Aerospace Structures

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WINGS

Wings

Wings develop the major portion of the lift of a heavier than air aircraft. **Wing structures carry some of the heavier loads** found in the aircraft structure

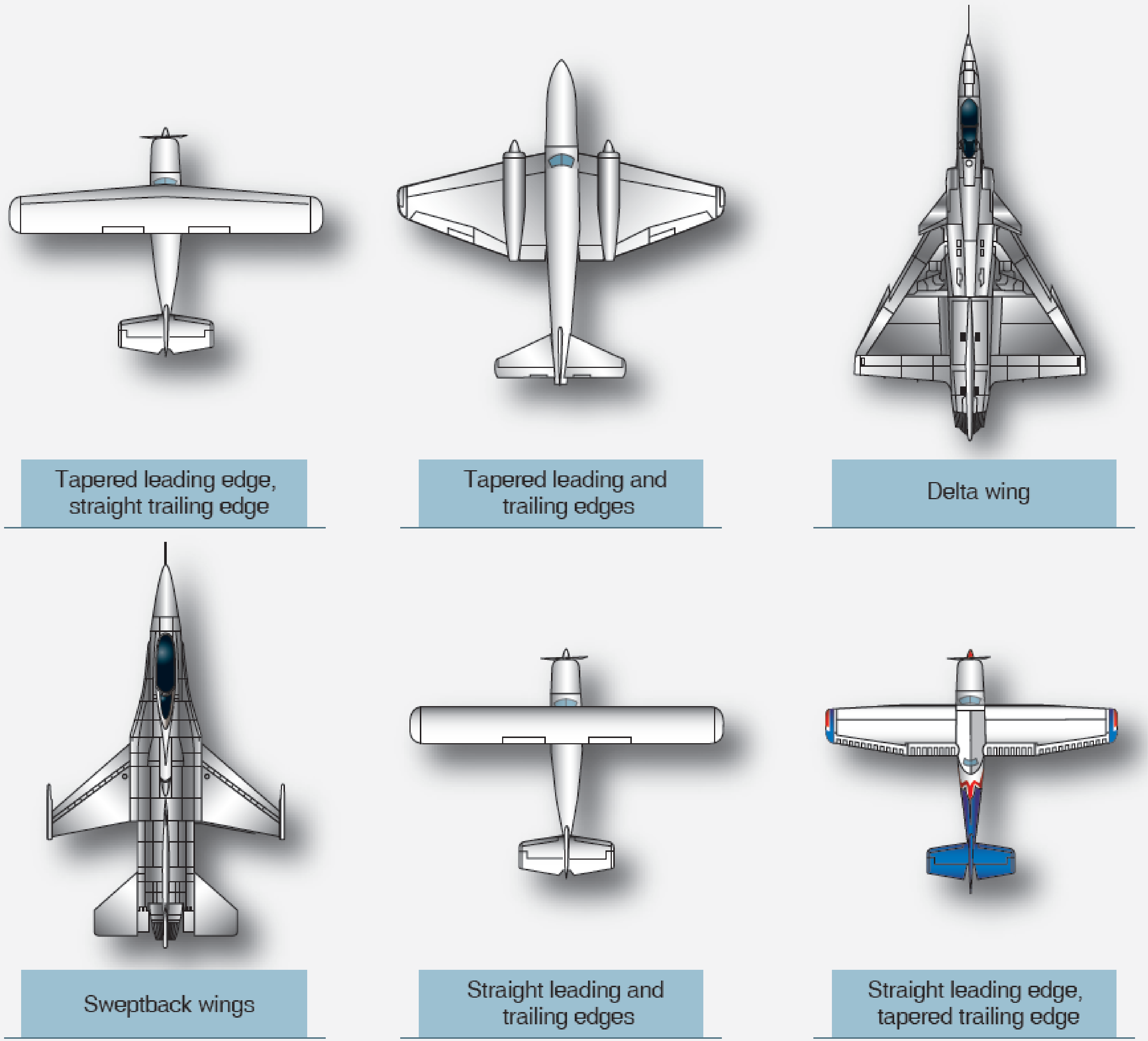
Any wing requires longitudinal members

These **members are lengthwise with the wing** and withstand a variety of loads

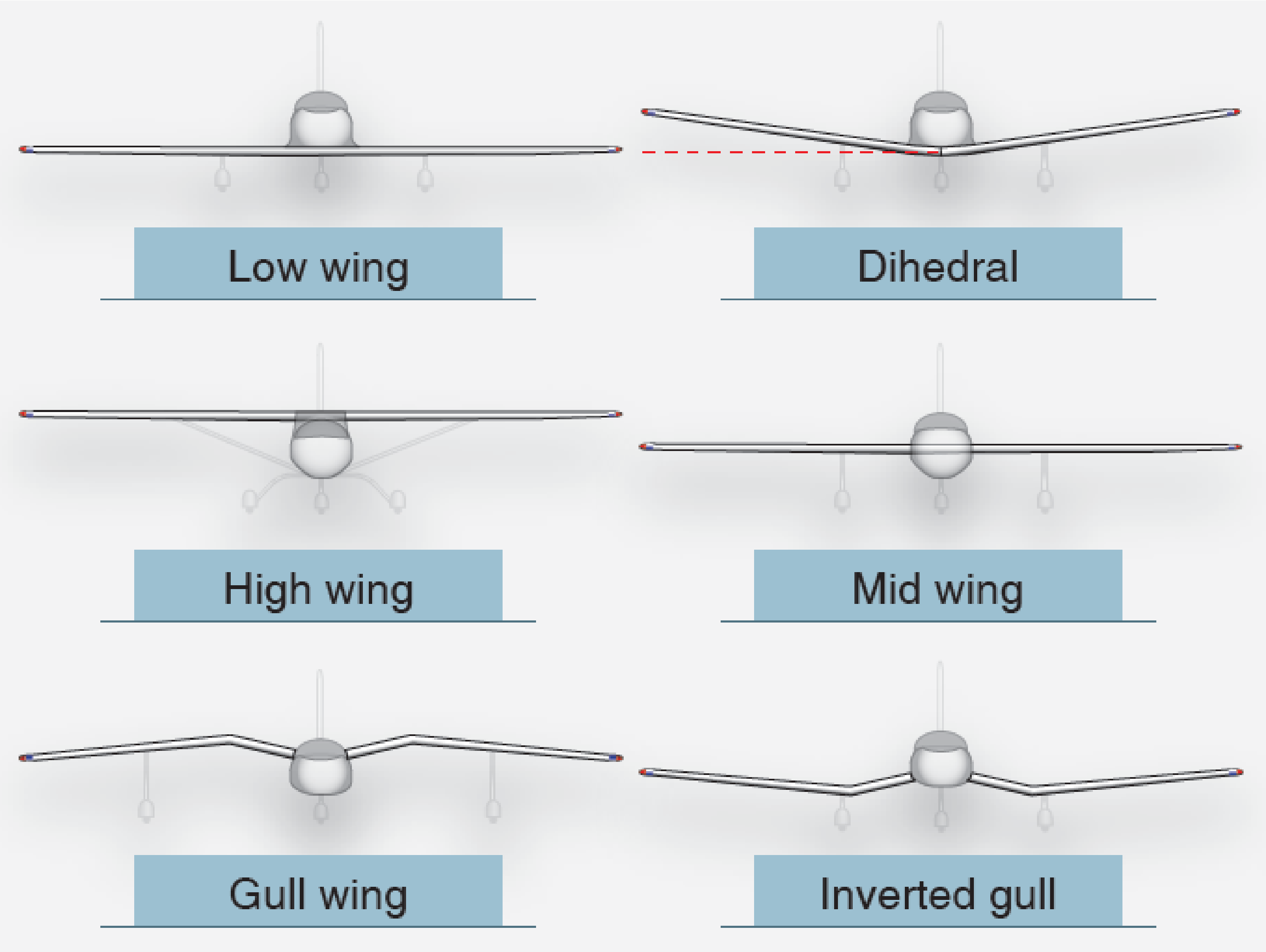
Wings

Left

Right

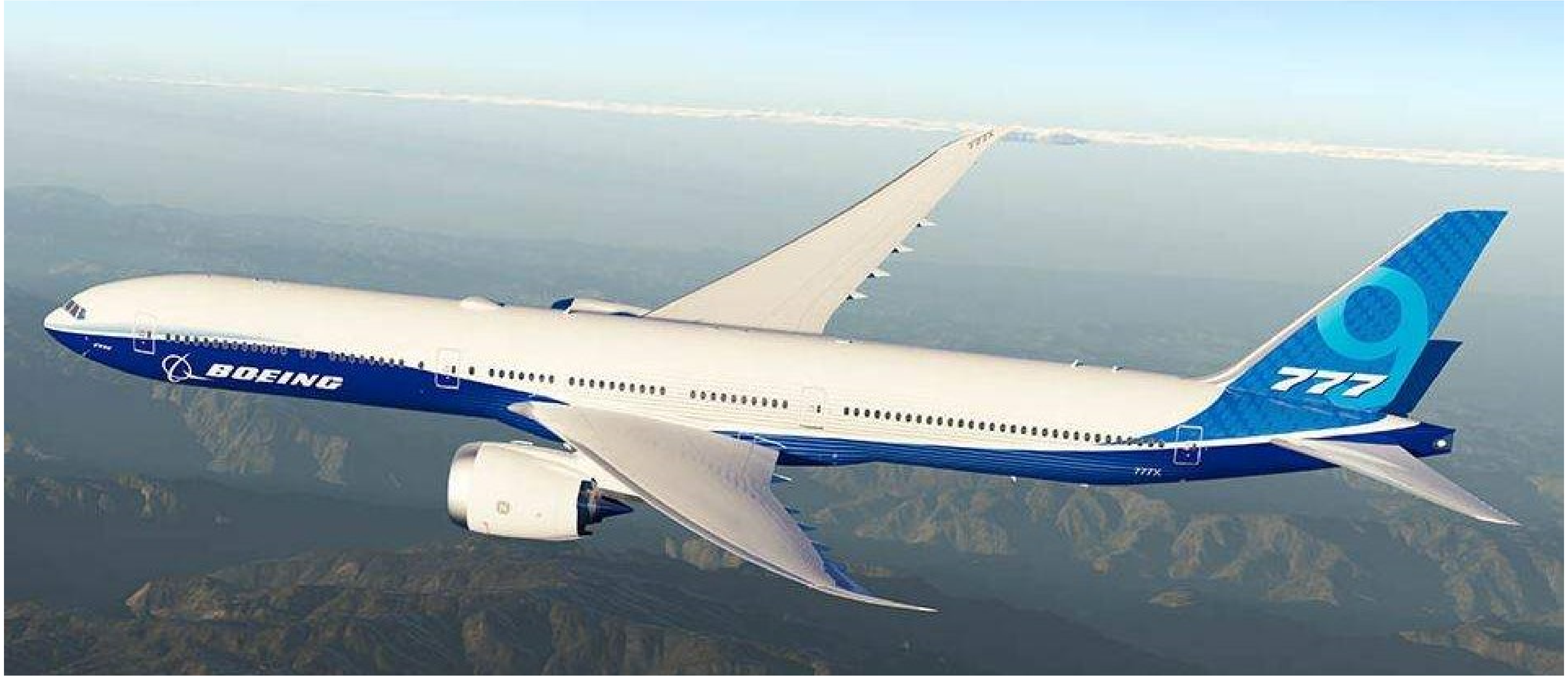

Tapered leading edge, straight trailing edge
Tapered leading and trailing edges
Delta wing
Sweptback wings
Straight leading and trailing edges
Straight leading edge, tapered trailing edge

