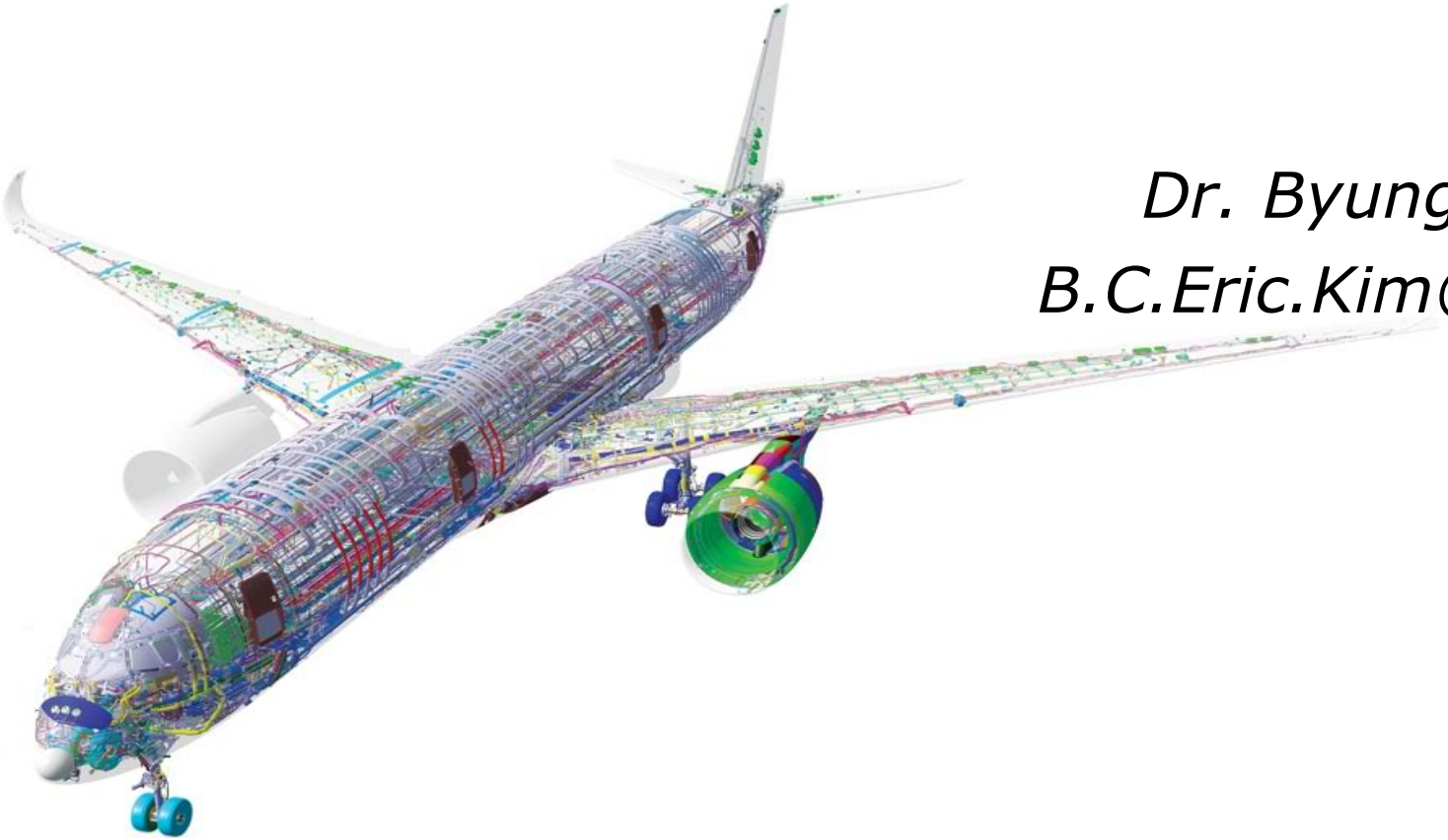
University of BRISTOL

StM3. Aircraft manufacture
Part 3



Dr. ByungChul Eric Kim
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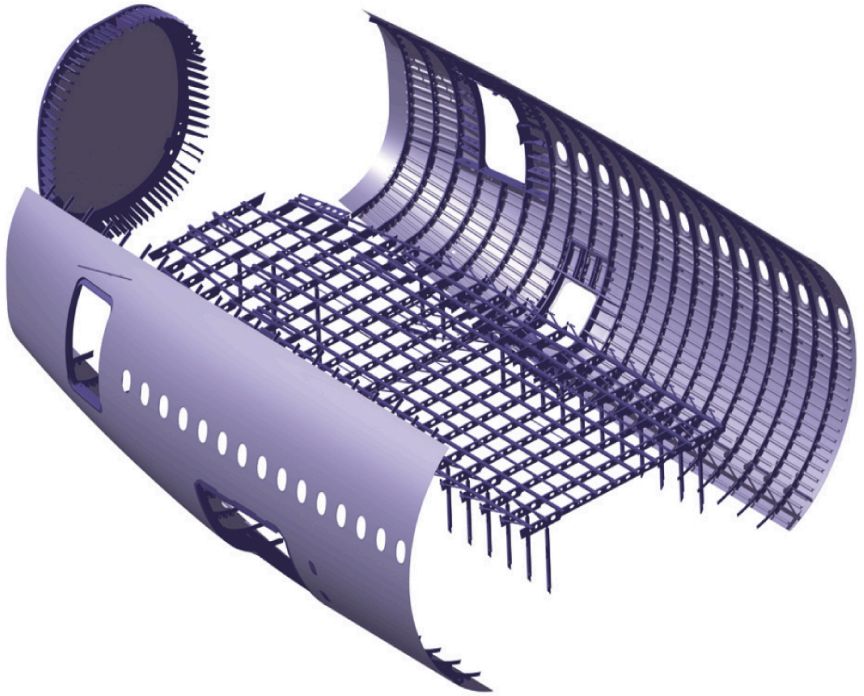
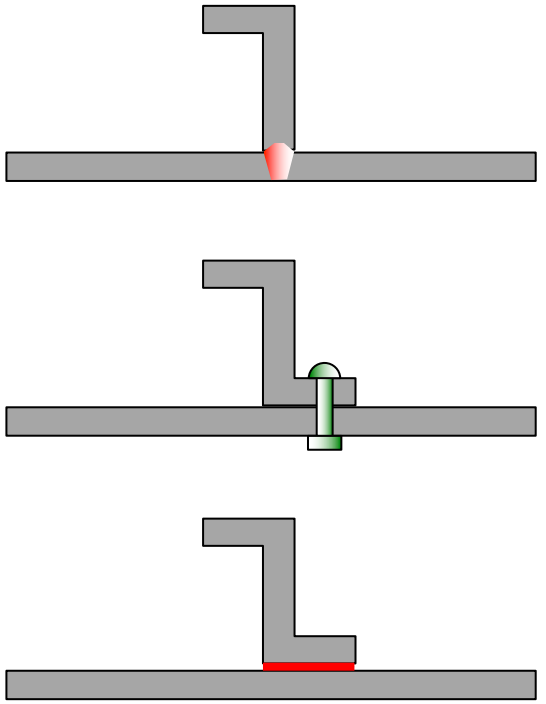
Case study – Aircraft wings

	Metallic ***A340, A380***	***Composite*** ***A350XWB, A400***
Main raw material	2000 and 7000 series Aluminium alloys	Carbon/epoxy composite
Raw material processing	Hot rolling	Prepreging
Key Manufacturing Processes	1. Metal cutting 2. Forming - Creep age forming - Die forging - Sheet metal forming	1. Automated Fibre Placement/Tape Laying 2. Drape forming 3. Autoclave curing 4. Composite machining
Assembly Process	**Mechanical joining** + Welding	Adhesive + **Mechanical joining**

Joining

- Airframe - Stiffened shell structure

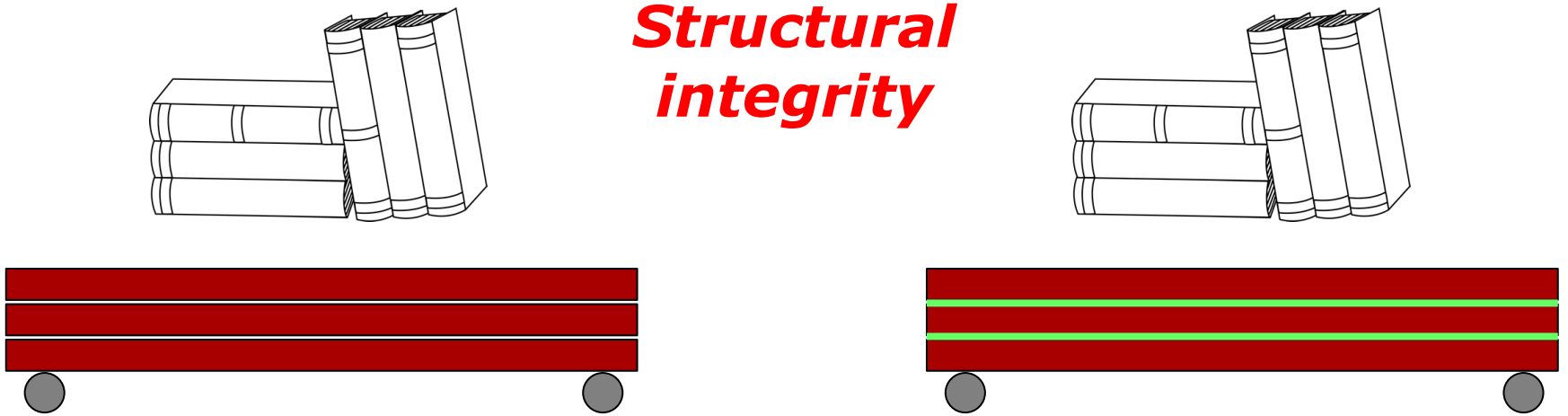




- How to attach the parts together and increate the stiffness

Welding | Fastening | Bonding

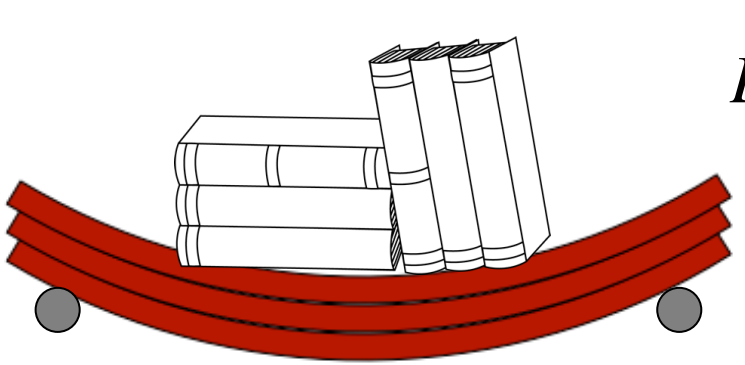
Why joining is important?

