# Aircraft Structures

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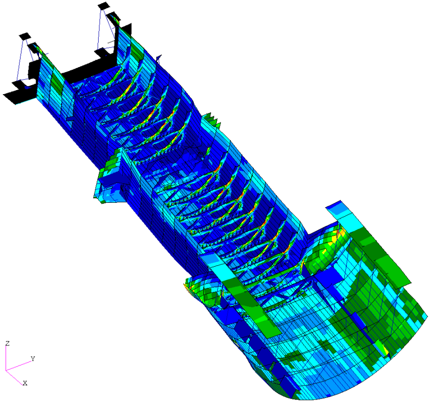
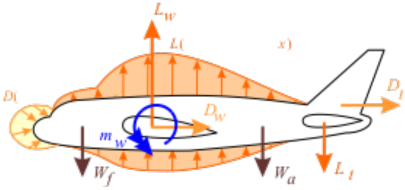
Section A1

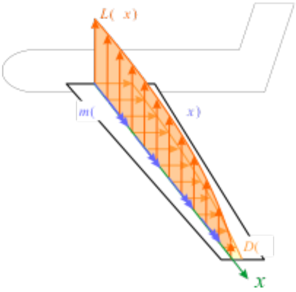
# Aircraft loads and structural analysis



# Aircraft loads

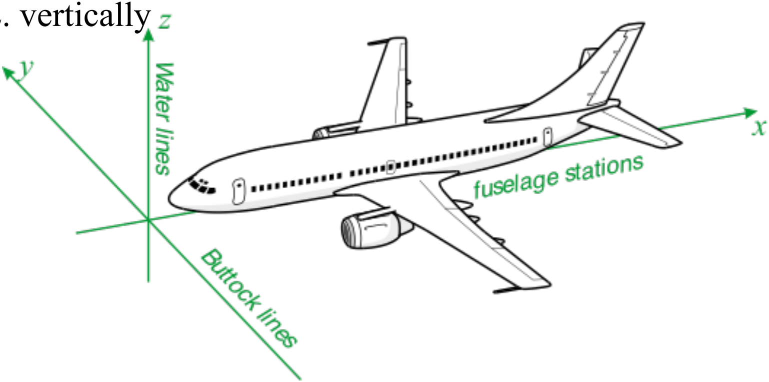
- Air loads
  - Aerodynamics
  - Passive loads
  - Thrust
  - Empennage
  - Inertia/Manoeuvres
- Ground loads
  - Landing gear
  - Taxiing
  - Takeoff/Landing



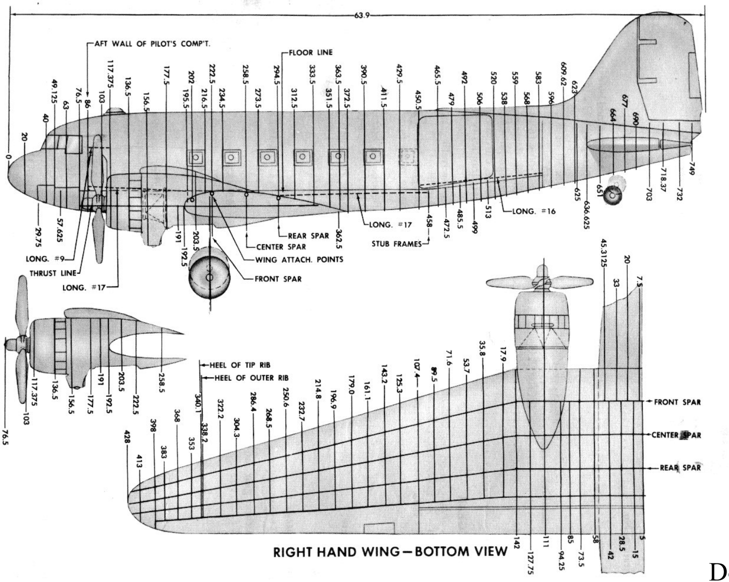



# Reference frame

- Structural description frame:
  - F.S. along fuselage
  - (W.)B.L. along wing
  - W.L. vertically