Wings


Low wing
Dihedral
High wing
Mid wing
Gull wing
Inverted gull

Wings

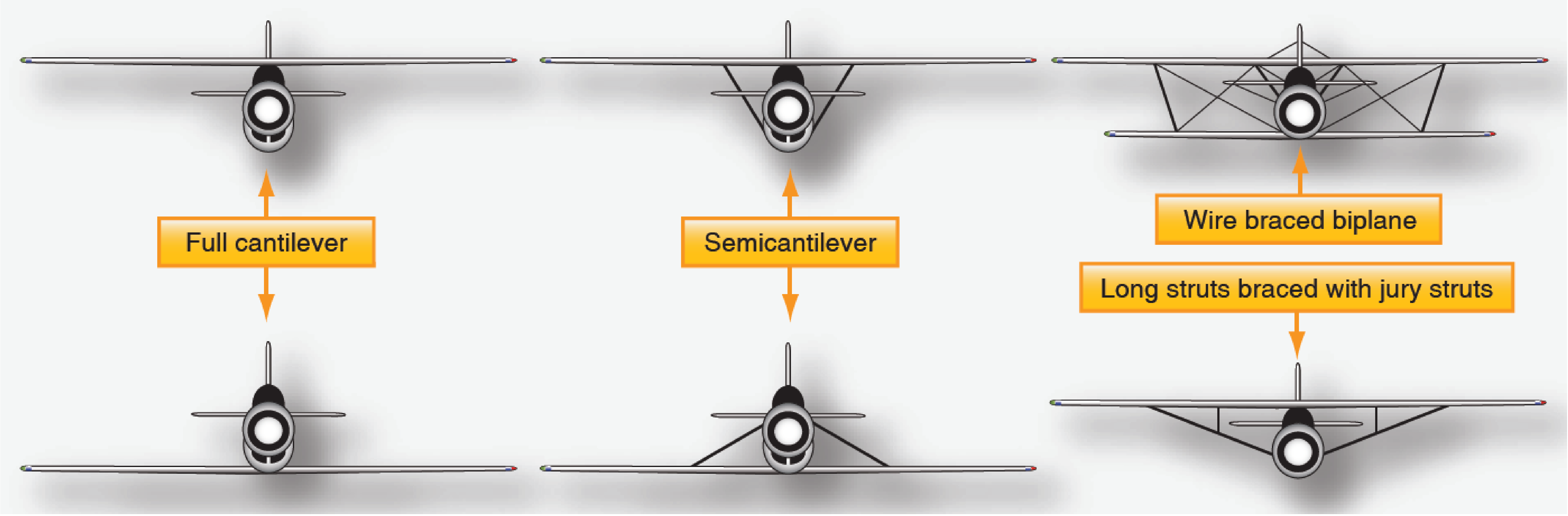
Higher performance aircraft usually have **cantilever wings**



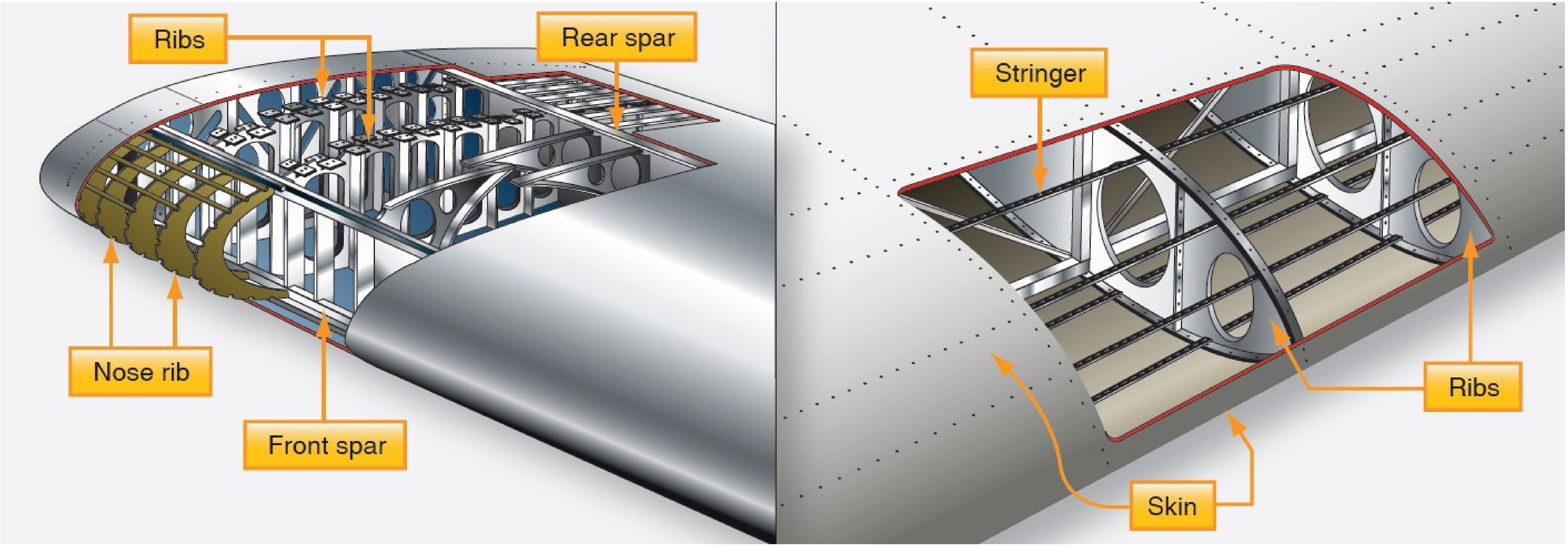
Wings

Light aircraft may have **external struts** for wing bracing

Wings


Full cantilever
Semicantilever
Wire braced biplane
Long struts braced with jury struts

Wings



Wings

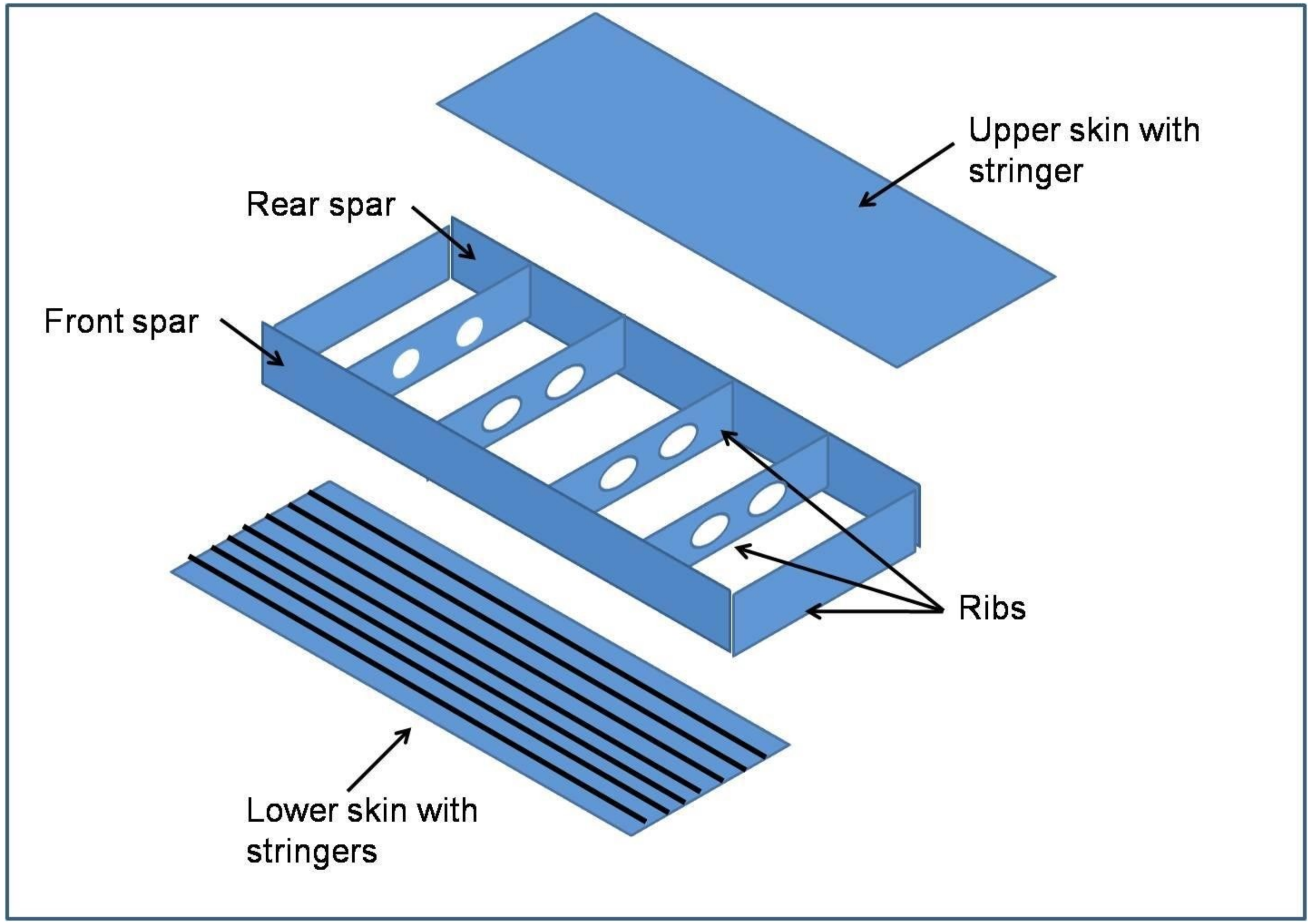
The wing is essentially a beam which **transmits and gathers all of the applied air load** to the central attachment to the fuselage.

The wing itself is a **lightweight, stiff and strength** internal structure.

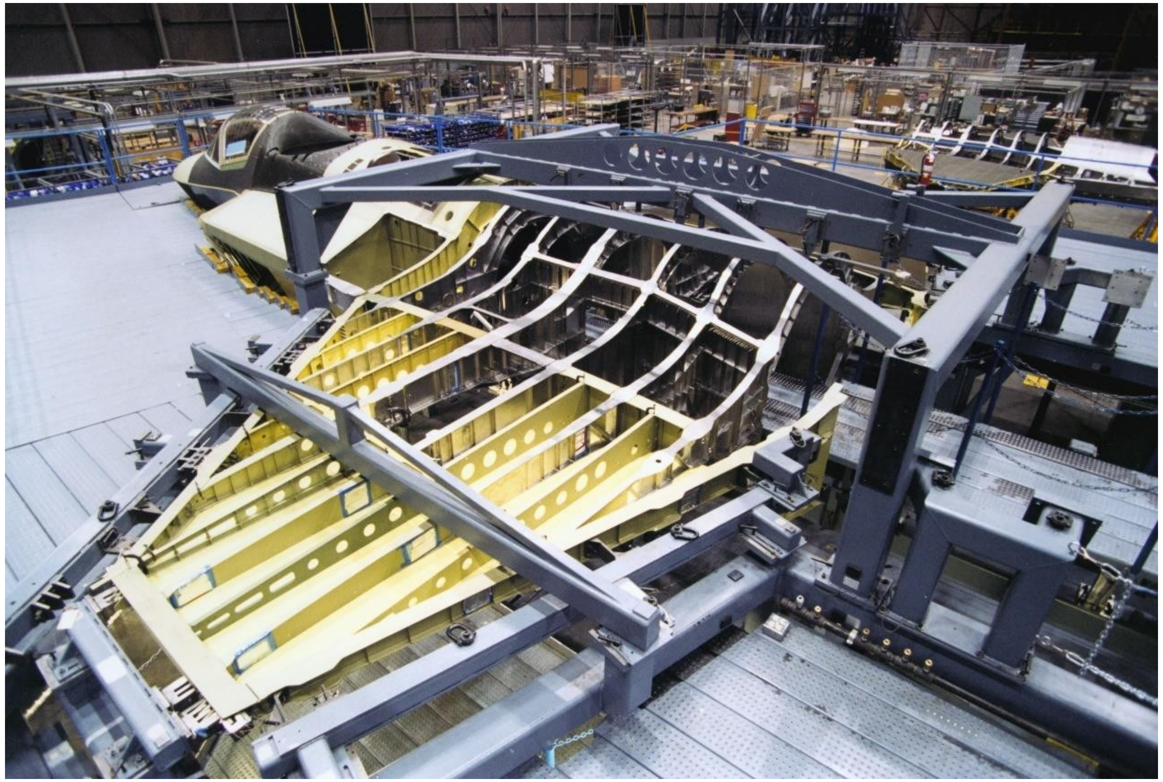
For preliminary purposes:

$$\text{wing load} = \text{aircraft weight} \times \text{load factor} \qquad \times 1.5$$