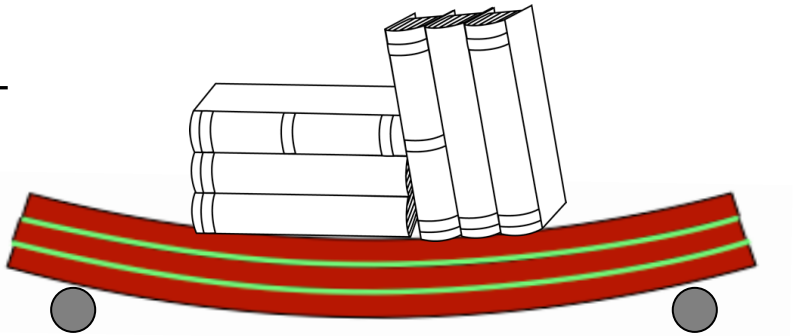


Structural integrity

Flextural Stiffness

$$EI = E\frac{bh^3}{12}$$

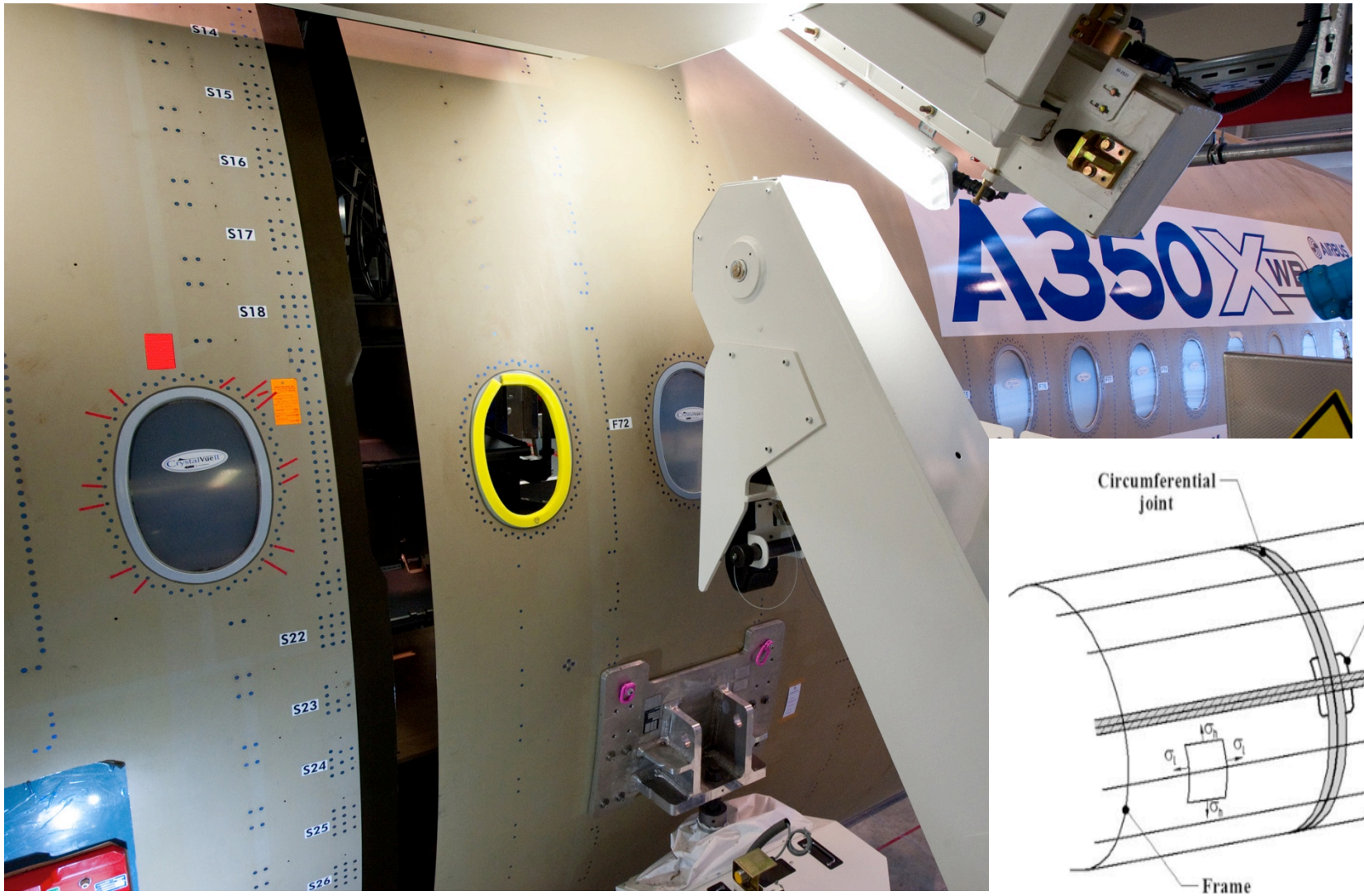




$3 \times EI$

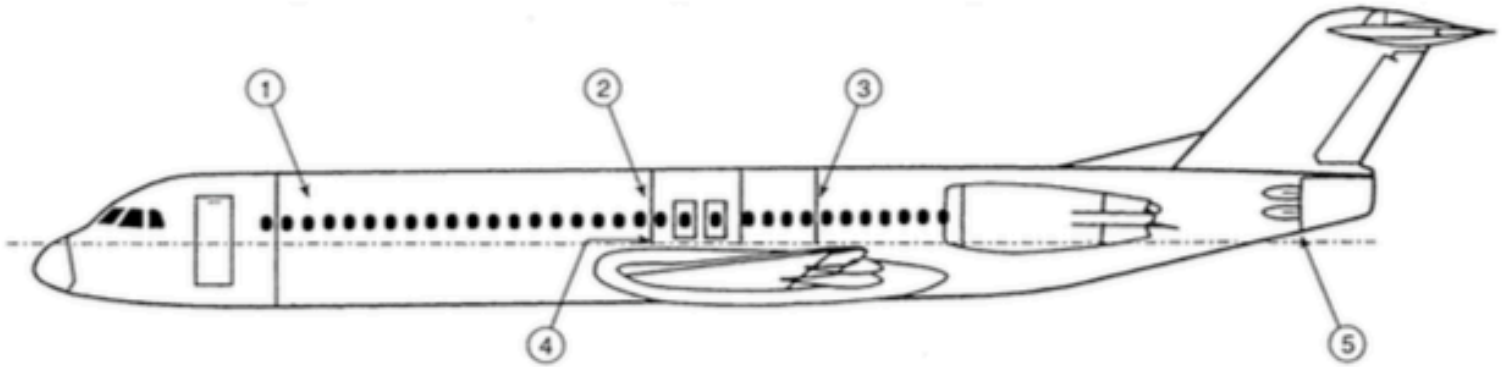
$$EI' = E\frac{b(3h)^3}{12} = 27EI$$

Why joining is important?



Airbus A350XWB fuselage sections come together in Toulouse
http://videos.airbus.com/video/0101e599dc8s.html

Why joining is important?



① front fuselage : pressurization stresses only

② body crown just before front spar attach frame : pressurization + bending stresses

③ body crown just behind rear spar attach frame : pressurization + bending stresses

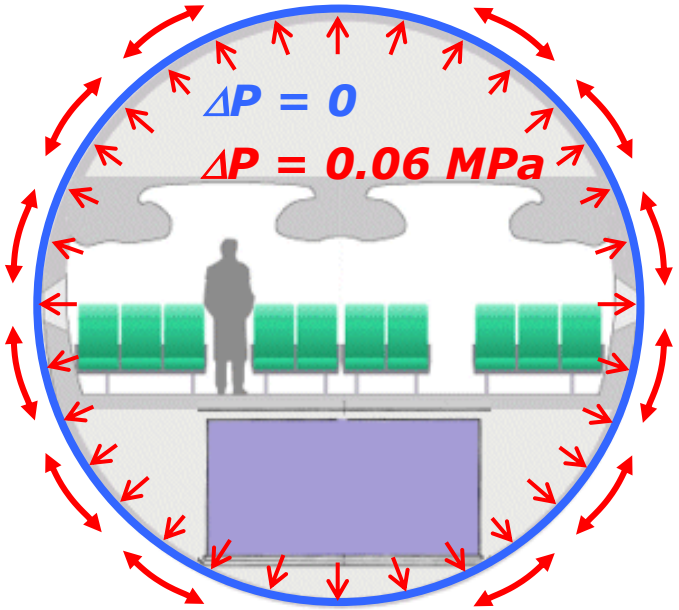
④ mid-fuselage before front spar attach frame : pressurization + shear stresses

⑤ neutral line : pressurization stresses only

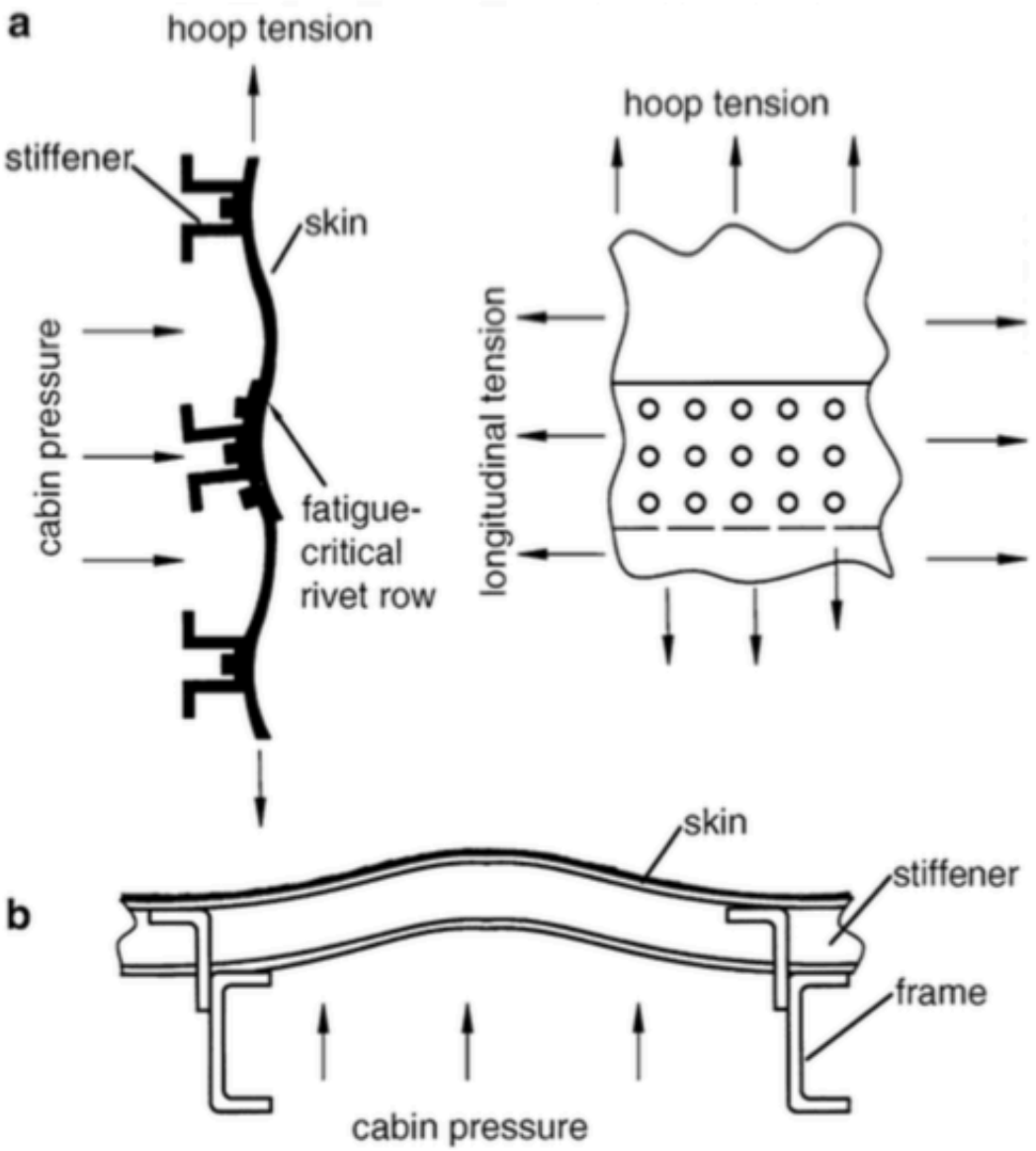
Fig. 1.9 Transport aircraft fuselage loading conditions (Wanhill 1996)