# Stations example




Douglas DC3

# Airworthiness

- Aircraft must be safe to fly
  - Structural strength and stiffness
  - Performance
  - Handling
  - Operational requirements & procedures
  - …
- Airworthiness certification codes
  - FAR, EASA, MIL, …

# It happens…

- 25th May 2008 – Brussels Airport

# It happens…

# It happens…

# It happens…

# It happens…

# Airworthiness targets

Maintenance errors
3 per billion

Cabin utilities
3 per billion

Control system
3 per billion

Airframe systems
3 per billion

Structure
3 per billion

*Our target in the « big picture » : the structure cannot be accounted for more than 3 fatal accidents per billion flight hours flown.*

| Airframe | Powerplant | Power systems | Avionics |
|---|---|---|---|
| 15 per billion | 1 0 | 1 5 | 1 5 |

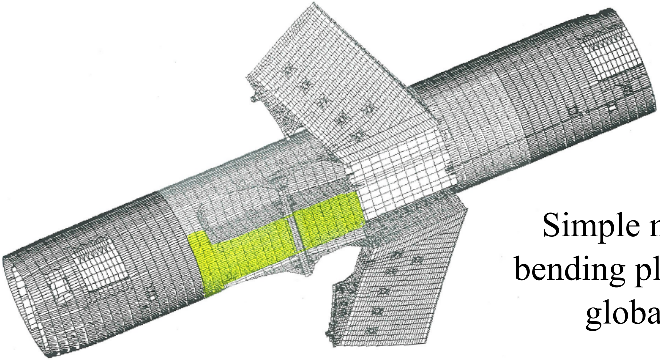
**AIRCRAFT**
55 per billion

| Crew error | ATC error | Terrorism | Acts of God |
|---|---|---|---|
| 10 per billion | 3 0 | 3 per billion | 2 per billion |

**TOTAL SYSTEM**
100 fatal accidents per billion flying hours

*after Howe, D.*

# The design process (1)



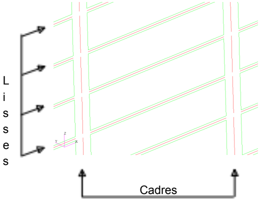
S.A.B.C.A.



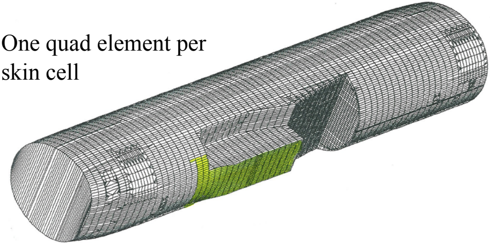
Simple model with one bending plane to determine global load paths