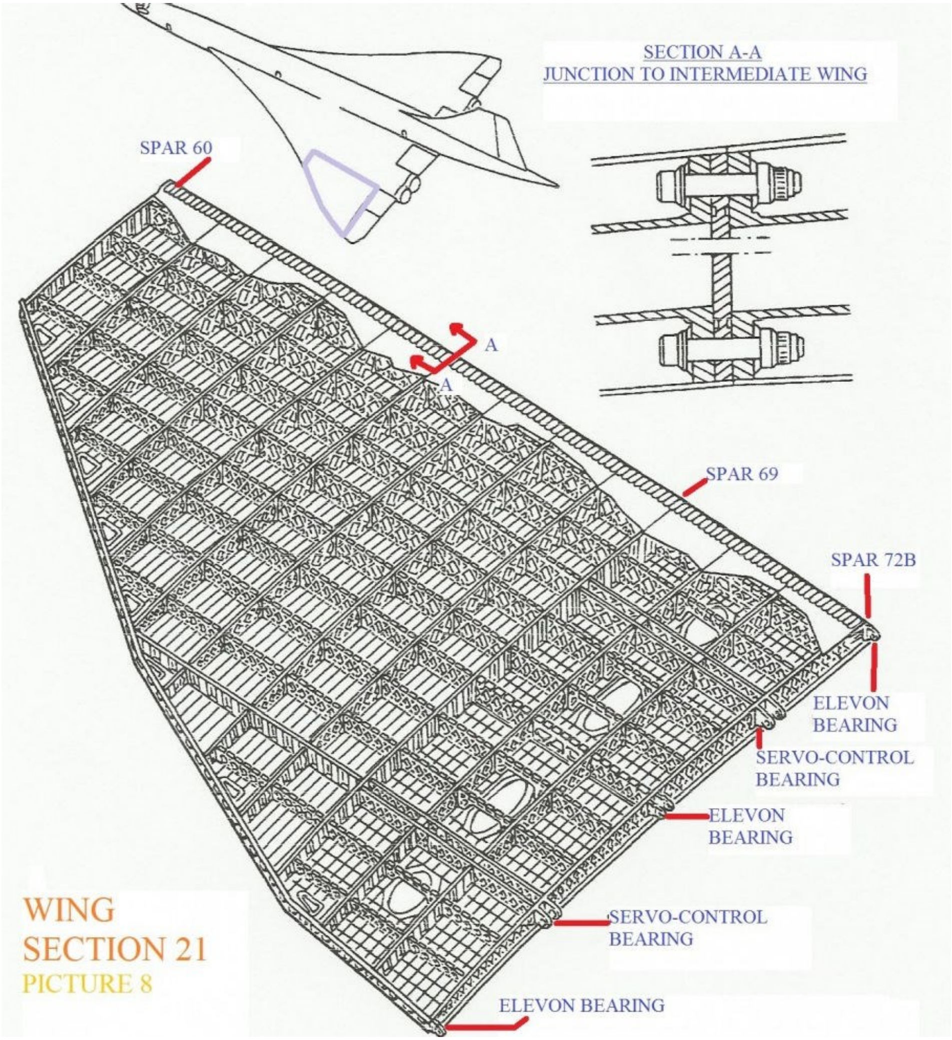
Wing type 1: Boxbeam structure

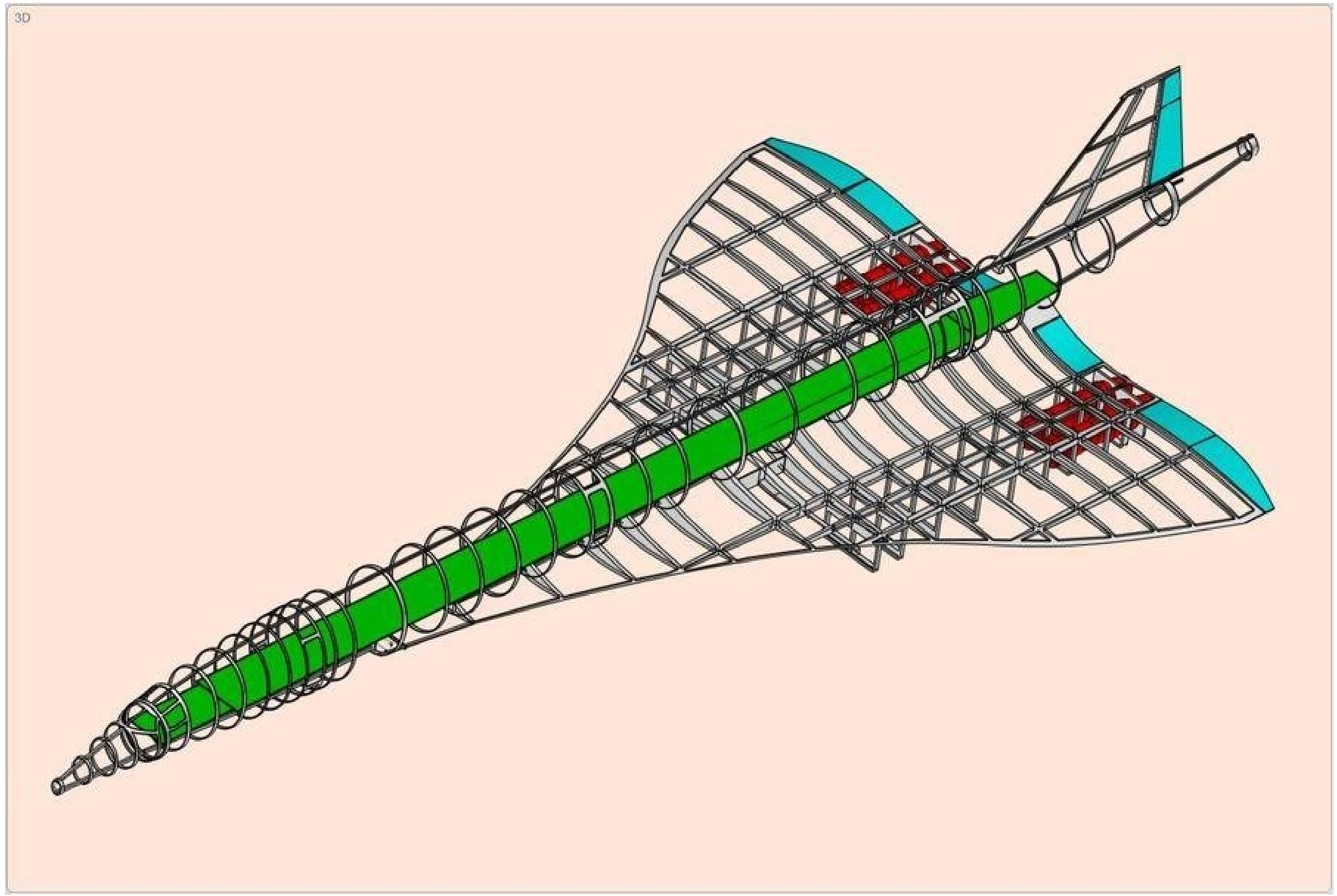


Wing type 2: Multispar wing (fighters)

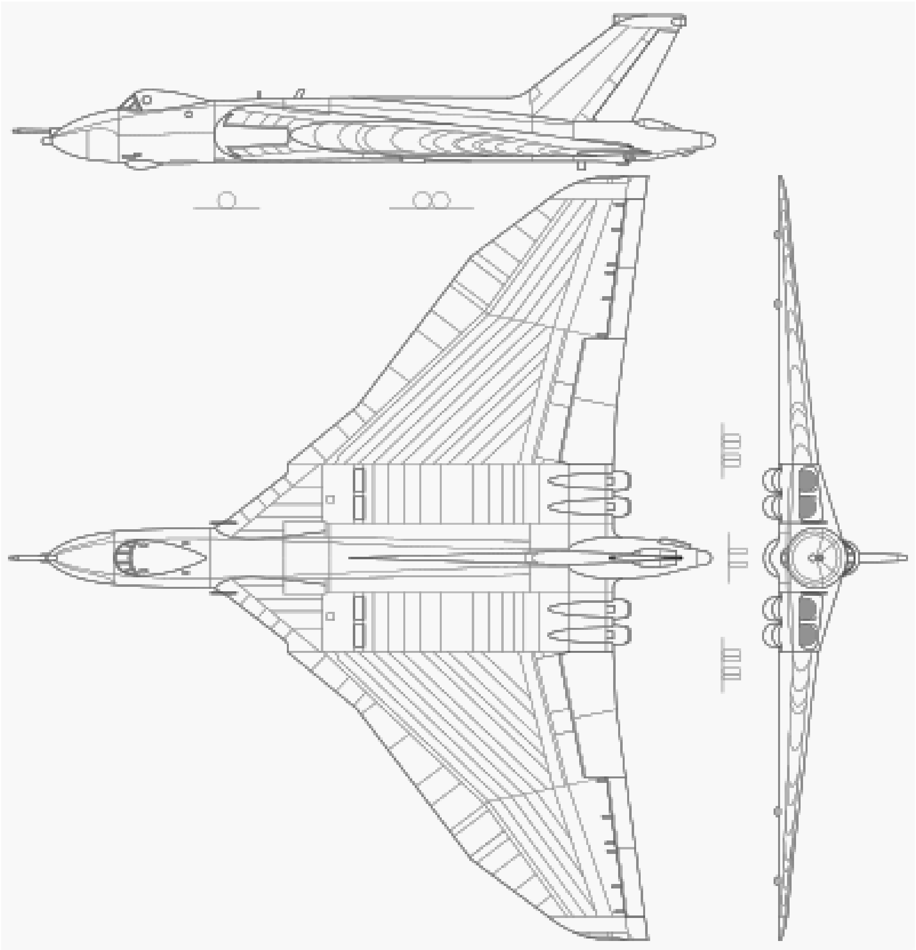


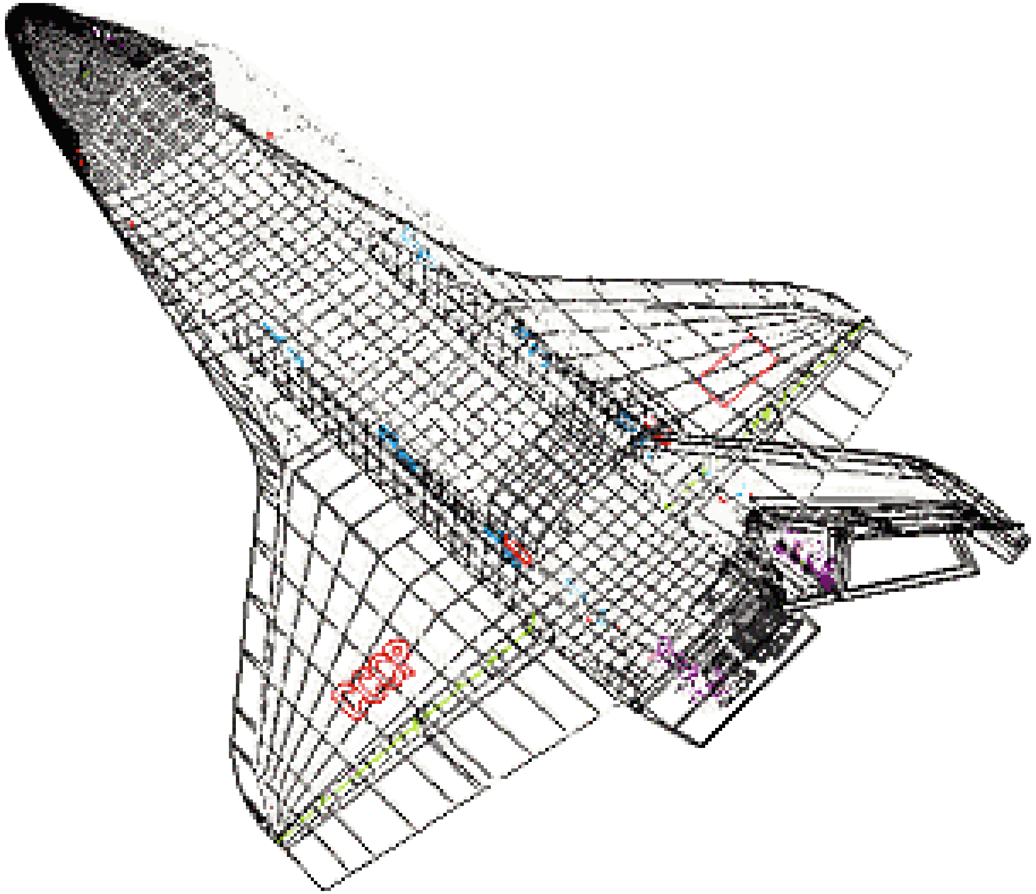
Wing type 3: Deltawing (multispar)