At 8,000ft, 0.075 MPa

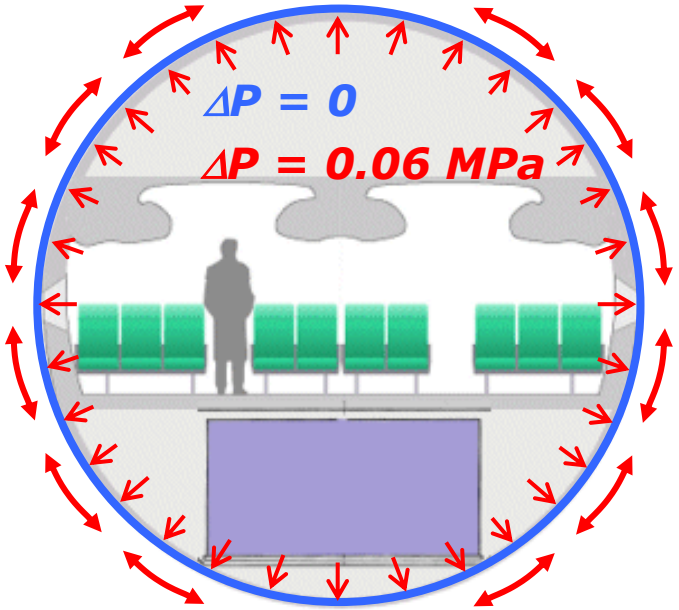
At 45,000ft, 0.014 MPa



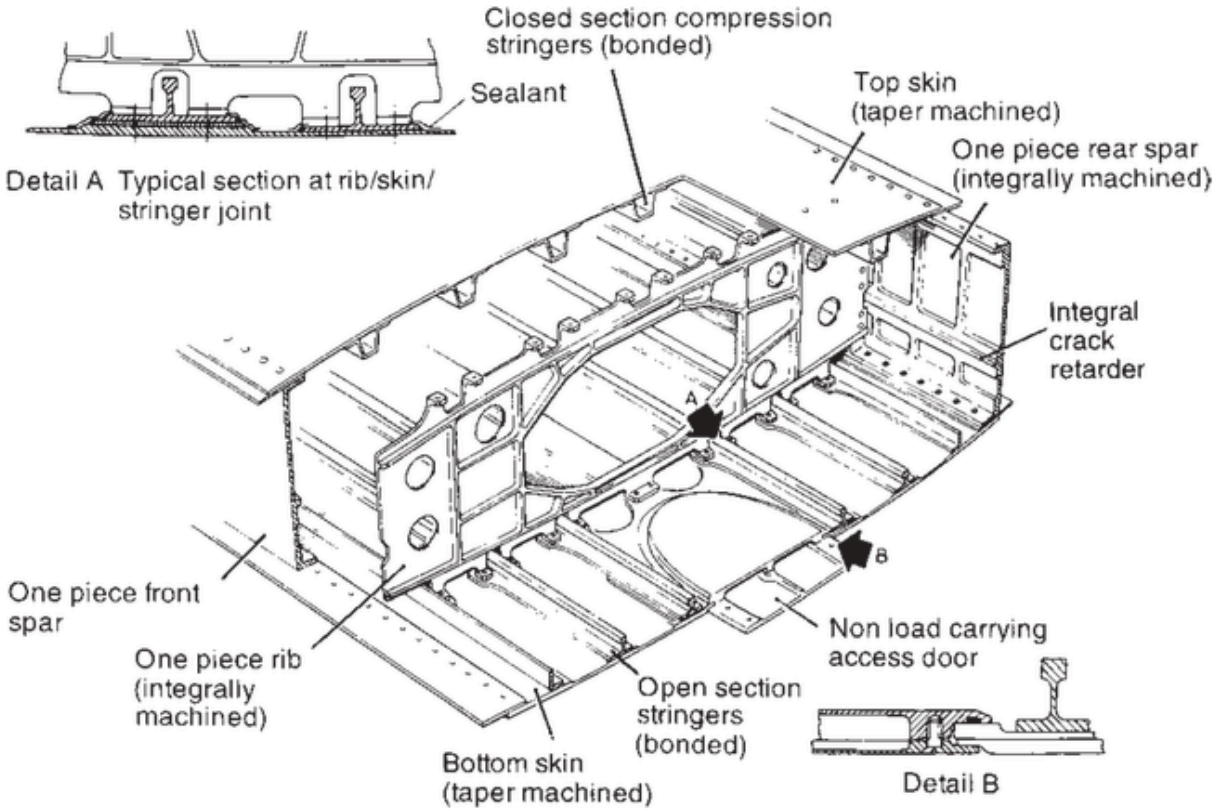
Why joining is important?



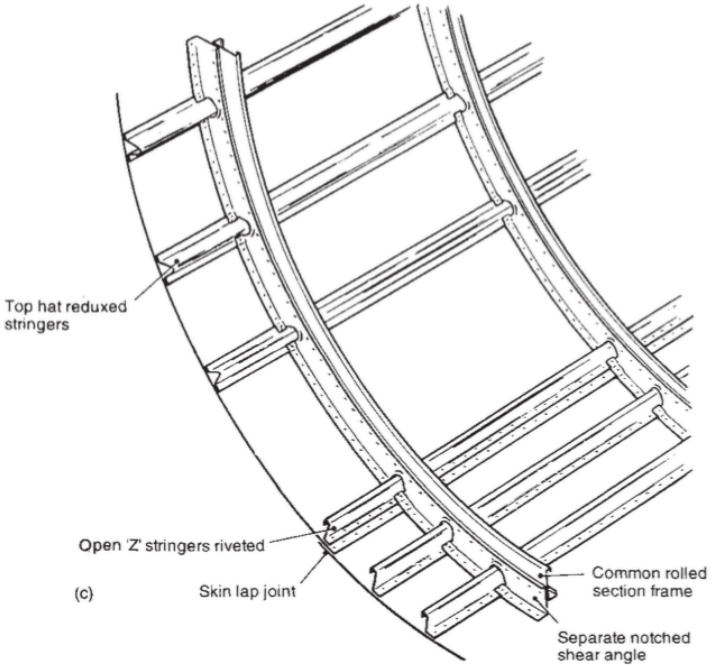
At 8,000ft, 0.075 MPa
At 45,000ft, 0.014 MPa



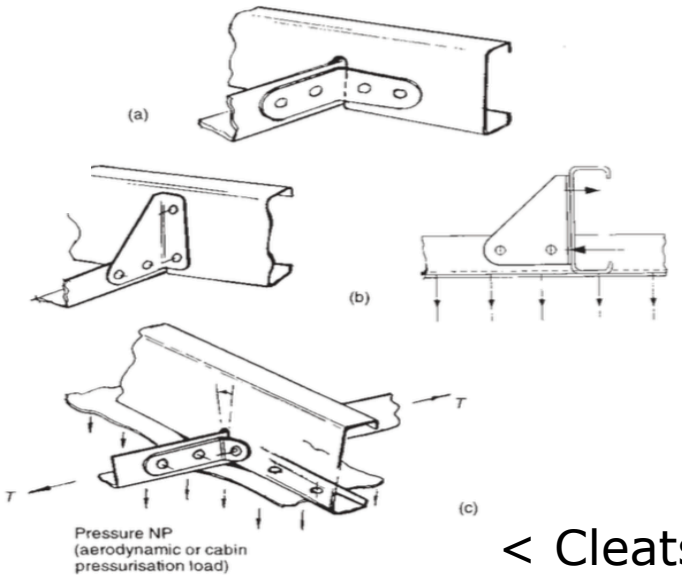
Joints in the airframe



< Wing box >



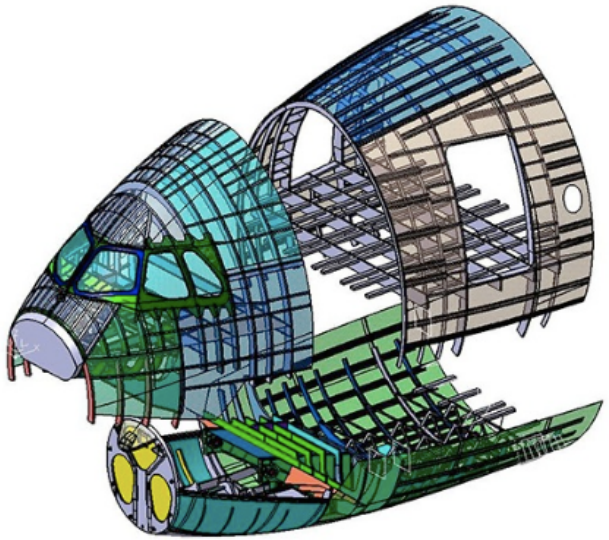
< Stringer/Frame >

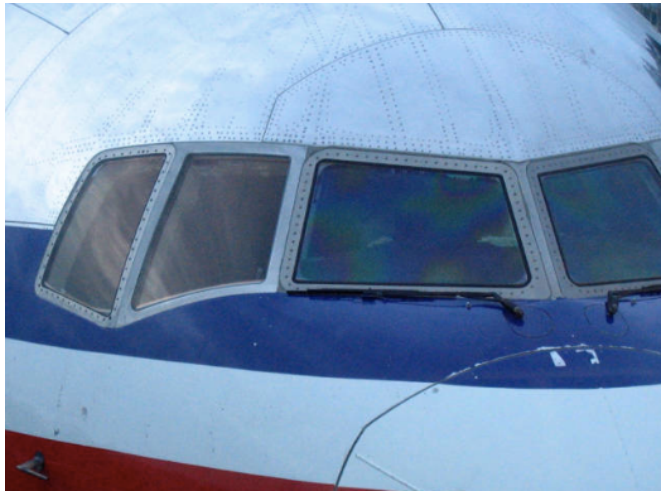


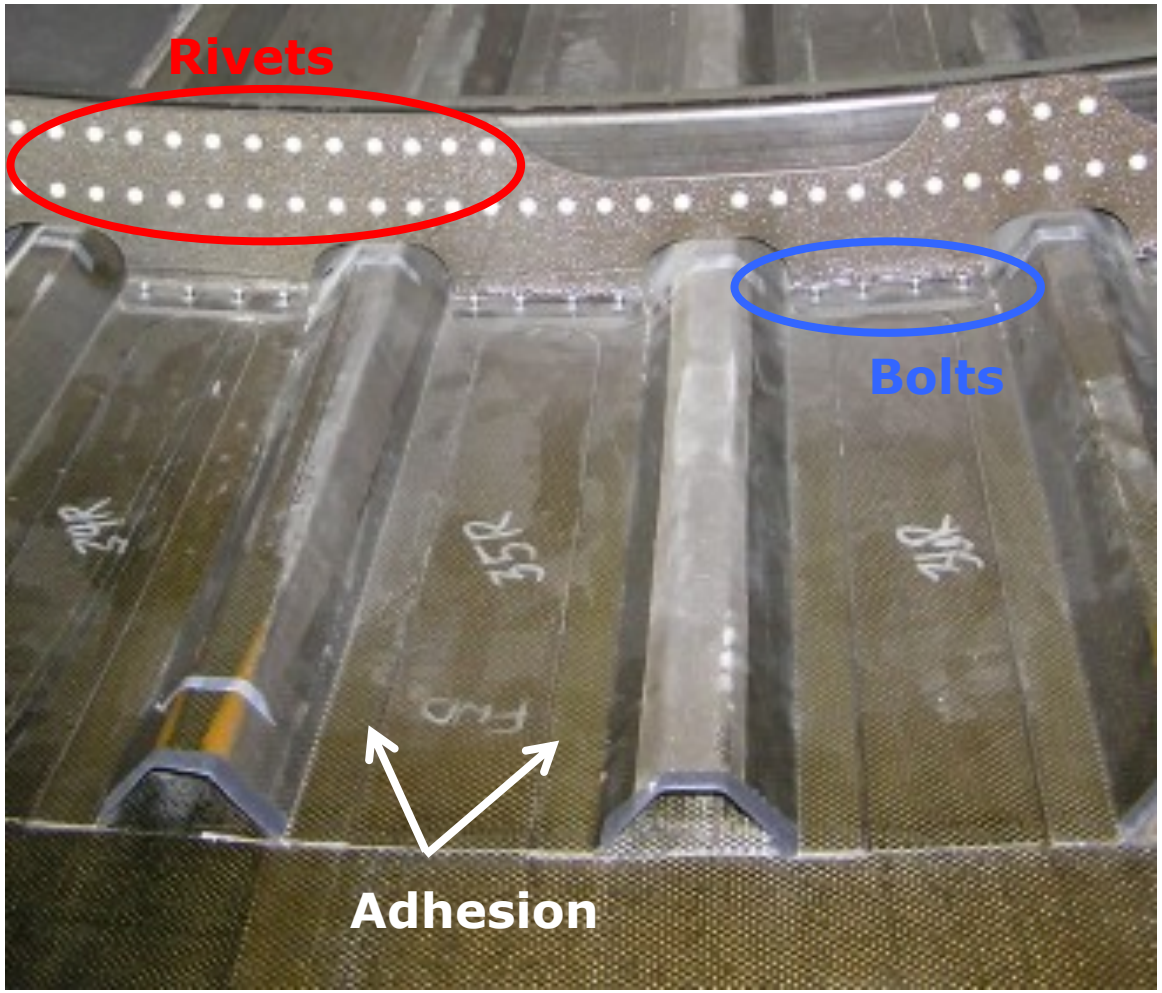
< Cleats or clips >

Joining in aircraft manufacturing

- Where are they used in the aircraft ?