Two 1D-beam elements per frame

Two 1D-rod elements per stringer

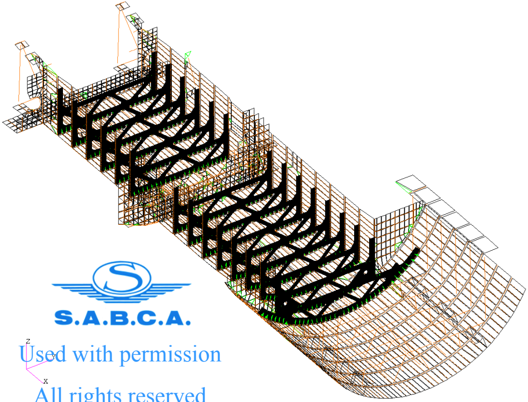



One quad element per skin cell

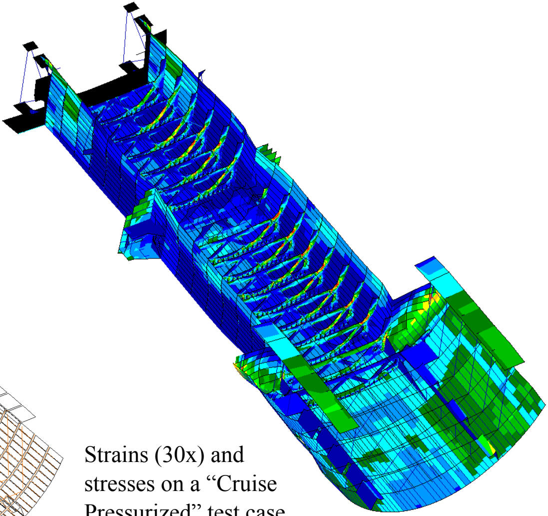


# The design process (2)

Finer FE model of the SABCA WP embedded in the Airbus model



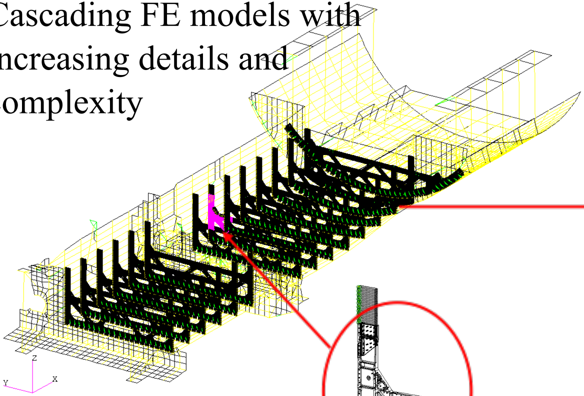


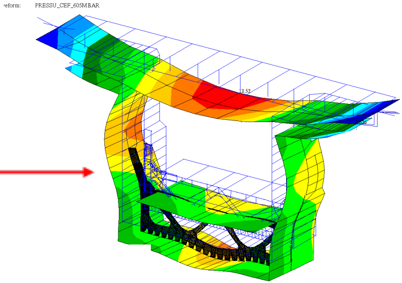



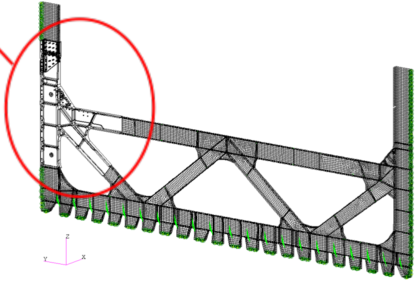
Strains (30x) and stresses on a "Cruise Pressurized" test case

# The design process (3)

Cascading FE models with increasing details and complexity





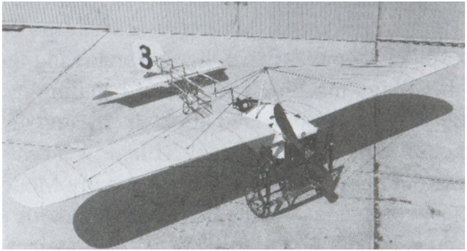
Detailed frame study using 3D tetrahedral elements in a 3D shell structure connected to the global model

S.A.B.C.A.

# So it is important !

- Let's watch a couple of movies…
  - Design cases to be considered
    - Tailstrike during actual landing
    - A380 high-alpha take-off test
    - A380 blade-off test
    - RR Trent 900 bird ingestion test
    - Aircraft carrier loads
  - Things that happen…
    - Aerobatic airplane losing a wing