Wing type 3: Deltawing (converging spars)

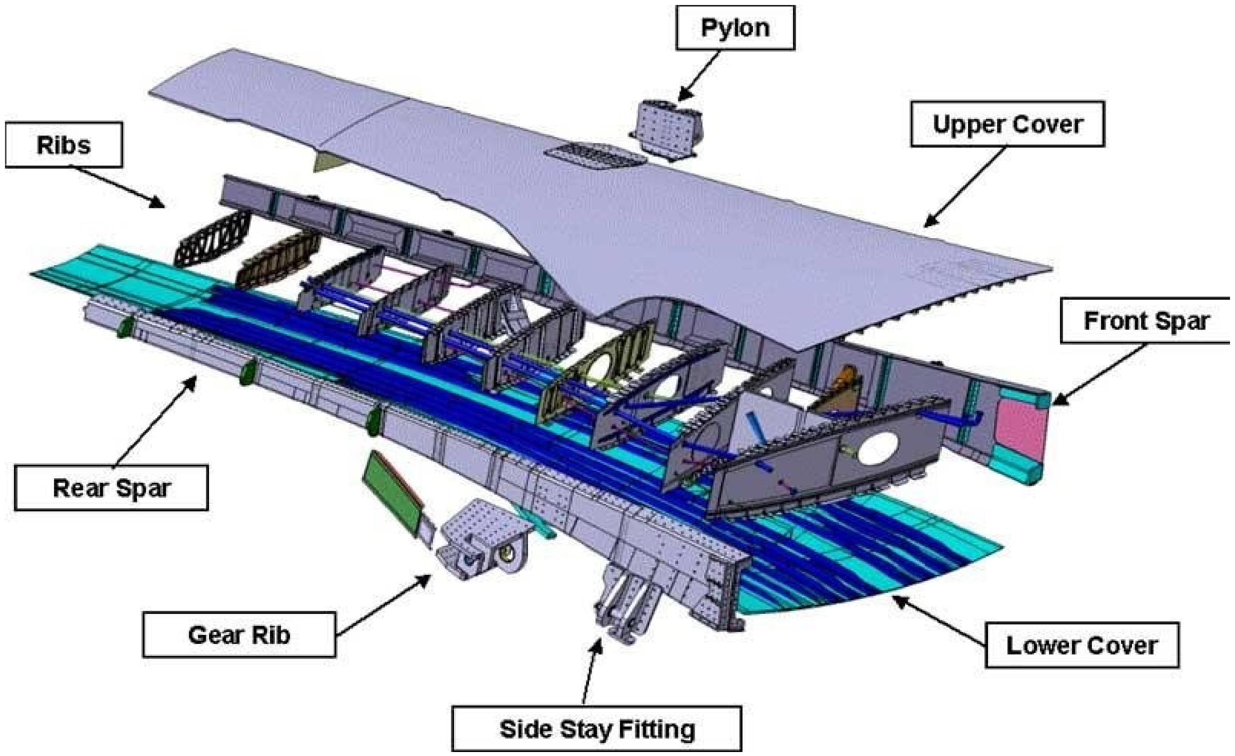




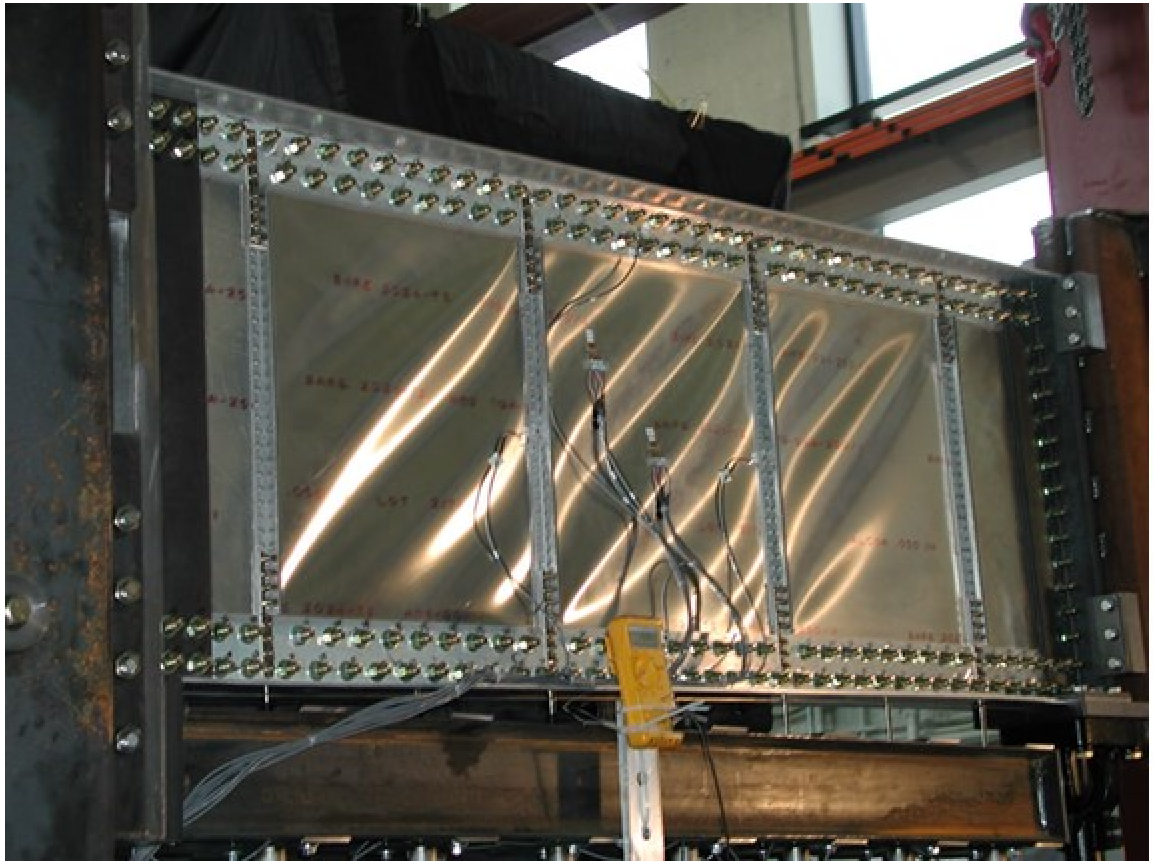
Wings

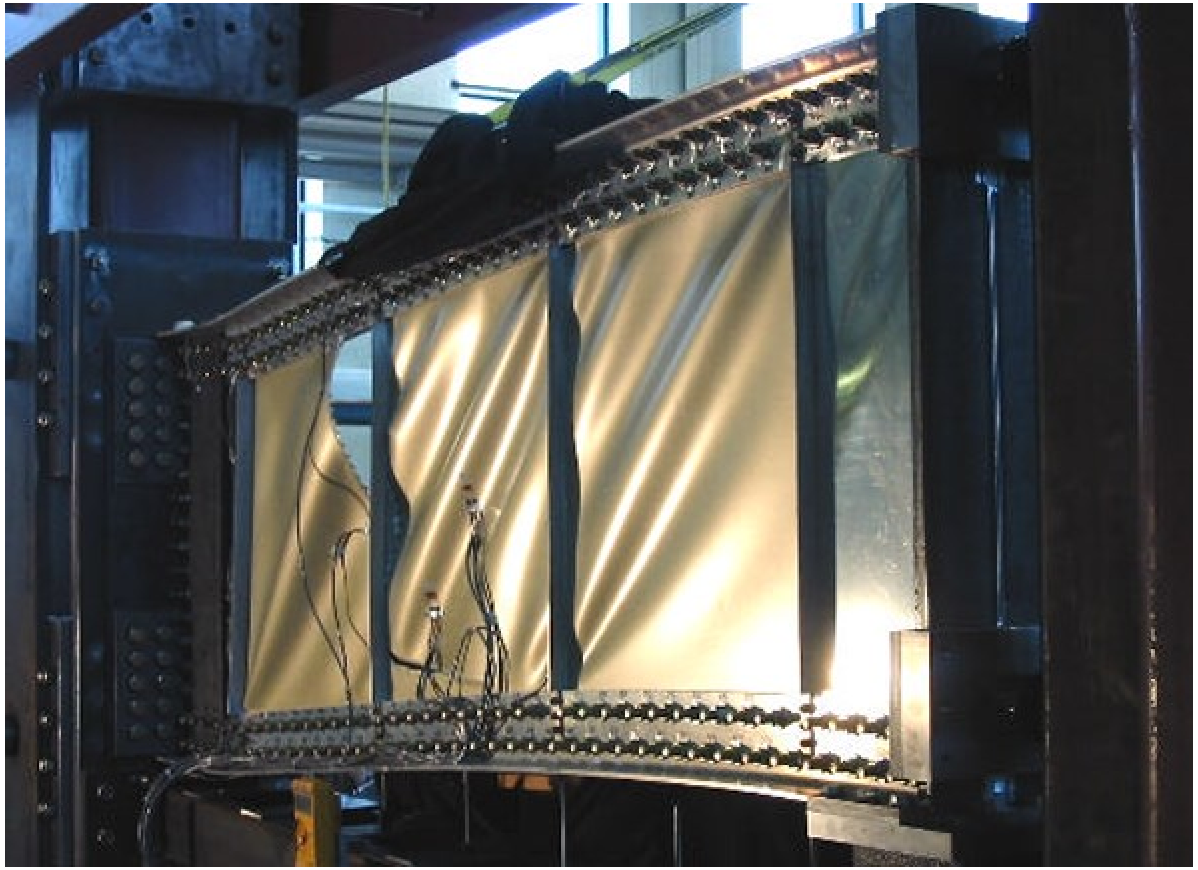
The applied air-loads result in increasing shear and bending moments towards the wing root with:

- The shear carried by the wing spars.
- The bending moment by the wing covers (stiffened skin).