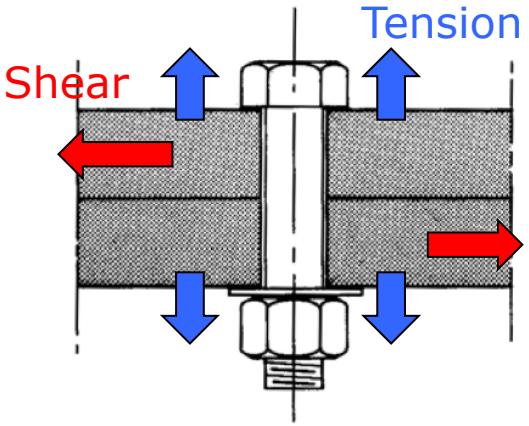


Composite fuselage of B787

Joining
Part 1

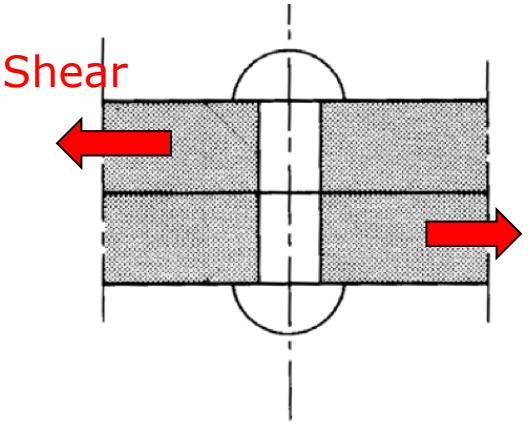
Mechanical joints

Mechanical Fastening



Bolt
Removable fastener

- Suitable for both **tensile & shear loads**
- Easy to be disassembled
- Preloading
- High cost
- Heavier than rivets & more parts
- Can be loosen in vibration



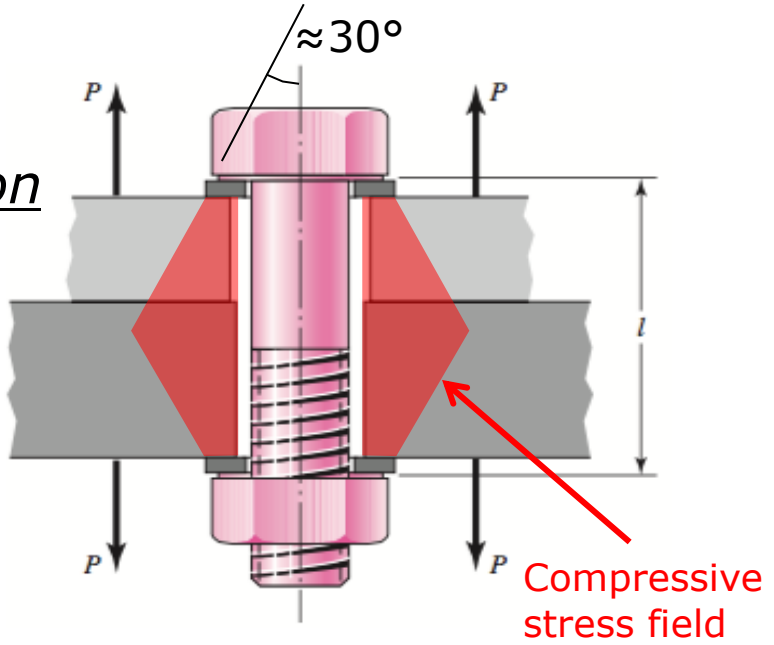
Rivet
Permanent fastener

- More suitable for **shear loads** (weak in tension, low preload)
- Low cost
- Lightweight
- Easy to assemble thin parts (skin/substructure assembly)
- Possible to be set from one side

- ***2.4 million (2,400,000) fasteners are used to for assemble a Boeing 787 aircraft. About 78% of them are rivets.***

Mechanical Fastening

- **Tensile load bearing** of bolt joints
  - Twisting the nut stretches the bolt producing the clamping force (*Pretension or bolt preload* on the bolt, but compression in the members.)



Tension load

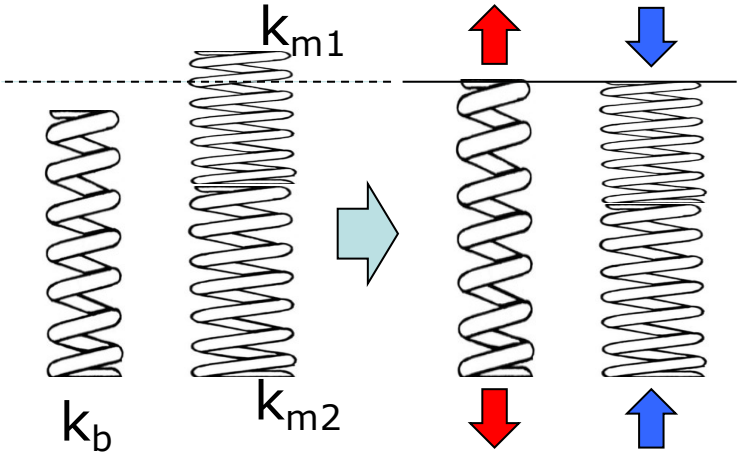
$$P = P_b + P_m \qquad \delta = \frac{P_b}{k_b} \quad \text{and} \quad \delta = \frac{P_m}{k_m}$$

$$P_b = \frac{k_b P}{k_b + k_m} = CP \qquad C = \frac{k_b}{k_b + k_m}$$

Preload

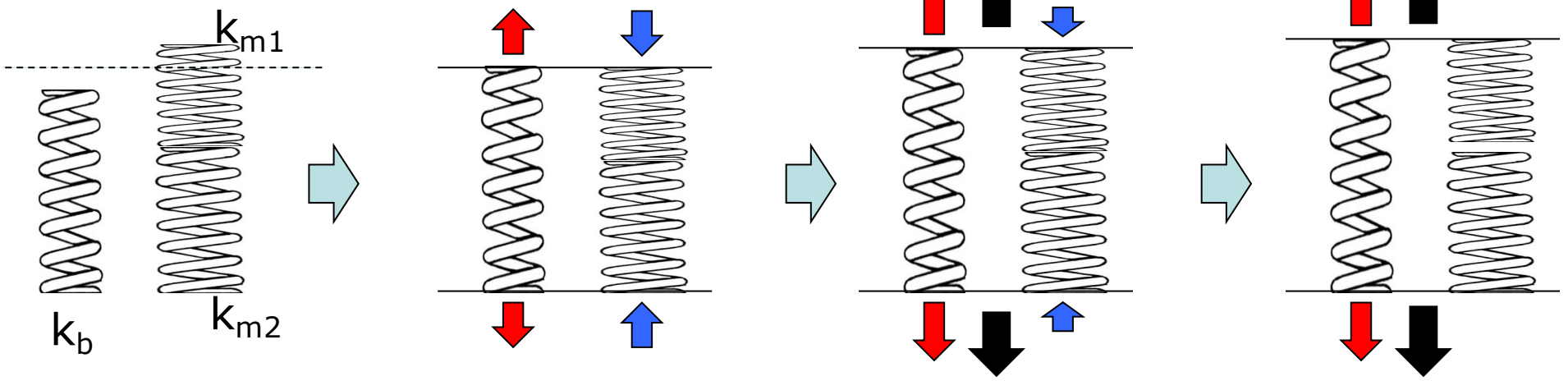
$$F_b = P_b + F_i = CP + F_i \qquad F_m < 0$$

$$F_m = P_m - F_i = (1 - C)P - F_i \qquad F_m < 0$$



Normally, (1 - C) is more than 0.8.
80% of external load is taken by the members.

Mechanical Fastening

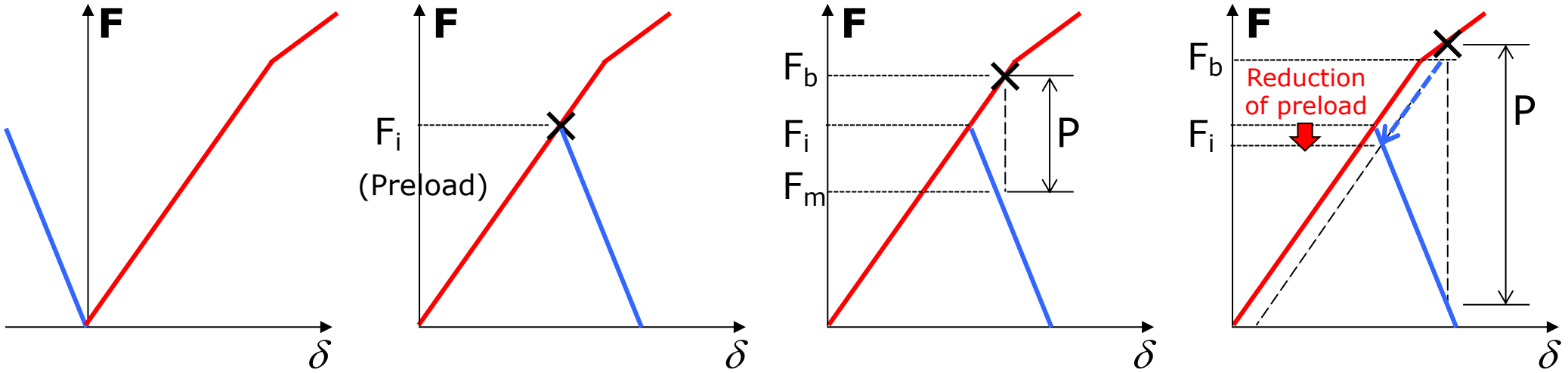


< Before assembly >
$1/k_m = 1/k_{m1} + 1/k_{m2}$

< After assembly: Preloaded >

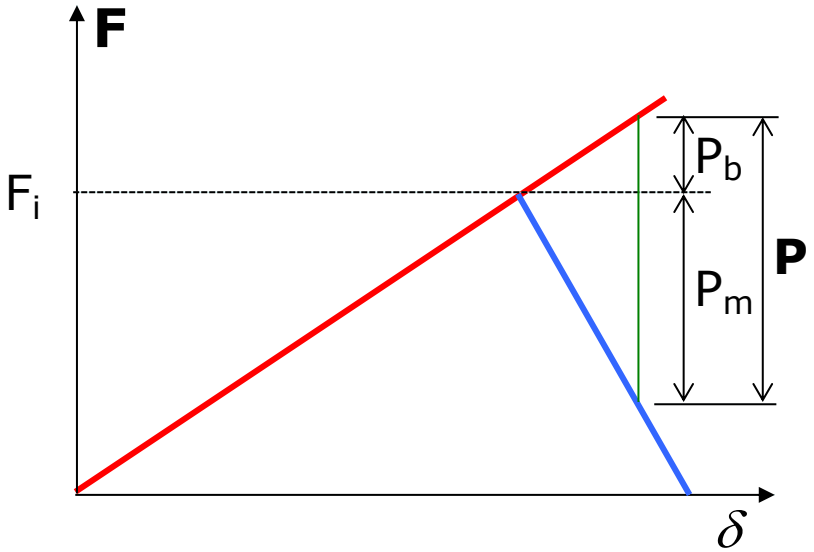
< External force applied >

< Overloaded >



Mechanical Fastening

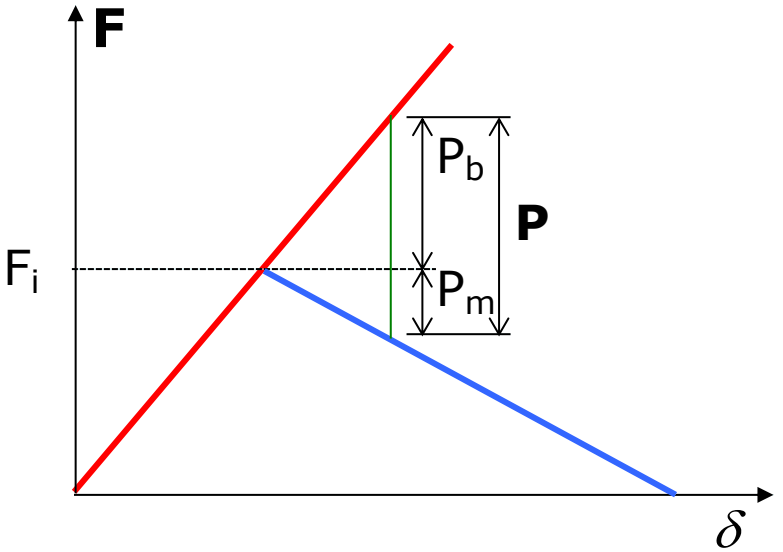
- Effect of the bolt and member stiffnesses