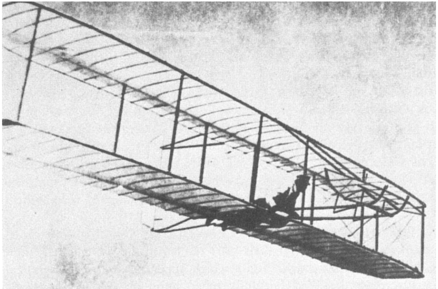
# Historical Overview

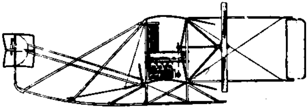



Blériot Model XI, 1909

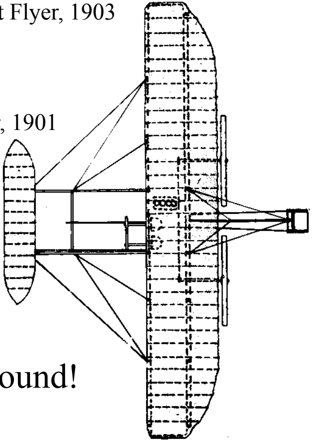
Airbus A380, 2006

# The 1900-1915 era





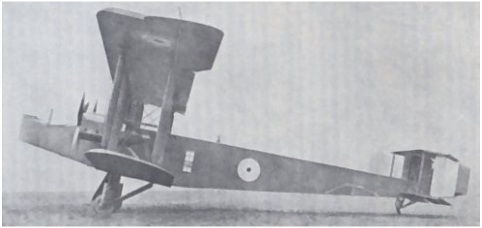
Wright Flyer, 1903



Wright Glider, 1901

- Structural infancy:
  - Trussed structures
  - Thin wings
  - Success = allow repair and turnaround!

# The 1915-1930 era



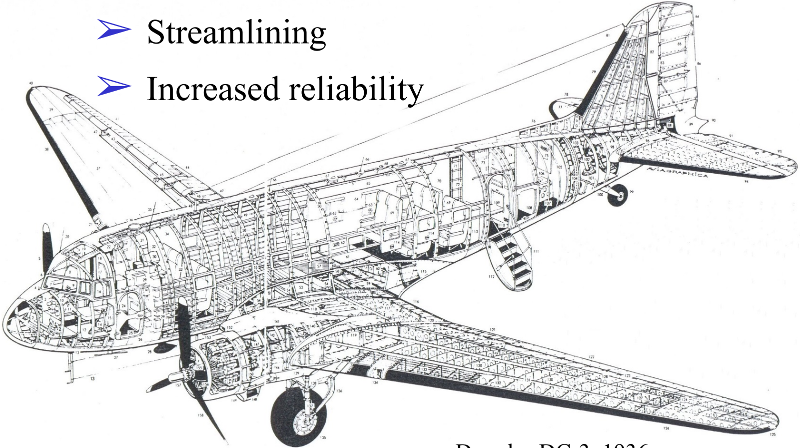
Handley Page 0/400 Bomber, 1917

Fokker D8, 1918

- Structural developments:
  - Covered fuselages
  - Monoplane wings / Cantilever wings
  - First aeroelastic problems !

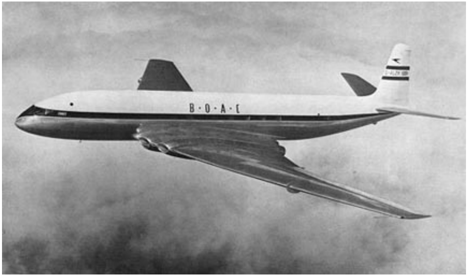
# The 1930-1940 era

- Structural developments:
  - Monocoque structures
  - Streamlining
  - Increased reliability




Douglas DC-3, 1936

# The 1940-1960 era

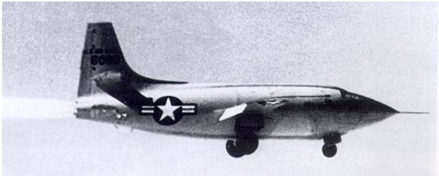



De Havilland Comet, 1952


Boeing 707, 1954

- Performance improvements:
  - The jet engine age
  - High altitude flight
  - First fatigue problems !