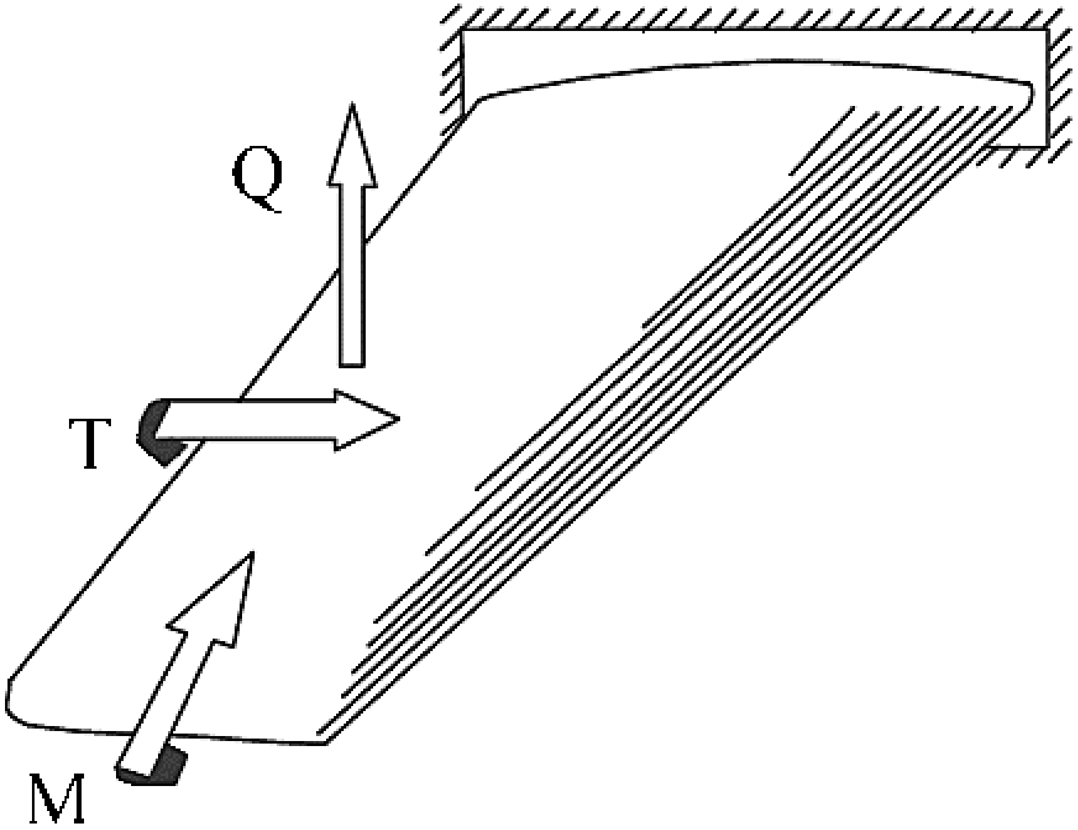


Wings

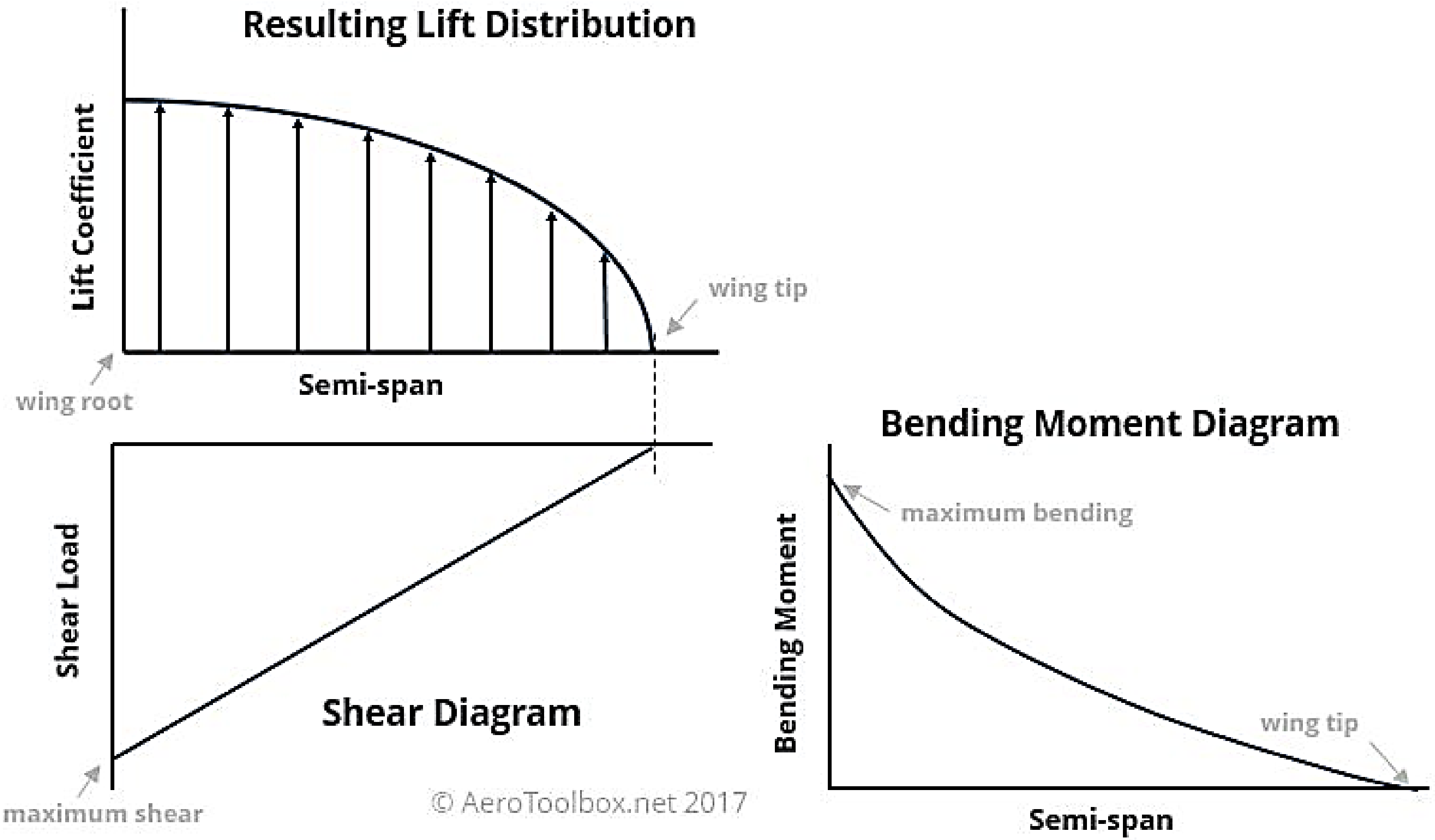




Wings



Wings



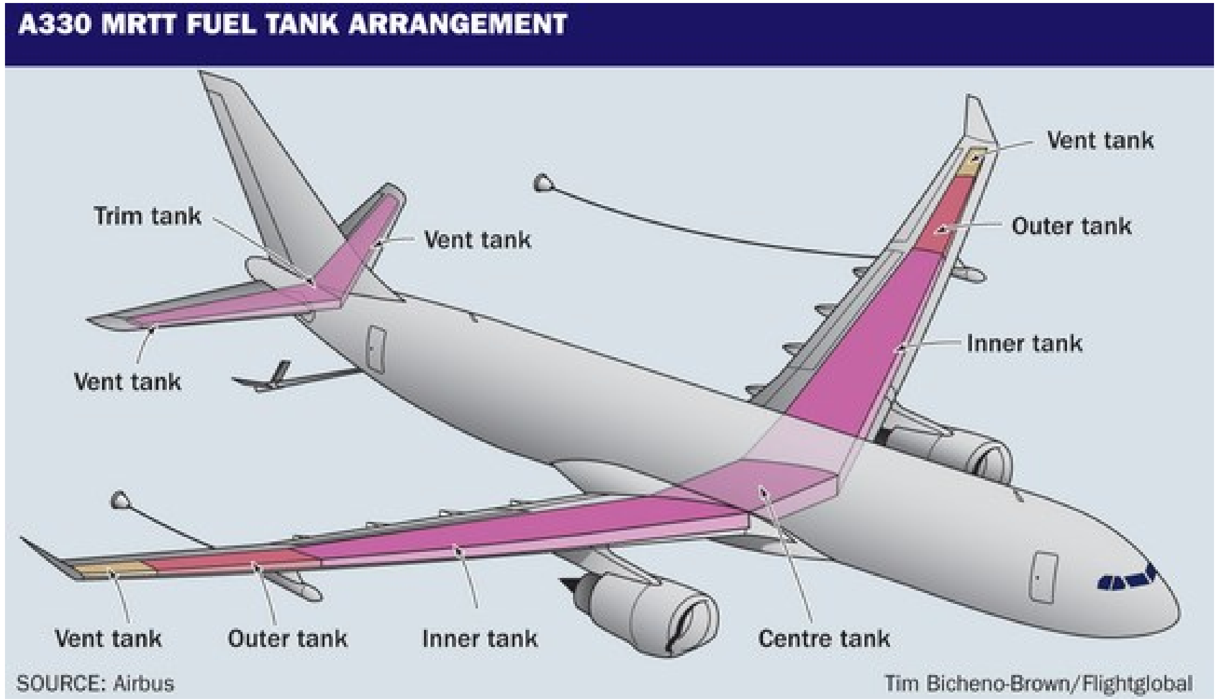
Resulting Lift Distribution
Lift Coefficient
wing tip
wing root
Semi-span
Bending Moment Diagram
maximum bending
Shear Load
Bending Moment
Shear Diagram
wing tip
maximum shear
© AeroToolbox.net 2017
Semi-span

Other wing loads (secondary loads)

Internal fuel pressure (static and dynamic)

Landing gear attachment loads

Wing leading and trailing loads



Covers

Since covers typically represent **50% to 70%** of the structural weight of the wing, they have to be **designed as efficiently as possible**.

Lower cover is loaded primarily in **tension**, its design is fairly straight forward.

Upper cover optimum design is far **more complex and configuration dependent**. Upper cover is loaded **primarily in compression**, its design efficiency is dictated primarily on how well it can be stabilized, that is, **prevented for buckling**


QANTAS
← B8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Variable swept wings

The pivot pin of the B-1 is a titanium pin

L = 38 in (96.54 cm)
D = 18 in (45.72 cm)

https://www.youtube.com/watch?v=ZcZ8G3oxtUY

Wings (general layout)

The design of the wing-body joint, and development and sizing of the hydraulic components, control components, and electrical systems **may require changing the spar locations as design progresses**.

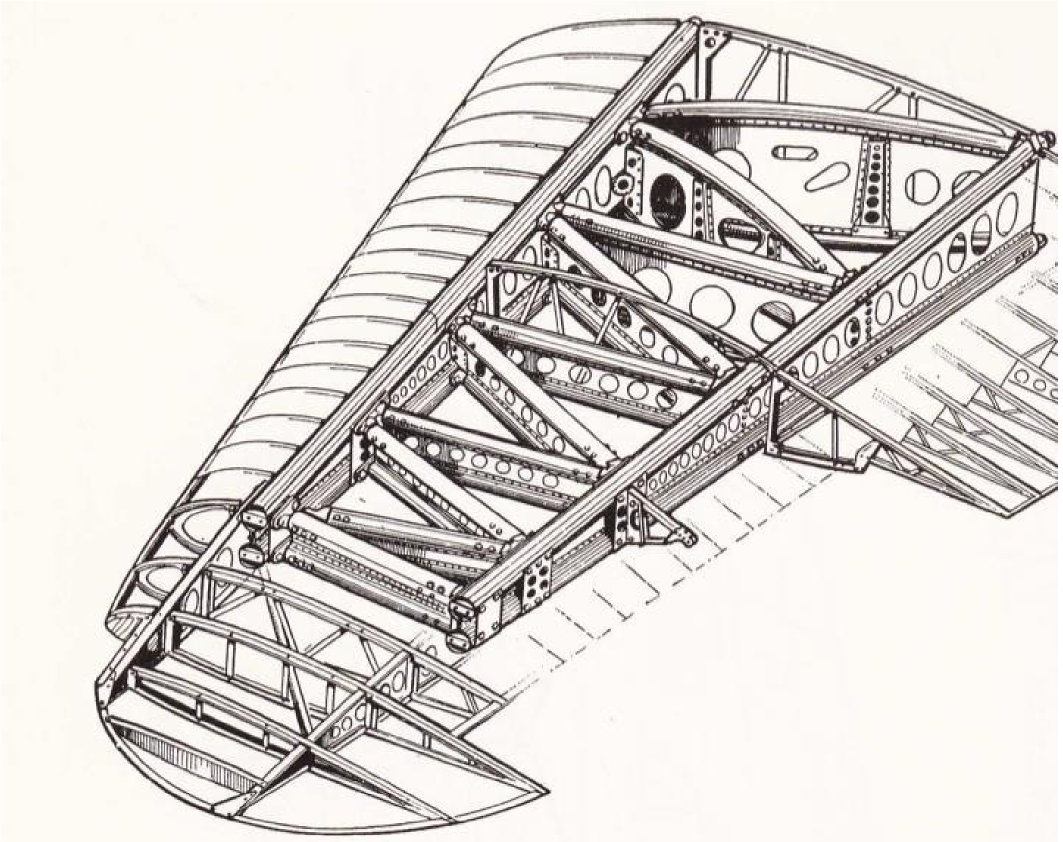
However, **firm spar location must be stablished very early in the design**.

Wings (general layout)

Rear spar must be located at suitable chord wise station, leaving **sufficient space for the flaps** and for **housing** the aerodynamic control surface systems.

- A rearward shift of the spar increases the "cross-sectional" area of the torsion box (fuel capacity)
- The reduction in height will make the spar less efficient to bending.

The same criteria apply to the front spar when is moved.