Low stiffness bolt with a high stiffness member

$P_b < P_m$

The bolt takes only a small portion of the external force.
(Recommended)



High stiffness bolt with a low stiffness member

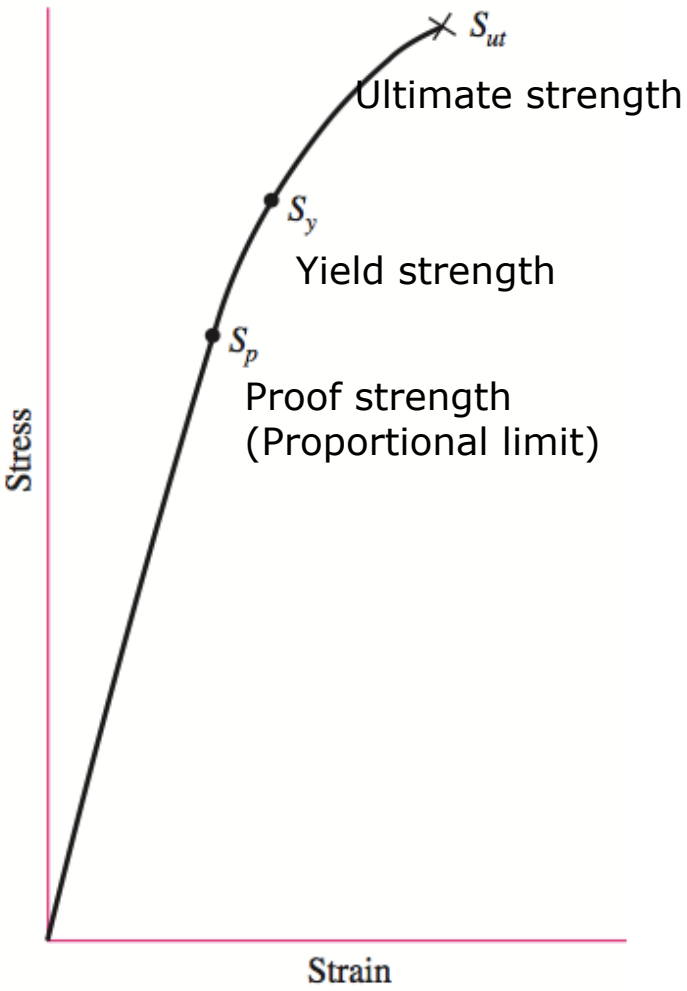
$P_b > P_m$

The bolt takes the majority of the external force.
The bolt size needs to be reduced.

Mechanical Fastening

- Importance of Preload in tension
  - If it is too low,
    - Joint separation in vibration
    - Joint slip in transverse vibration
    - Gasket leakage
  - The washer increases the area of load transfer and prevent local deformation on the joint members.

Stress-strain curve of good bolt materials



- Recommended preload

Proof load

$$F_p = A_t S_p$$

A_t: Tensile stress area

$$F_i = \begin{cases} 0.75F_p & \text{for nonpermanent connections, reused fasteners} \\ 0.90F_p & \text{for permanent connections} \end{cases}$$

Mechanical Fastening

- **Shear load bearing**

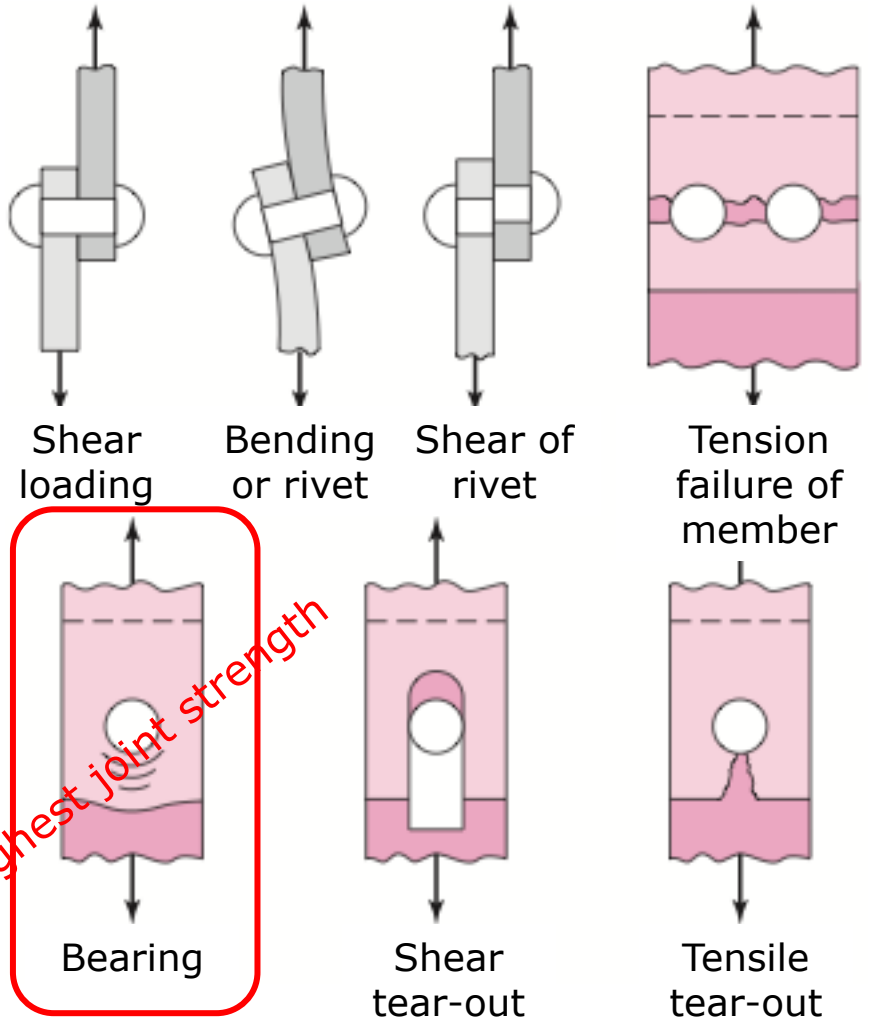
Bending failure $\sigma = \frac{M}{I/c}$

Shear failure $\tau = \frac{F}{A}$

Tension failure $\sigma = \frac{F}{A}$

Bearing failure $\sigma = -\frac{F}{A}$

Shear & Tensile tear-out failures should be avoided by spacing the fasteners away from the edge.



< Different failure modes >

Mechanical Fastening

- **Shear load bearing**

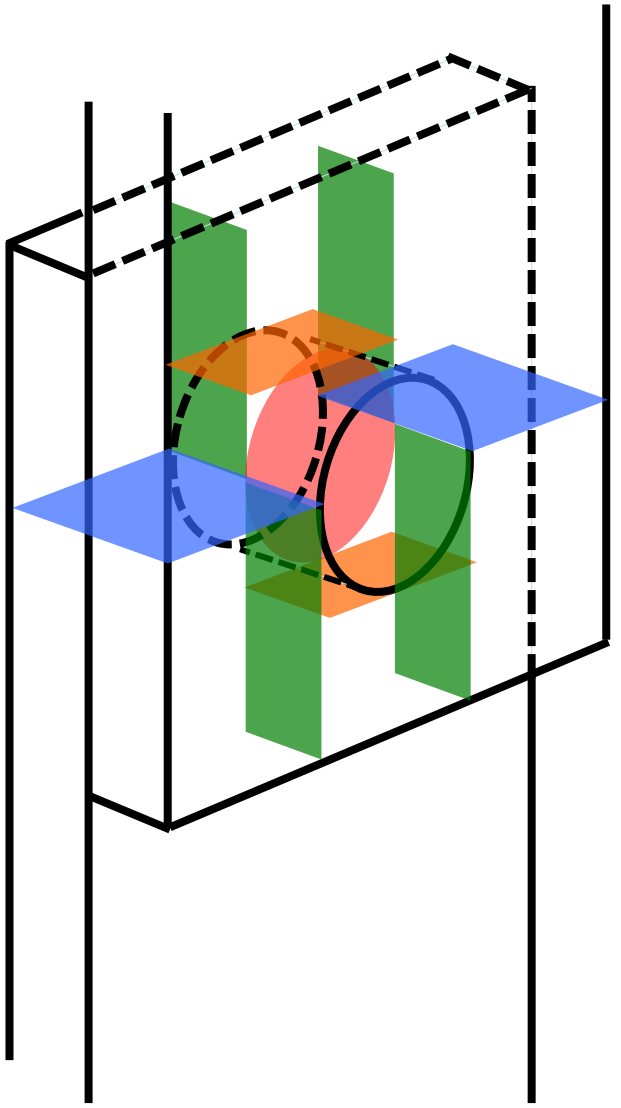
Bending failure $\sigma = \frac{M}{I/c}$

Shear failure $\tau = \frac{F}{A}$

Tension failure $\sigma = \frac{F}{A}$

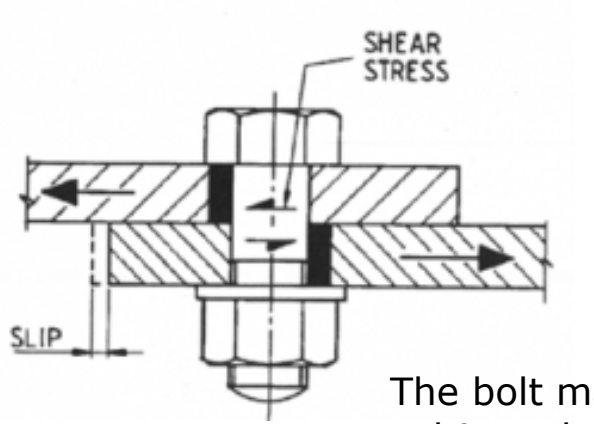
Bearing failure $\sigma = -\frac{F}{A}$

Shear tear-out & Tensile tear-out failures should be avoided by spacing the fasteners away from the edge.