# The 1940-1960 era (2)



Bell X-1, October 14, 1947

- Performance improvements:
  - Supersonic flight
  - Thermal loads
  - Highly stressed structures

Dassault Mirage III, 1956

# The modern era

Boeing 747, 1970

Airbus A-380, 2006

- Structural design principles:
  - Static ultimate yield strength
  - Fail-safe design (fatigue life of clean and damaged structure)
  - Static residual strength of damaged structure

Section A5

# Structural design requirements

# Civil aircraft certification

- U.S. regulations
  - Federal Aviation Regulations (F.A.R. 23 or 25)
- European Union regulations
  - Formerly Joint Aviation Authorities (J.A.A. & J.A.R.)
  - Now in the hands of European Aviation Safety Agency (E.A.S.A.)
  - 2003: publication of Certification Specifications (CS)

# Civil aircraft certification

- List of main CS which concern the structure
  - CS-22

    *Certification Specifications for Sailplanes and Powered Sailplanes*
  - CS-23

    *Certification Specifications for Normal, Utility, Aerobatic, and Commuter Category Aeroplanes*
  - CS-25

    *Certification Specifications for Large Aeroplanes*
  - CS-27

    *Certification Specifications for Small Rotorcraft*
  - CS-29

    *Certification Specifications for Large Rotorcraft*
  - *CS-Definitions, CS-VLA, CS-VLR, CS-LSA (in writing)*

# Airplane categories

- Normal
  - normal flight,
  - stall,
  - lazy eights, chandelles and steep turns or similar maneuvers, in which the angle of bank is not more than 60°.
- Utility
  - as normal + spin and maneuvers to 90° of bank.
- Aerobatic
  - any flight manoeuvre allowed by flight tests.

# CS-LSA aeroplanes

- Light sport aeroplane
  - Single engine (spark- or compression-ignition)
  - No more than 2 occupants
  - Max. certified TO weight ≤ 600 kg
  - Stall speed in landing conf. ≤ 45 knots
  - Approved for day-VFR only

# CS-VLA aeroplanes

- Very light aeroplane
  - Single engine (spark- or compression-ignition)
  - No more than 2 occupants
  - Max. certified TO weight $\leq$ 750 kg
  - Stall speed in landing conf. $\leq$ 45 knots
  - Approved for day-VFR only

# CS-22 aeroplanes

- Sailplane
  - Max. certified TO weight ≤ 750 kg
  - No more than 2 occupants
- Powered sailplane
  - Max. certified TO weight ≤ 850 kg
  - No more than 2 occupants
  - Single engine (spark- or compression-ignition)
  - W/b2 ≤ 3 kg/m2

# CS-23 aeroplanes

- Normal, utility, aerobatic
  - Seating ( excluding pilot seat(s)) ≤ 9
  - Max. certified TO weight ≤ 5670 kg (12500 lb)
- Commuter
  - Propeller-driven twin-engined aeroplanes
  - Seating ( excluding pilot seat(s)) ≤ 19
  - Max. certified TO weight ≤ 8618 kg (19000 lb)

# CS-25 aeroplanes

- Large aeroplanes
  - transport aeroplanes
  - aeroplanes of the CS-23 type which do not fit restrictions

# CS-VLR rotorcraft

- Very light rotorcraft
  - Not powered by turbine or rocket engine(s)
  - No more than 2 occupants
  - Max. certified TO weight $\leq$ 600 kg
  - Approved for day-VFR only

# CS-27 rotorcraft

- Small rotorcraft
  - Seating ( excluding pilot seat(s)) $\leq$ 9
  - Max. certified TO weight $\leq$ 3175 kg (7000 lb)

# CS-29 rotorcraft

- Large rotorcraft
  - Two categories based on seating and maximal certified TO weight
  - Category A:
    - seating 10+ and TOW > 9072 kg (20000 lb)
  - Category B:
    - seating 9– and TOW < 9072 kg (20000 lb)
    - seating 10+ and TOW < 9072 kg: add reqs. from A
    - seating 9– and TOW > 9072 kg: add reqs. from A

