Introduction to Aerospace Engineering

Lecture slides
Introduction to Aerospace Engineering
9 & 10. Structural concepts

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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
  • 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

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<th>Materials</th>
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What were the first composite applications? When?
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 Specifications**

- **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

![I-Beam Diagram]
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 cannot 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.
“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:
- Web plate
- Girders
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**

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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

- Web plate
- Girders
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

\[ n = \frac{L}{W} \]

What is the load factor at cruise?
Loads

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

- Ultimate load: limit load \times 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
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

\[ \Delta p = p_2 - p_1 \]

\[ 2\sigma.t = \int \Delta p \sin(\varphi).R \, d\varphi = \Delta p \cdot 2R \]

\[ \sigma_{circ} = \Delta p \cdot R/t \]

\[ \sigma \cdot 2\pi R \cdot t = \Delta p \cdot \pi R^2 \]

\[ \sigma_{long} = \Delta p \cdot R/2t \]

Ratio: \[ \sigma_{circ}/\sigma_{long} = 2 \]
Example

Radius $R = 2 \text{ m}$
Pressure at high altitude (11,000 m) $p_1 = 22620 \text{ Pa (Pa = N/m}^2\text{)}$
Pressure in the aircraft $p = 70928 \text{ Pa (70\% of sea level)}$

So $\sigma_c = \Delta p \cdot R/t$

or $\sigma \cdot t = \Delta p \cdot R = 96616 \text{ N/m}$

And $\sigma_{long} = \frac{1}{2} \sigma_c = 48308 \text{ N/m}$

for $t = 1 \text{ mm}$ $\sigma_c = 96.6 \text{ MPa (=N/mm}^2\text{)}$
for $t = 2 \text{ mm}$ $\sigma_c = 48.3 \text{ MPa}$

etc.
Pressure cabin - bulkheads

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

S-N CURVE FOR BRITTLE ALUMINIUM WITH A UTS OF 320 MPa

Stress (MPa)

Life (cycles)
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)