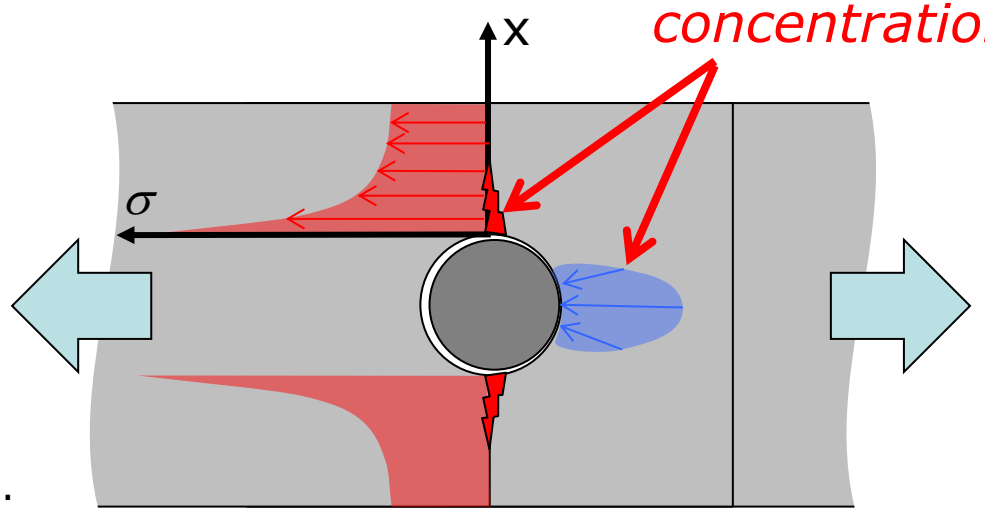


Mechanical Fastening

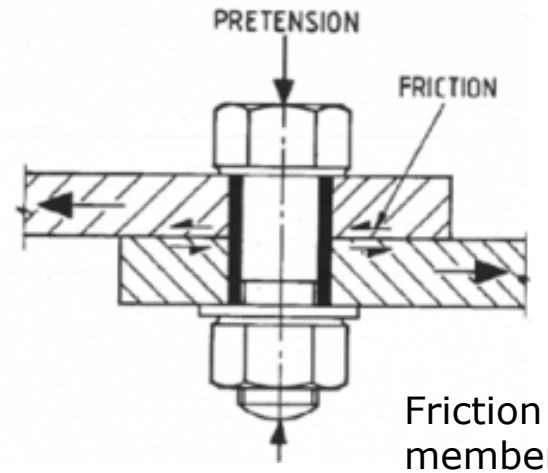
- Importance of Preload in Shear



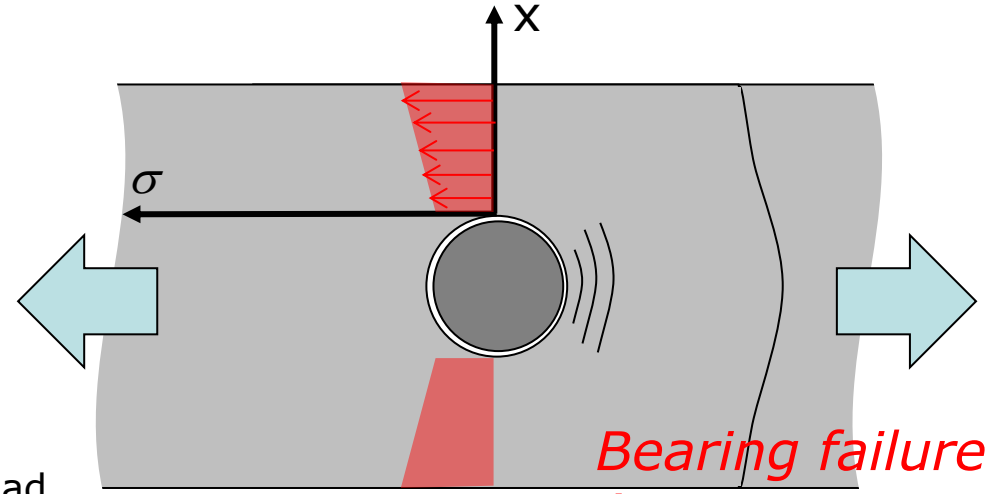
The bolt may be subjected to shear load.



Stress concentration



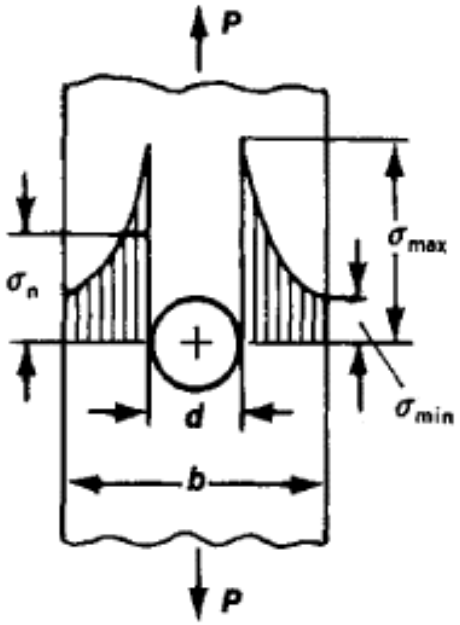
Friction between the members carries the load.

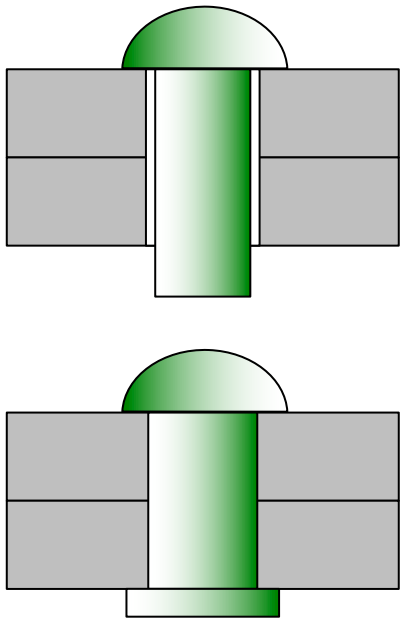


Bearing failure (Not catastrophic)

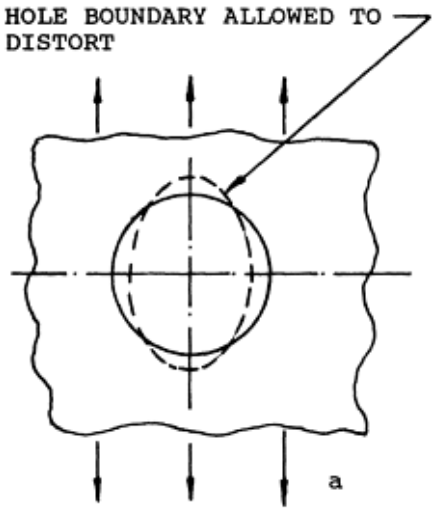
Mechanical Fastening

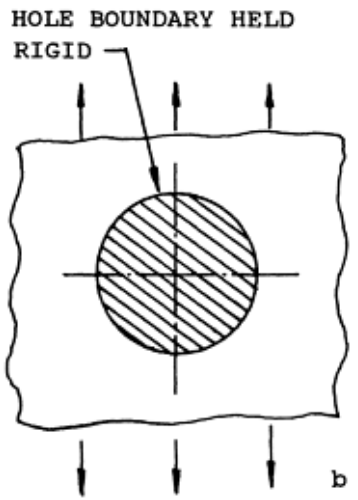
- Common rivets cannot provide high preload. However, better hole filling can reduce the stress concentration.

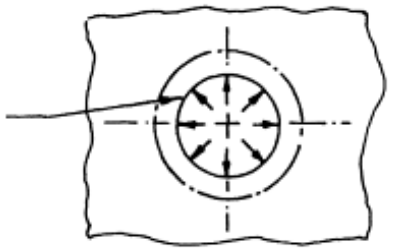




Ref. S.N. Atluri, S.G. Sampath, P. Tong, Structural Integrity of Aging Airplanes, Springer-Verlag, 1991.



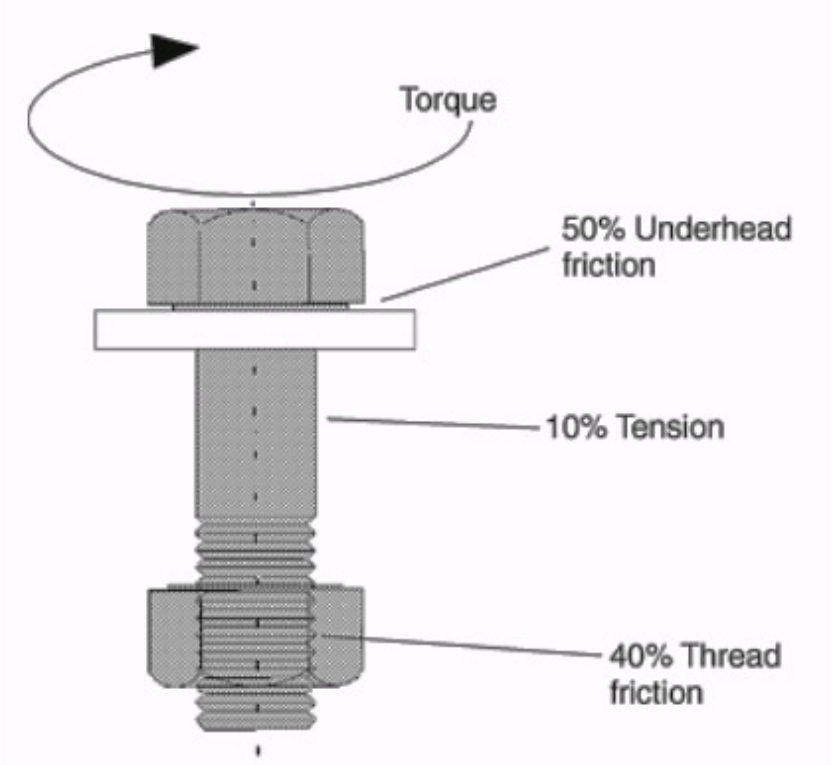




Mechanical Fastening

- How to apply the preload
  - Torque wrenches are the most popular way. However, there is always an error since the friction on the contact surfaces might take a considerable torque or the bolt might be twisted.

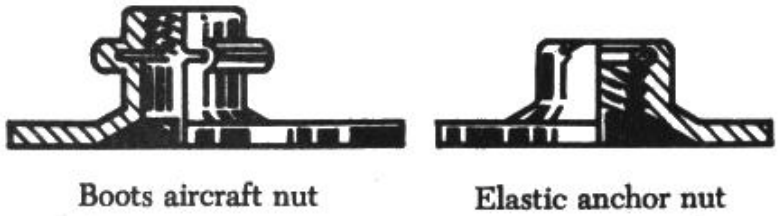
Typical distribution of energy from torque applied to a bolted assembly

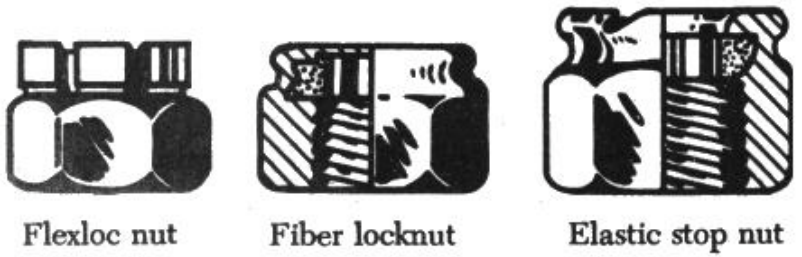


Method		error
Torque wrench on	Unlubricated bolts	±35%
	Cad-plated bolts	±30%
	Lubricated bolts	±25%
Strain gages		±1%
Computer controlled wrench	Below yield	±15%
	Yield sensing	±8%
Measuring bolt elongation		±5%

