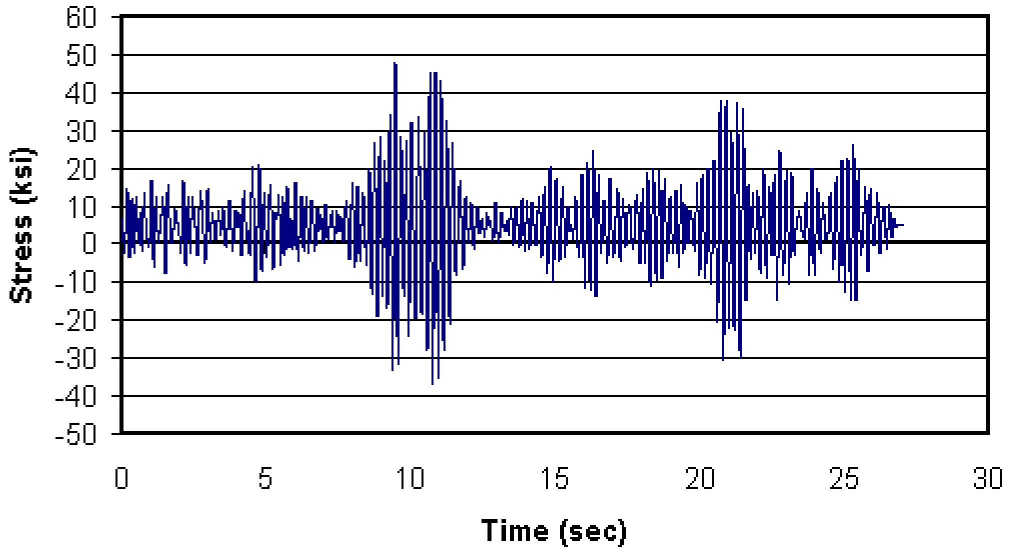
SN-curve

Fatigue

In reality: Variable Amplitude (VA) fatigue

Flight spectrum



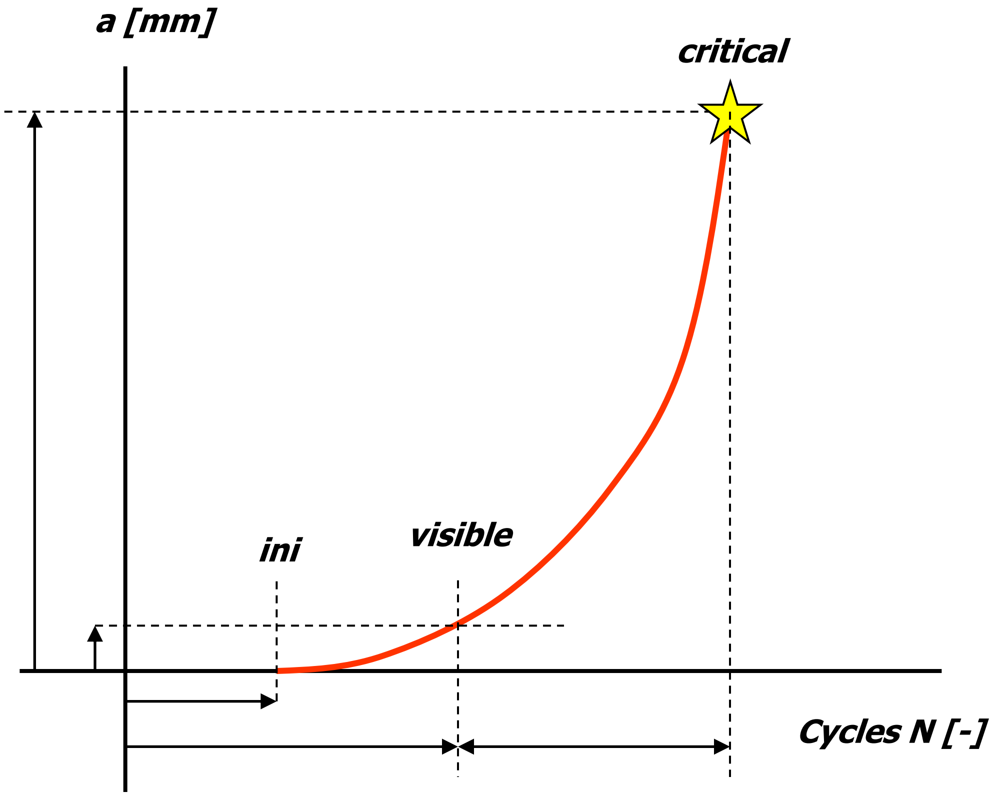


Fatigue

Fatigue
  Crack initiation
  Crack growth

Two limits:
  visibility limit (detection)
  criticality limit (failure)

Inspection intervals
  3 times between
  visible and critical



Fatigue - locations

Wing loads:

- remous (variations in wind velocities)
- manoeuvres
- flaps, engine trust, etc.

Fuselage

- pressurization (once every flight)
- bending moments + remous & manoeuvres

Summary

- The Structure is the “skeleton” of the aircraft
- Function are: carrying loads, protection, attachment points

- From truss to beams: webplate + girders
- Most Structural Elements are based on “beam concept”

- After WW2: Jet Age; pressurized cabins
- Metal fatigue (Comet)