Wings (general layout)

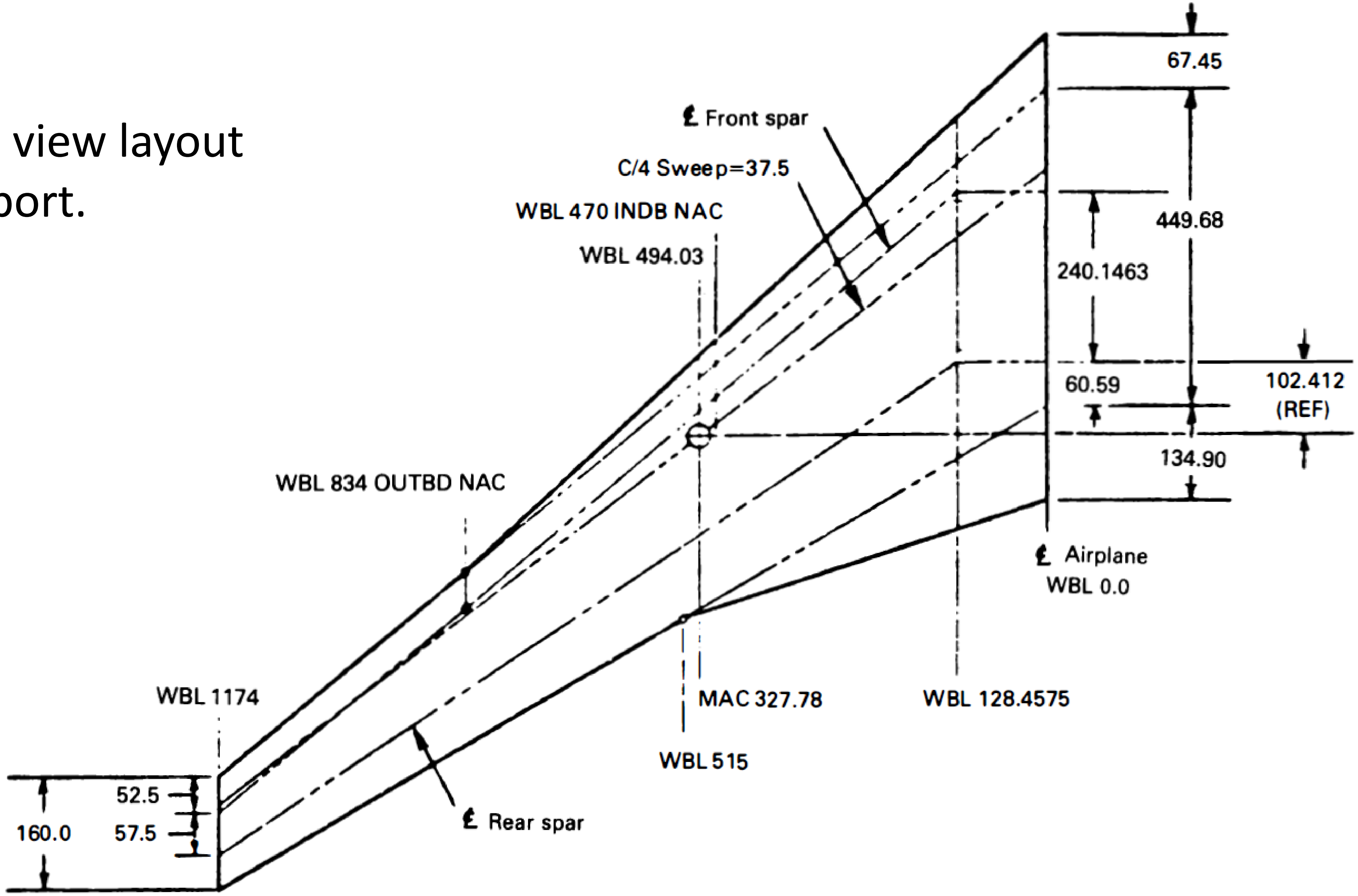
Instruction recommendation for wing layout (Niu 1988)

1. Draw planform with necessary dimensions.

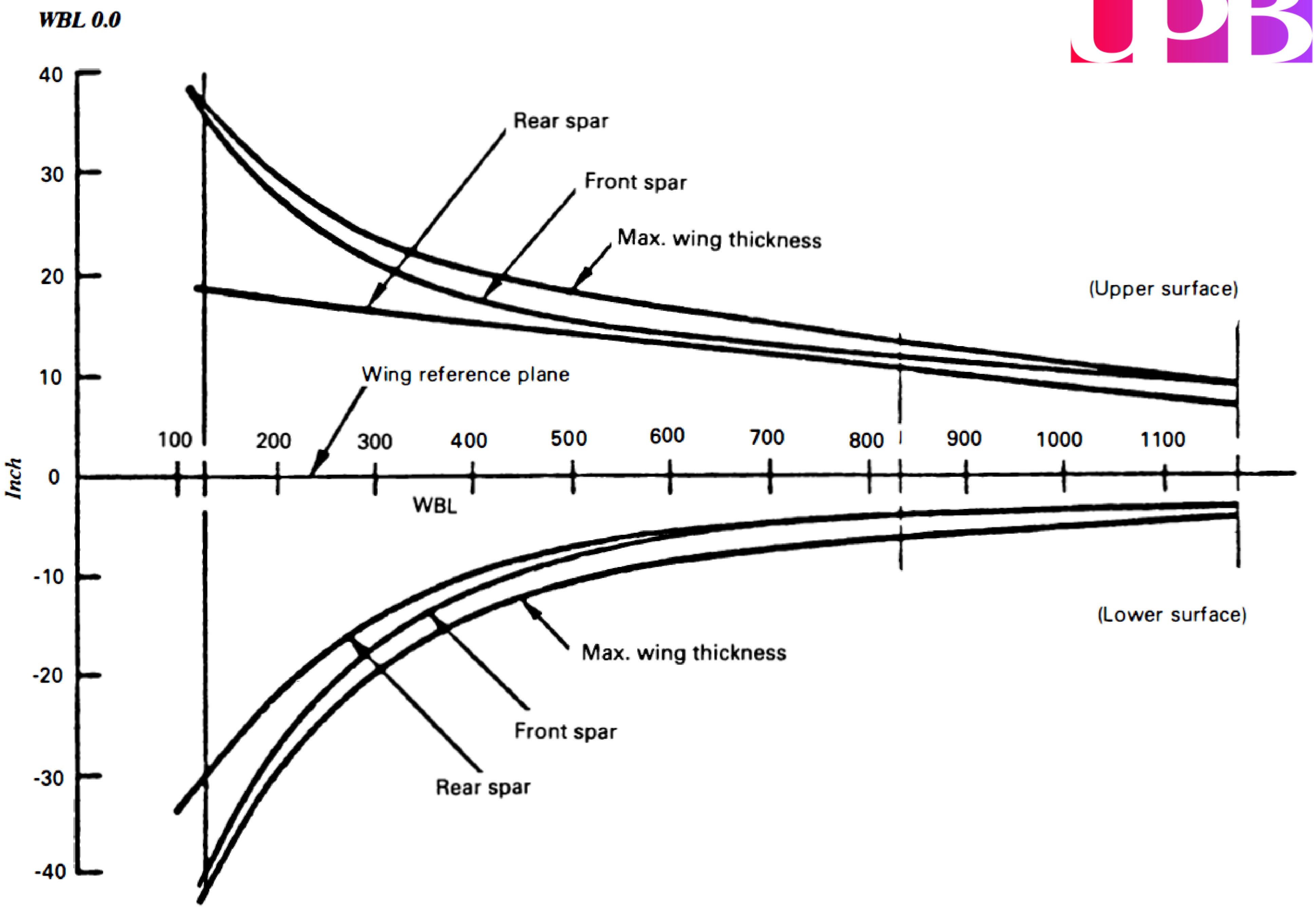
2. Determine the MAC and check the relation or the effect in the CG

3. Locate the frontspar at a constant percentage of the chord, the front spar is located between 12 to 17% of the wing chord. The spar may not be in line with the leading edge.

Wing plan view layout of a transport.



Preliminary view of spars and wing maximum thicknesses of a transport



Wings (general layout)

4. Locate the rearspar similarly. at a constant percentage of the chord, the rear spar is located between 55 to 60% of the chord. Usually 60% to accommodate a 30% chord aileron.

5. Neither rearspar and frontspar are extended to the extreme wingtip.

6. The leading edge of the aileron may be parallel to the rear spar.

7. If the flap chord is less than the aileron chord, an auxiliary spar is needed to support flap hinges.

8. Ribs are likely to be located at each aileron and flap hinge.

Wings (general layout)

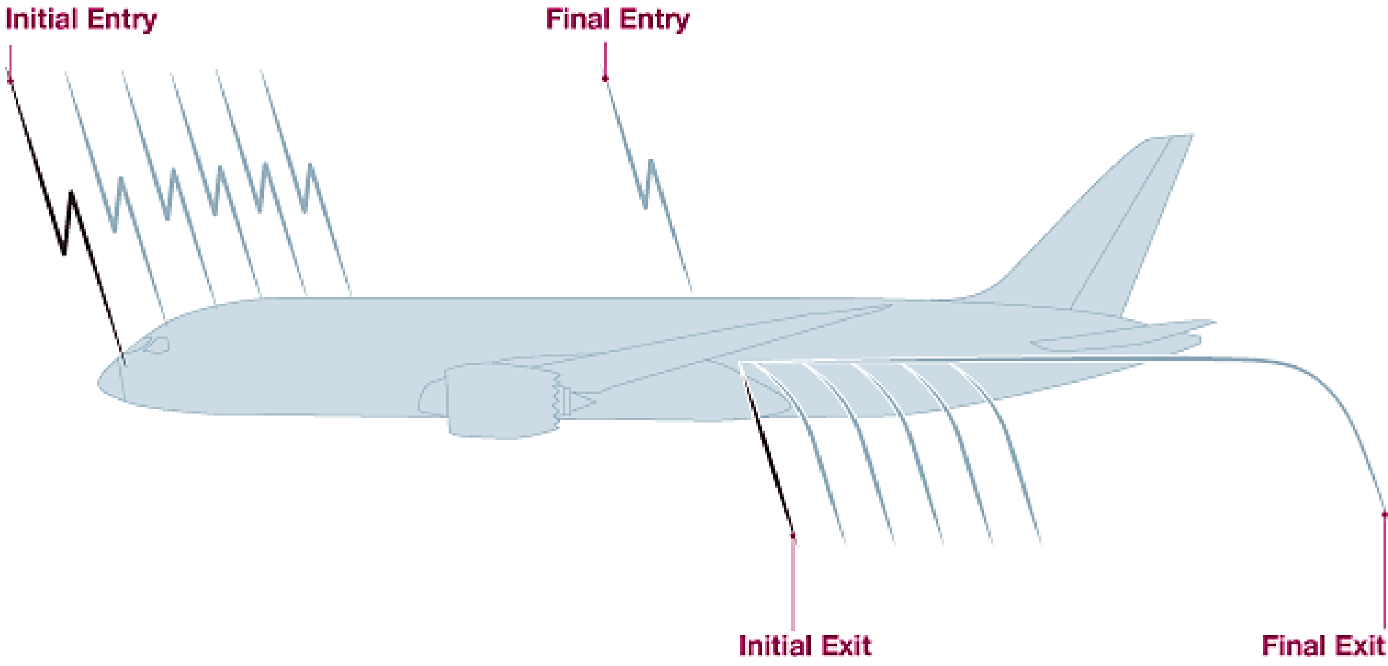
9. The rib spacing is determined form panel size considerations. Reinforced ribs are needed for engine-mount attachments, landing gear attachment and fuel tank or external store support.

10. Stringers may be placed parallel to each other or at constant percentages of the wing chord.

11. Stringers are discontinued at intervals of the tip, so that fewer and fewer stringers are left from the mid-span to the tip.