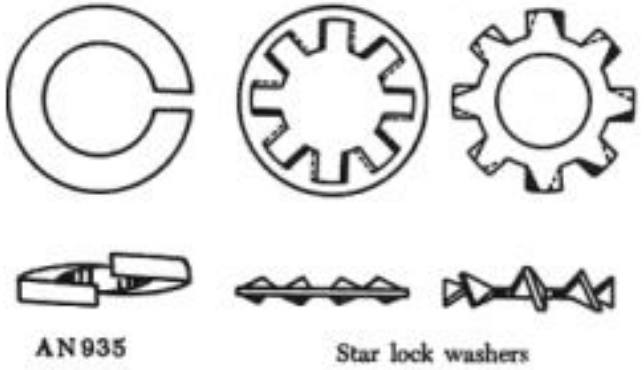
Mechanical Fastening

- Prevention of loosening





< Self-locking nuts >

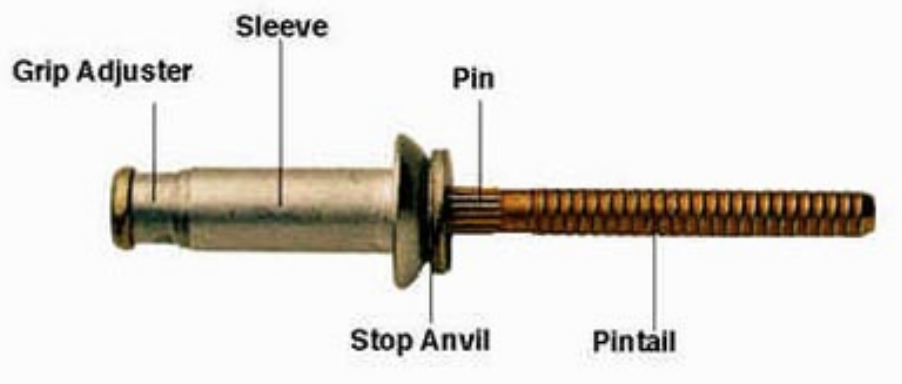


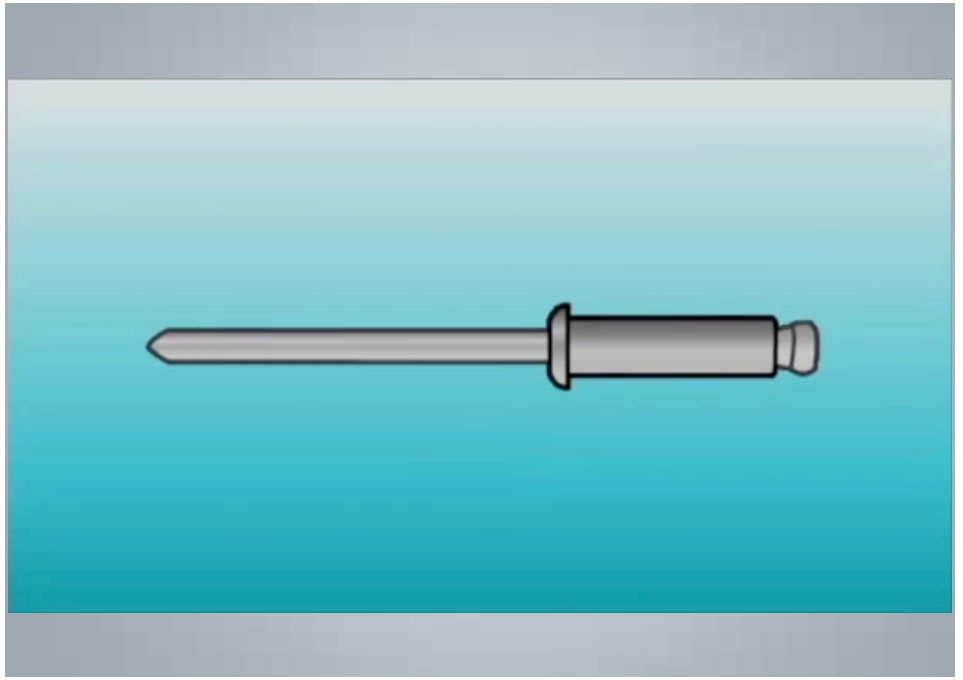
< Spring or Self-locking washers >

Rivets

Solid rivet

Blind rivet





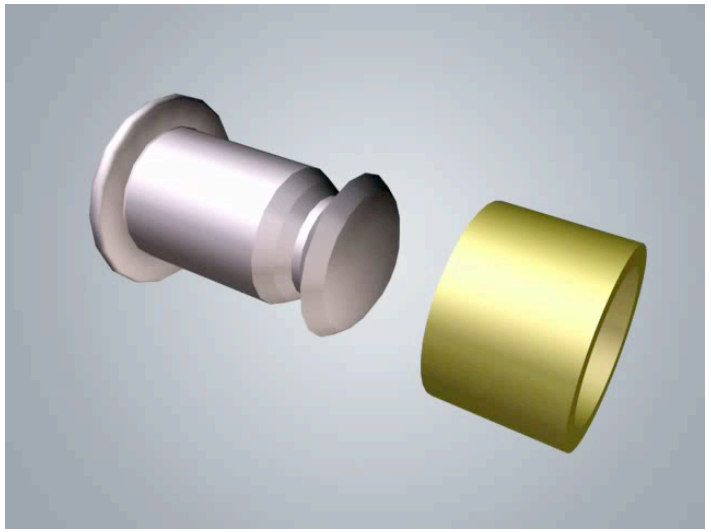
Rivet installation process

How to repair a dent in the aircraft fuselage - http://youtu.be/b7pkHXtgM5A

Fastener materials

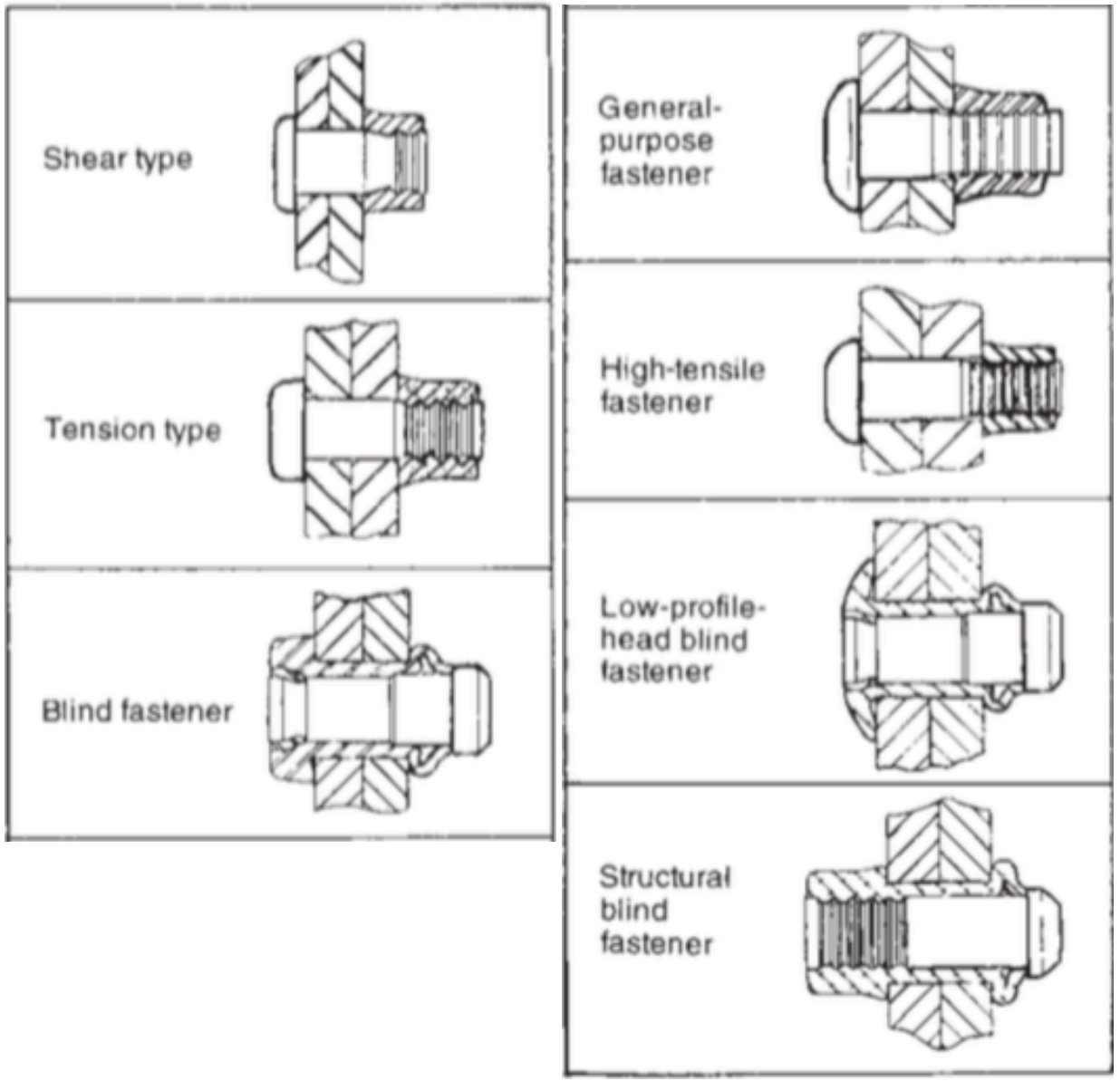
- Bolts
  - Carbon steel, alloy steel, stainless steel, titanium, aluminium
  - Steel fasteners are usually plated or coated for corrosion protection. (e.g. Cadmium or Zinc plating)
  - Steel fasteners should not be used at low temperature (become brittle).
  - Galvanic corrosion, Stress corrosion (fatigue life reduction)
- Rivets
  - Ductile
  - The materials must have cold-forming capability without cracking.
  - Aluminium, Monel (nickel alloy), brass, steel, stainless steel, titanium