# Contents (1)

- Book 1: airworthiness code
  - All the rules that define aircraft certification
  - Includes appendices specific to the CS
- Book 2: acceptable means of compliance
  - Methods that can be used to prove that certification criteria are satisfied
  - May include flight test methodology

# Contents (2)

**BOOK 1 – AIRWORTHINESS CODE**



**CS-23 BOOK 1 – APPENDICES**

# Contents (3)

# CS 25 - C – general (1)

**CS 25.301 Loads**

(a) Strength requirements are specified in terms of limit loads (the maximum loads to be expected in service) and ultimate loads (limit loads multiplied by prescribed factors of safety). Unless otherwise provided, prescribed loads are limit loads.

(b) Unless otherwise provided the specified air, ground, and water loads must be placed in equilibrium with inertia forces, considering each item of mass in the aeroplane. These loads must be distributed to conservatively approximate or closely represent actual conditions. (See AMC No. 1 to CS 25.301(b).) Methods used to determine load intensities and distribution must be validated by flight load measurement unless the methods used for determining those loading conditions are shown to be reliable. (See AMC No. 2 to CS 25.301(b).)

(c) If deflections under load would significantly change the distribution of external or internal loads, this redistribution must be taken into account.

# CS 25 - C – general (2)

**CS 25.303 Factor of safety**

Unless otherwise specified, a factor of safety of 1·5 must be applied to the prescribed limit load which are considered external loads on the structure. When loading condition is prescribed in terms of ultimate loads, a factor of safety need not be applied unless otherwise specified.

**CS 25.305 Strength and deformation**

(a) The structure must be able to support limit loads without detrimental permanent deformation. At any load up to limit loads, the deformation may not interfere with safe operation.

(b) The structure must be able to support ultimate loads without failure for at least 3 seconds. However, when proof of strength is shown by dynamic tests simulating actual load conditions, the 3-second limit does not apply. Static tests conducted to ultimate load must include the ultimate deflections and ultimate deformation induced by the loading. When analytical methods are used to show compliance with the ultimate load strength requirements, it must be shown that:

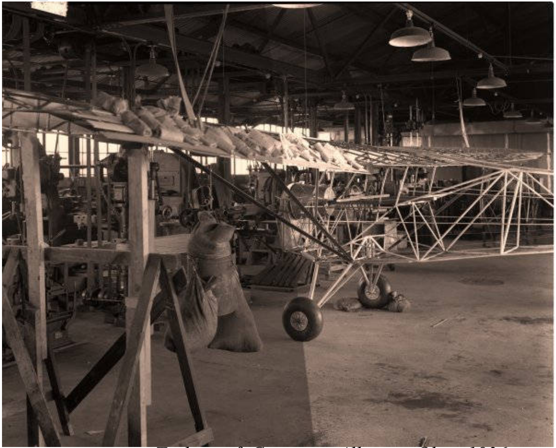
(1) The effects of deformation are not significant;

(2) The deformations involved are fully accounted for in the analysis; or

(3) The methods and assumptions used are sufficient to cover the effects of these deformations.