Wings (lightning strikes)

only external surfaces



Zone 1

Surfaces of the aircraft for which there is a high probability of direct stroke attachment. These surfaces are:

- All surfaces of the wing tips located approximately within 18 inches (45.7 cm) of the tip
- Engine nacelles, external fuel tanks, propeller disks
- Any other projecting part that might constitute a point of direct stroke attachment

Wings (lightning strikes)

only external surfaces

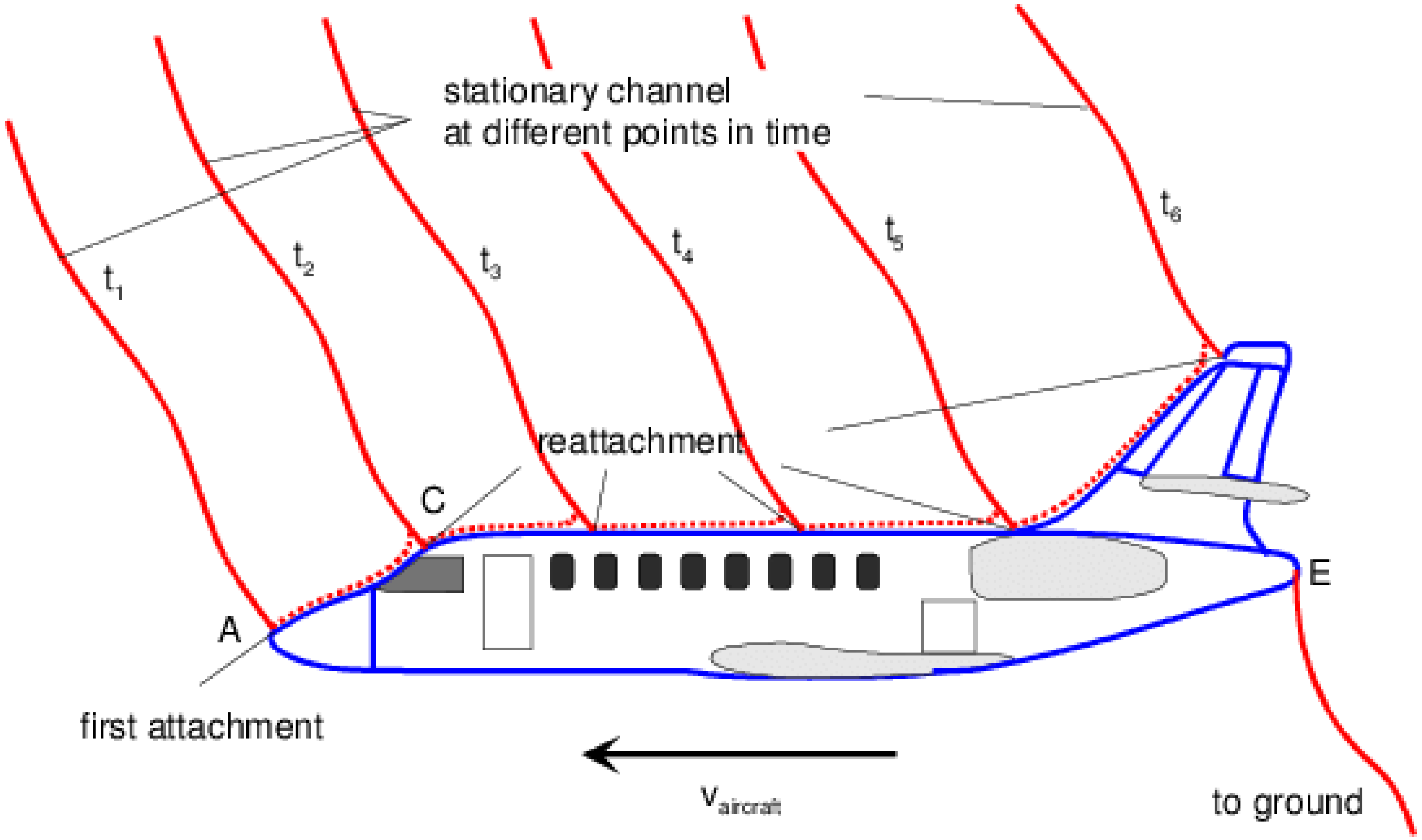
Zone 2

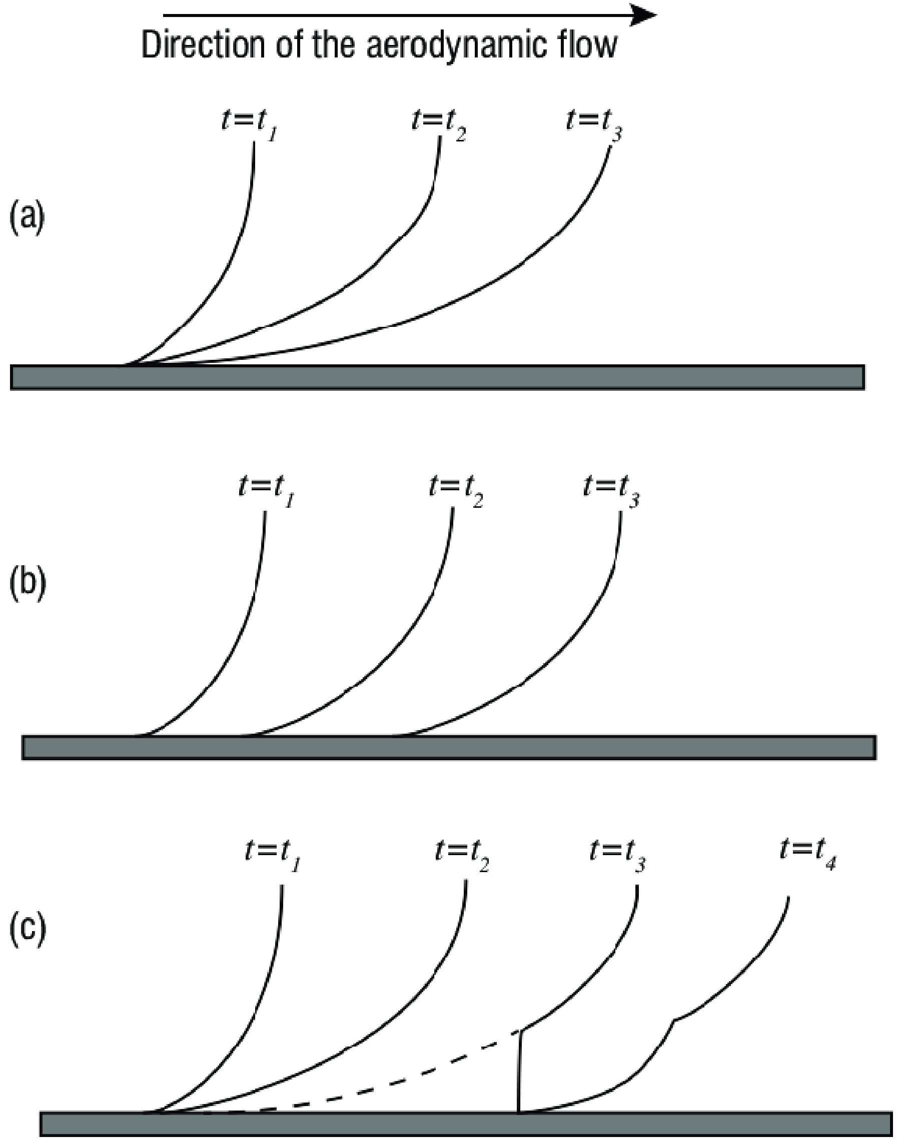
Surfaces for which there is a probability of strokes being swept rearward from a Zone 1 point of direct attachment, such as: engine nacelles, propellers, etc.

Zone 3

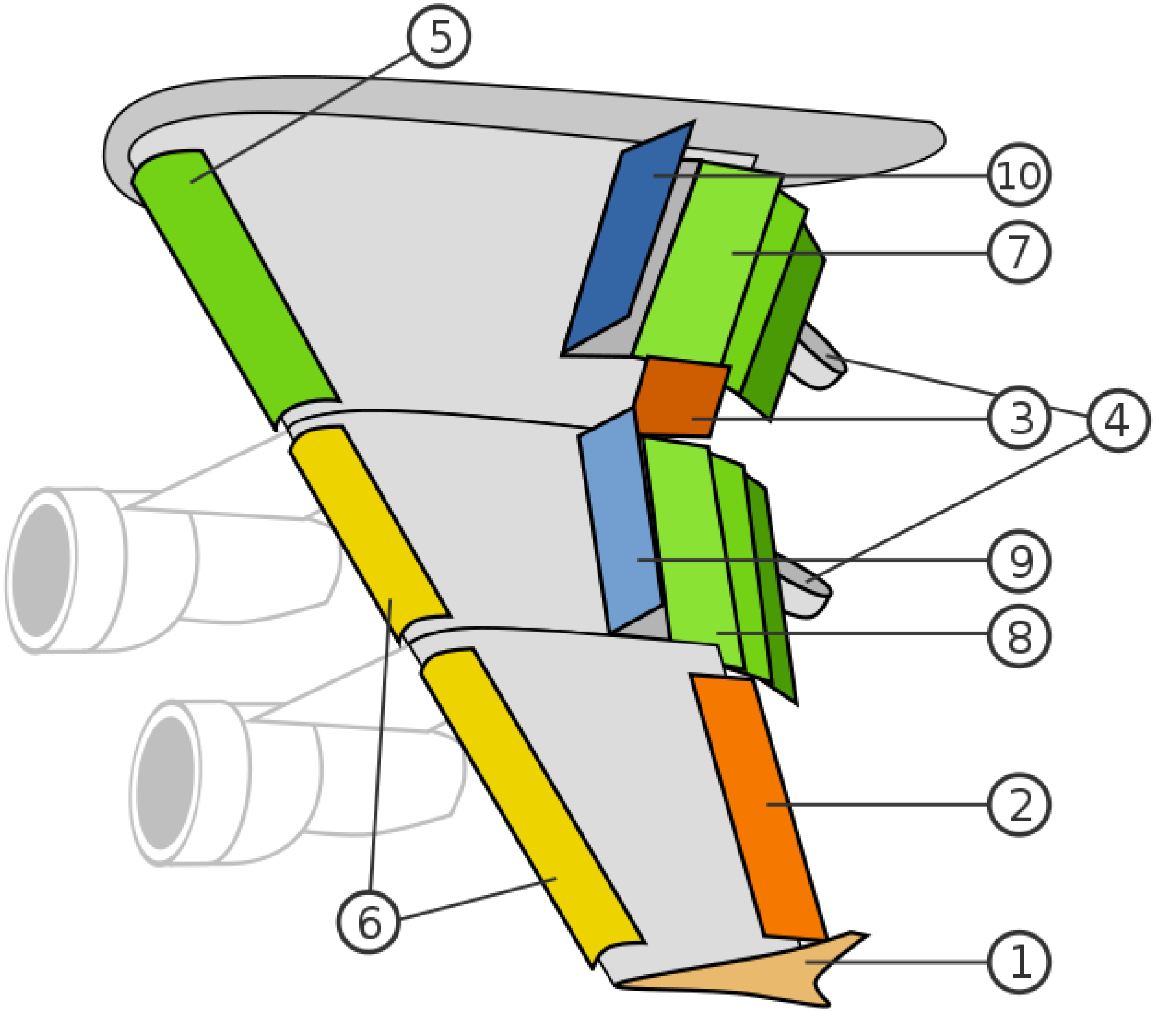
Surfaces for which there is low a probability of either direct of swept strokes.