Special fasteners



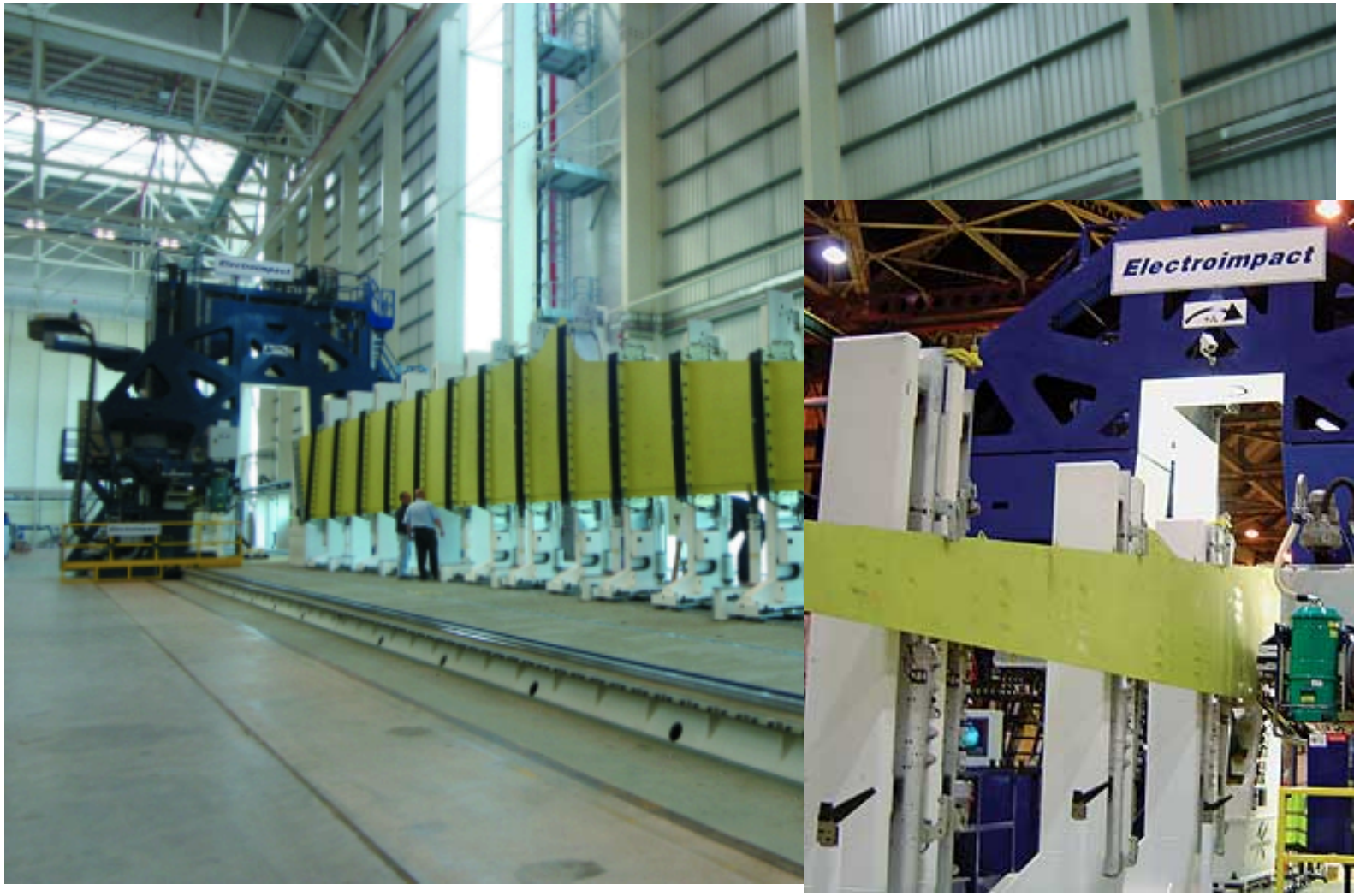
< Hi-Shear fastener >

< Hi-Loc fastener>

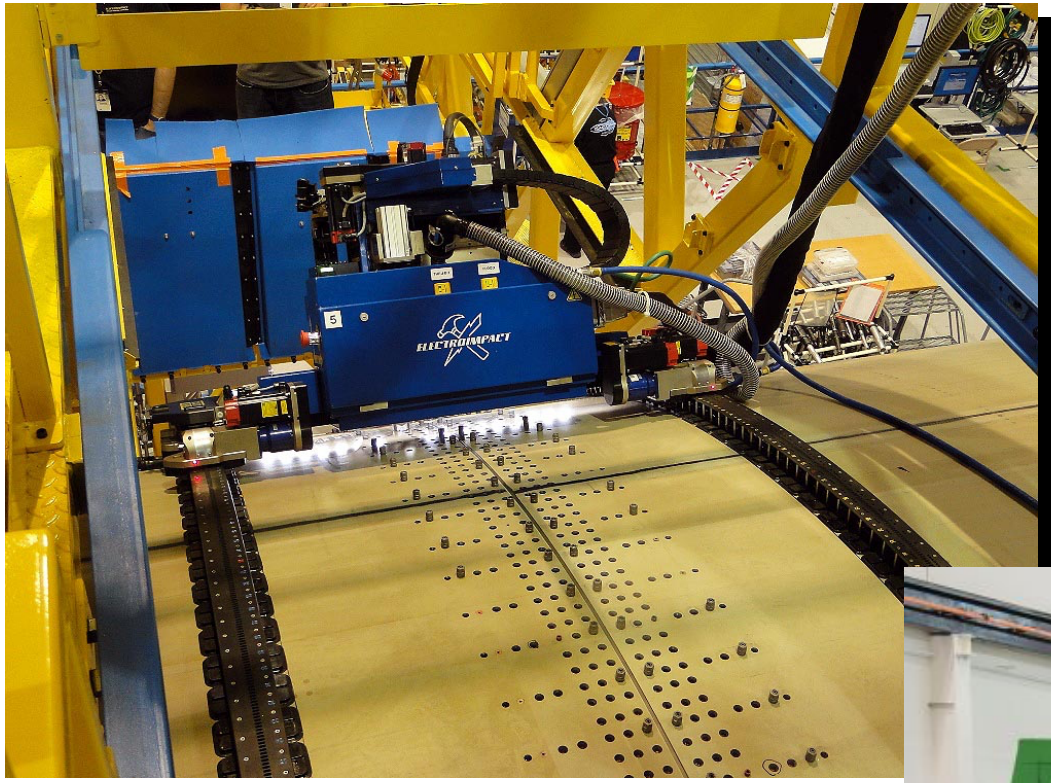


Automation

- Automated drilling / riveting machines



Automation



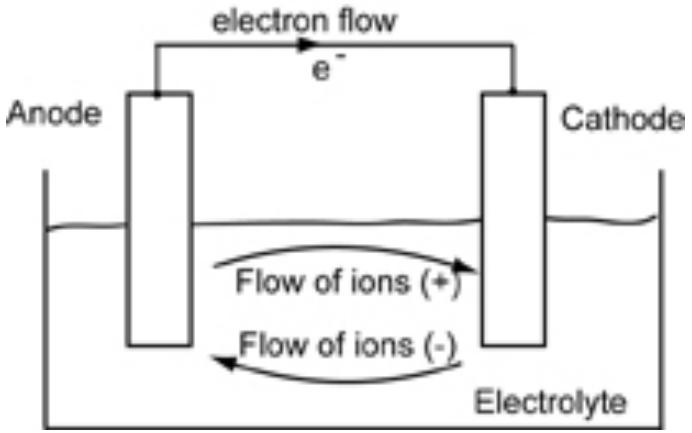
Flex Track (Electroimpact, USA)
https://youtu.be/ToRVNS_kuXo

Boeing FAUB (KUKA, Germany)
https://youtu.be/lgEQngIuifQ

The things you need to know for mechanical joining of composite materials

Mechanical joints for composites

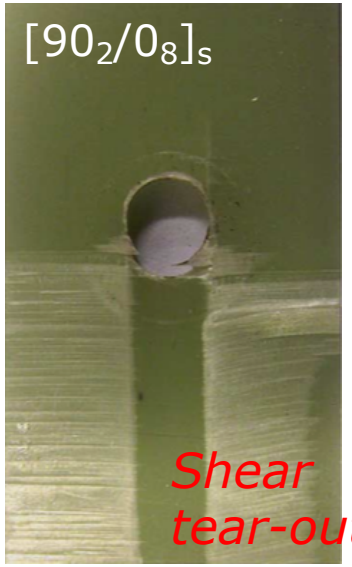
- Galvanic corrosion
  - Carbon fibre: Cathodic (Noble) vs. Metal: Anodic (Least noble)
  - Difference in electrical potential can promote metal corrosion in humidity.
  - Prevention:
    - Corrosion barriers (fiberglass or sealants) at the interface between composites and metals.
    - Insulation coating of fasteners
    - Using fasteners made of special alloys



< Source: Nedschroef, DE >

Mechanical joints for composites

- Failure modes affected by the *stacking sequence*



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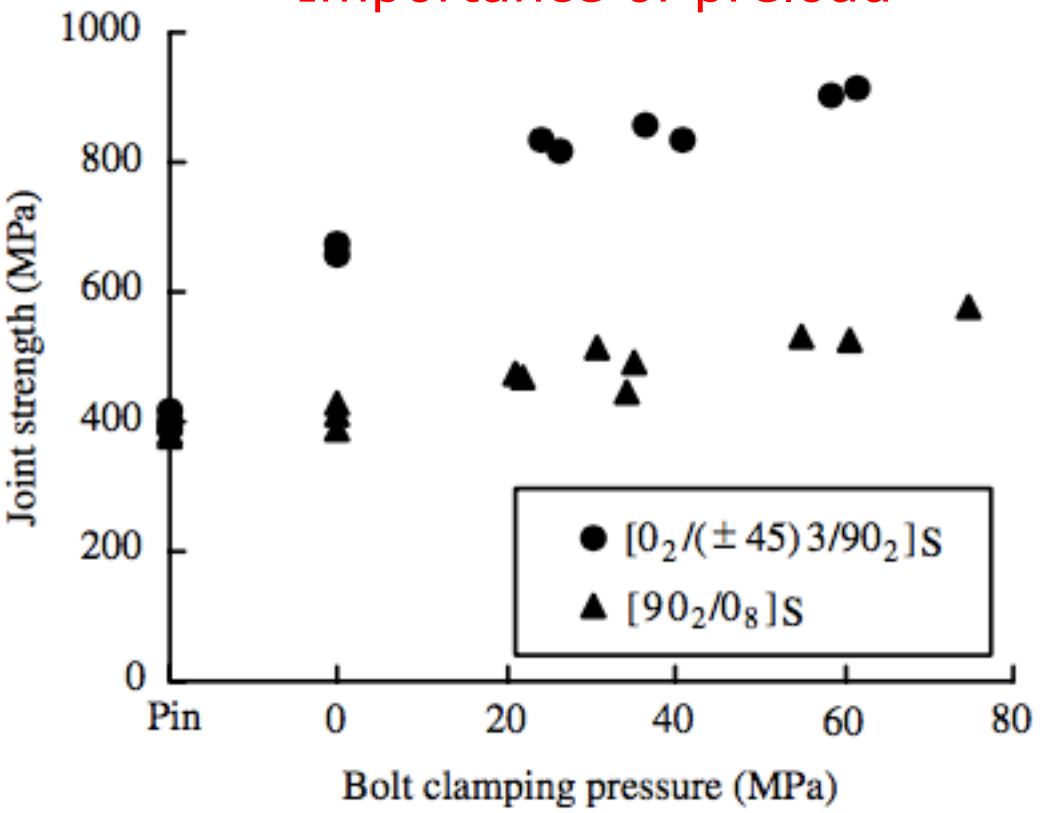
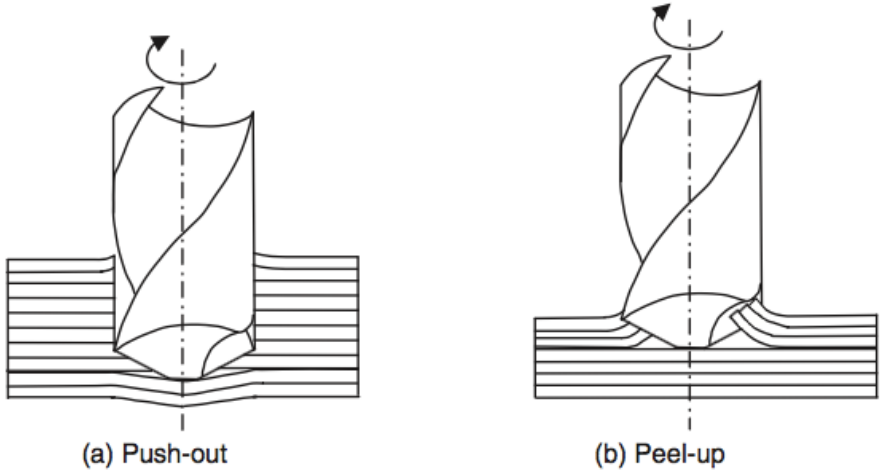
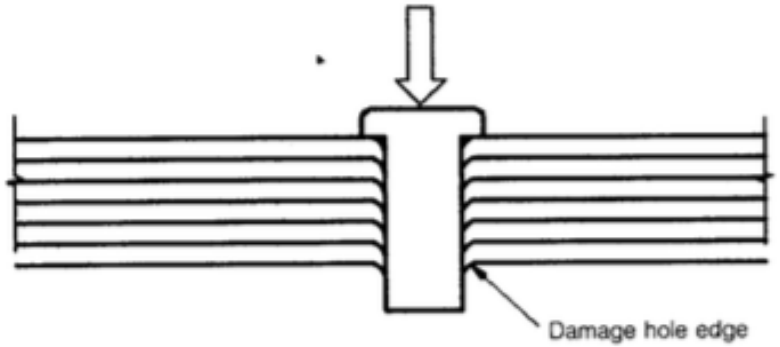


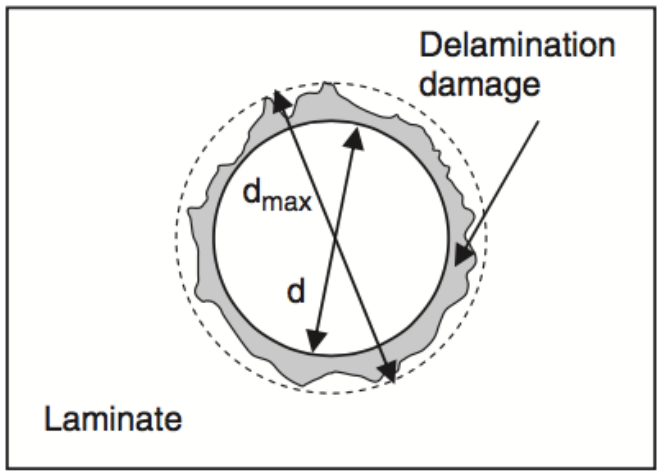
Ref. Lim TS, Kim BC, Lee DG. Fatigue characteristics of the bolted joints for unidirectional composite laminates, Compos Struct 2006;72:58-68.

Mechanical joints for composites

- Damages during machining and installation







- Tool material
- Tool wear
- Drilling speed, feed rate, thrust force
- Stacking sequence
- Clamping of work piece

Health & Safety issue

References

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Next Lecture

Adhesive Joining

Quiz