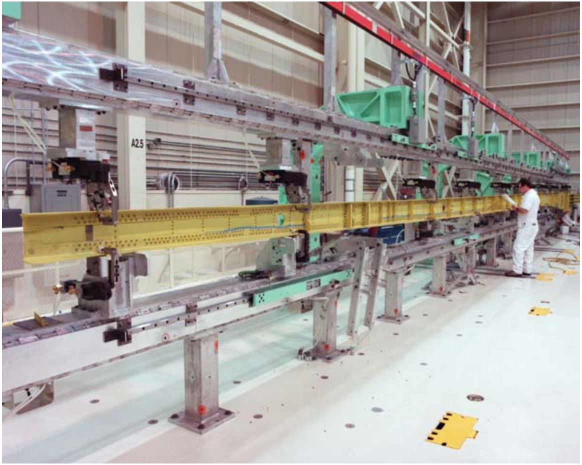
# Ultimate proof test

- Done from earliest times
- Modern proof test version: B-777 video

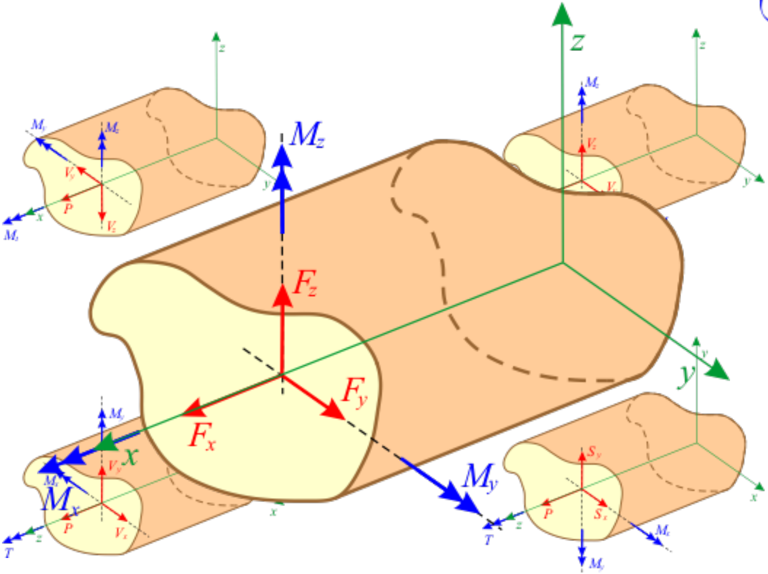


*wing torsion test, Taylorcraft Company, Alliance, Ohio, 1936*

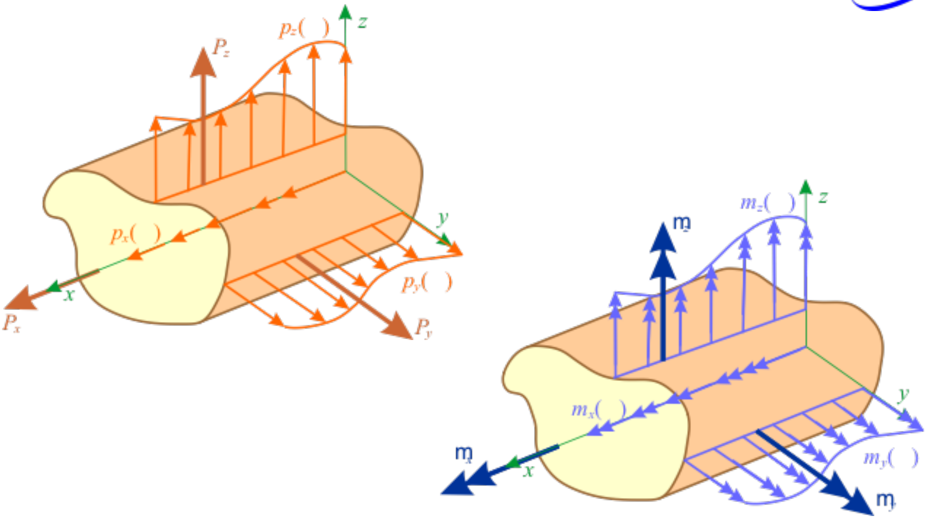
# Definitions and conventions



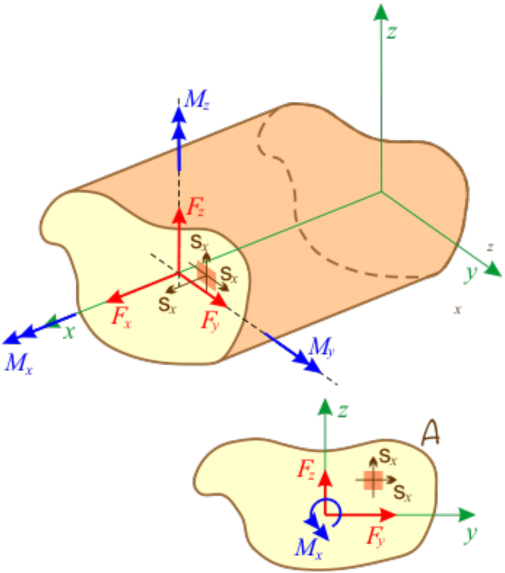
# Sign conventions



# External loads



# Internal load resultants



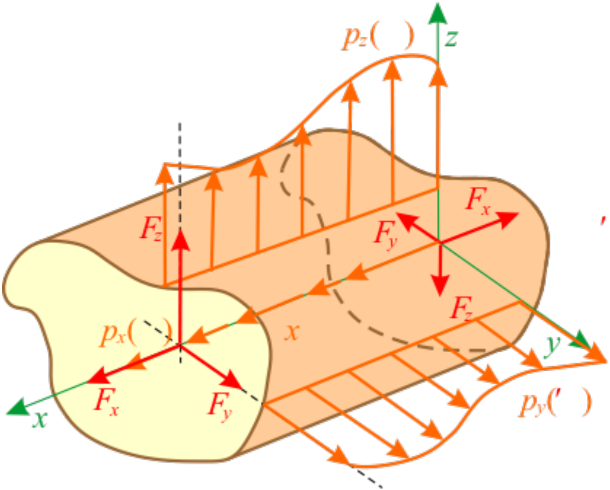

$$F_x = \int_A$$

$$F_y = \int_A$$

$$F_z = \int_A$$

# Differential equilibrium relations for beams

# Force equilibrium



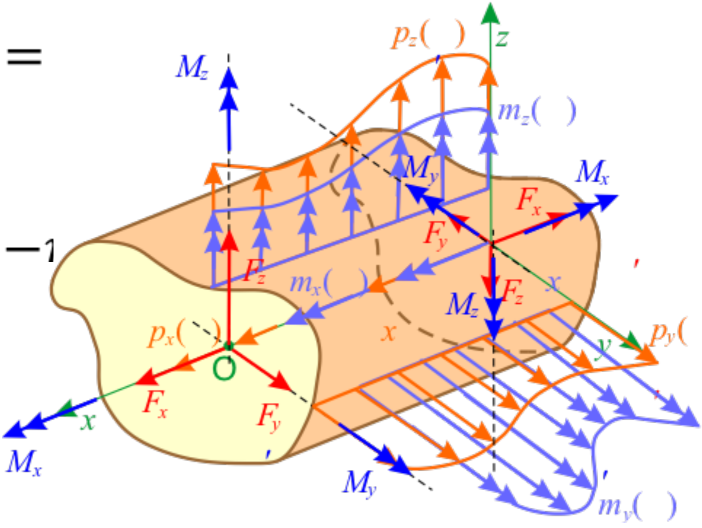

$$\frac{dF_x}{dx} =$$

$$\frac{dF_y}{} =$$

# Moment equilibrium

$$\frac{dM_x}{dx} =$$

$$\frac{dM_y}{dx} = -$$



# Illustrative exercise

- Study the respective distributions of internal resultants for two wings:
  - Cantilever wing (fixed-free)
  - Braced wing (strut supporting the wing at 30° angle at mid-wing)
  - In both cases, use the same distributed load (constant $q$ over the wing span)

# Exercise: Results

- Cantilever wing

For $0 \leq x \leq L$

- $F_x = 0$
- $F_y = q(L - x)$
- $F = 0$

# Exercise: Results

- Braced wing

For $L/2^{+} \leq x \leq L$

- $F_x = 0$
- $F_y = q(L - x)$

# Exercise: Results

- ➢ Braced wing

For $0 \leq x \leq {}^{L}\!/_{2}{}^{-}$

- $F_x = -\sqrt{3}qL$
- $F_y = -qx$