Lightning swept strokes



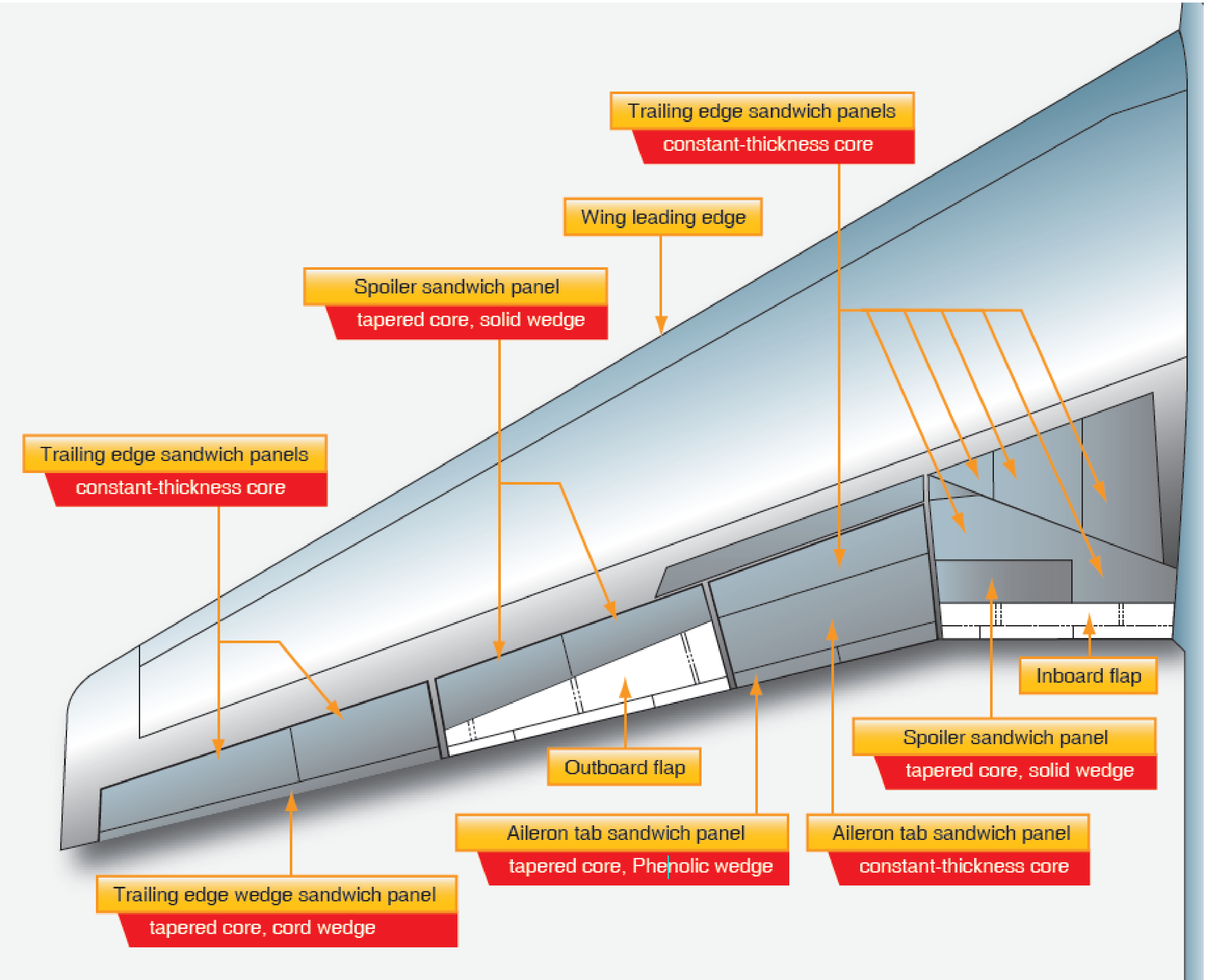


Wing surface layout



1 Winglet
2 Low Speed Aileron
3 Hight Speed Aileron
4 Flap track fairing
5 Krüger flaps
6 Slats
7 Three slotted inner flaps
8 Three slotted outer flaps
9 Spoilers
10 Spoilers-Air brakes

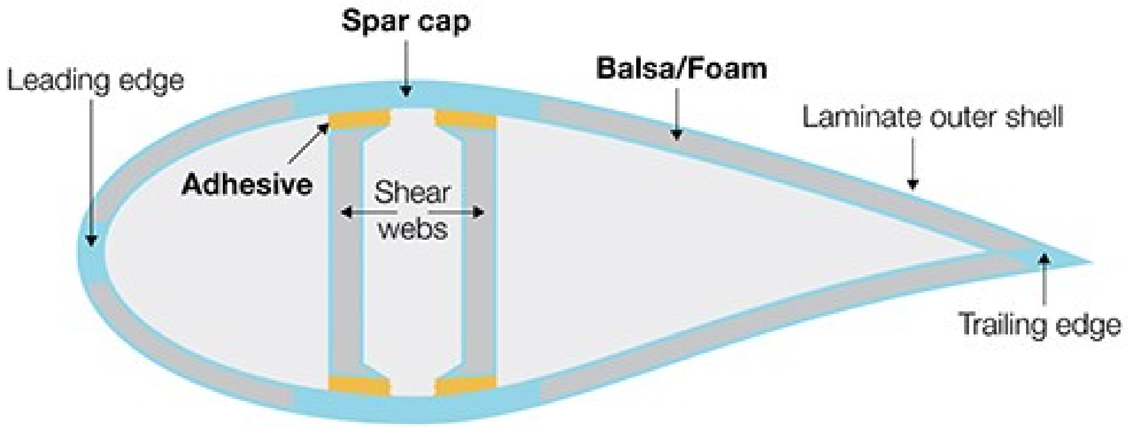
Wing surface layout



Wing covers

Wing structure can be classified according to the disposition of the bending load resistant material:

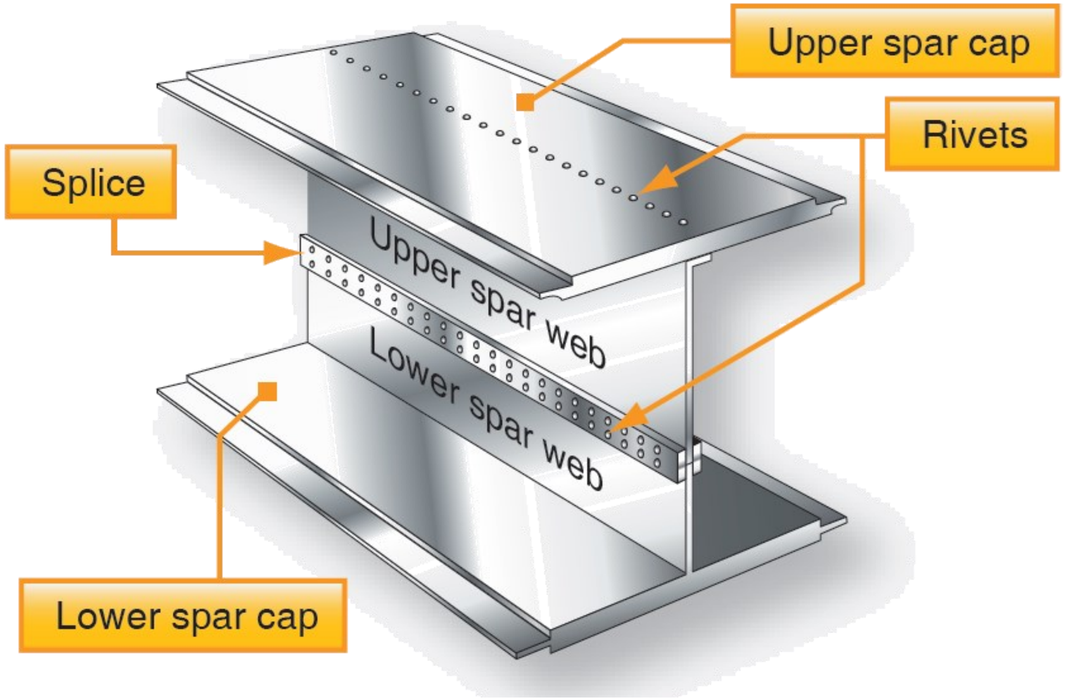
- All bending material is concentrated in the spar caps
- The bending material is distributed around the periphery of the profile
- Skin is primarily bending material



Concentrated spar caps

Advantages:

- Simplicity of construction.
- Spar caps can be designed so that buckling occurs near the ultimate stress of the material (concentration of material).
- The previous advantage allows the use of higher allowable stresses.



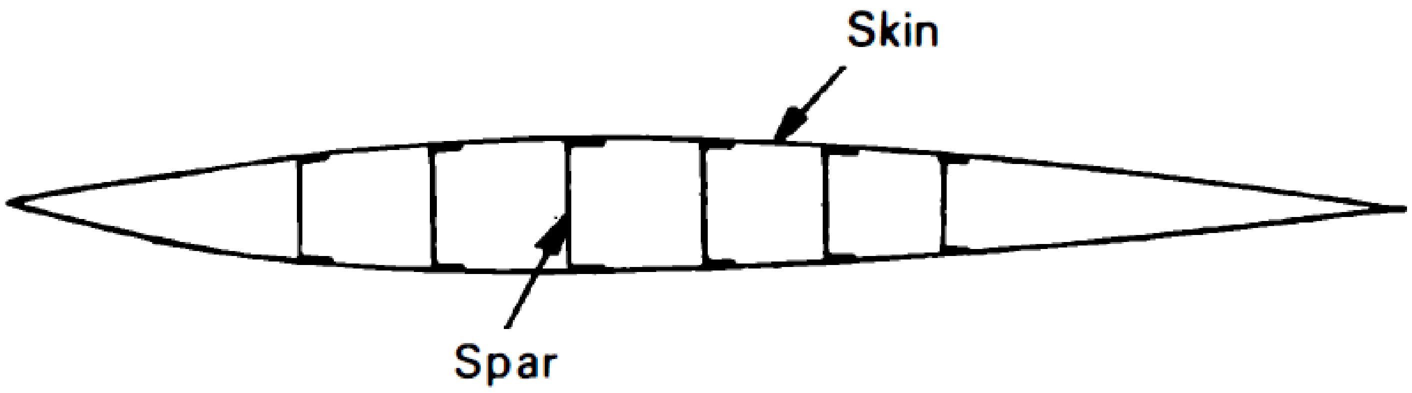
Concentrated spar caps

Disadvantages:

- Skin will buckle at a very low load. The load carrying ability of the skin is low
- Skin can be in a wave state having relatively large amplitudes which disturbs the airflow
- Fatigue failure due to local bending stress

Multi-spar skin bending material

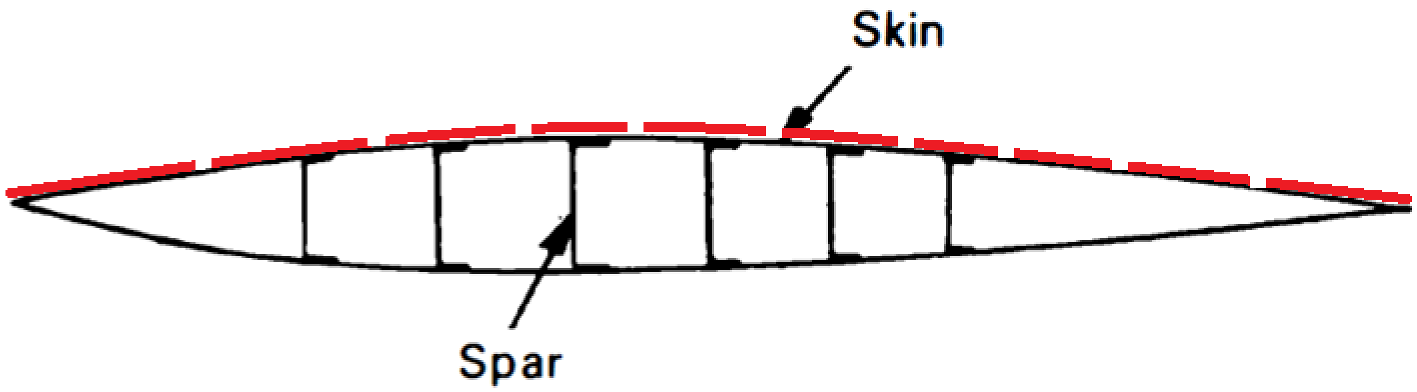
- The distributed bending material consists of stiffening elements running in a span-wise direction.
- In high speed airplanes, the wing structure is usually made of multiple spars which carry vertical shear loads.
- They may be built up shear webs or channel sections.



Boom XB-1

Multi-spar skin bending material

- The wing bending loads which cause compression on the upper surface of the wing **are generally higher than those at the lower surface.**
- Thus, the **stiffening elements in the upper surface must be more efficient** and also more closely spaced.




EXIT
BOOM

Skin as primarily bending material

The **torsional moments are primarily resisted by the skin** and the front and rear spar web.

The portion of the wing aft and rear spar usually **does not resist torsional loads**.

Skin as primarily bending material

The wing lower surface to meet FAR 25, require a fail-safe structure. This structure shall be able to carry:

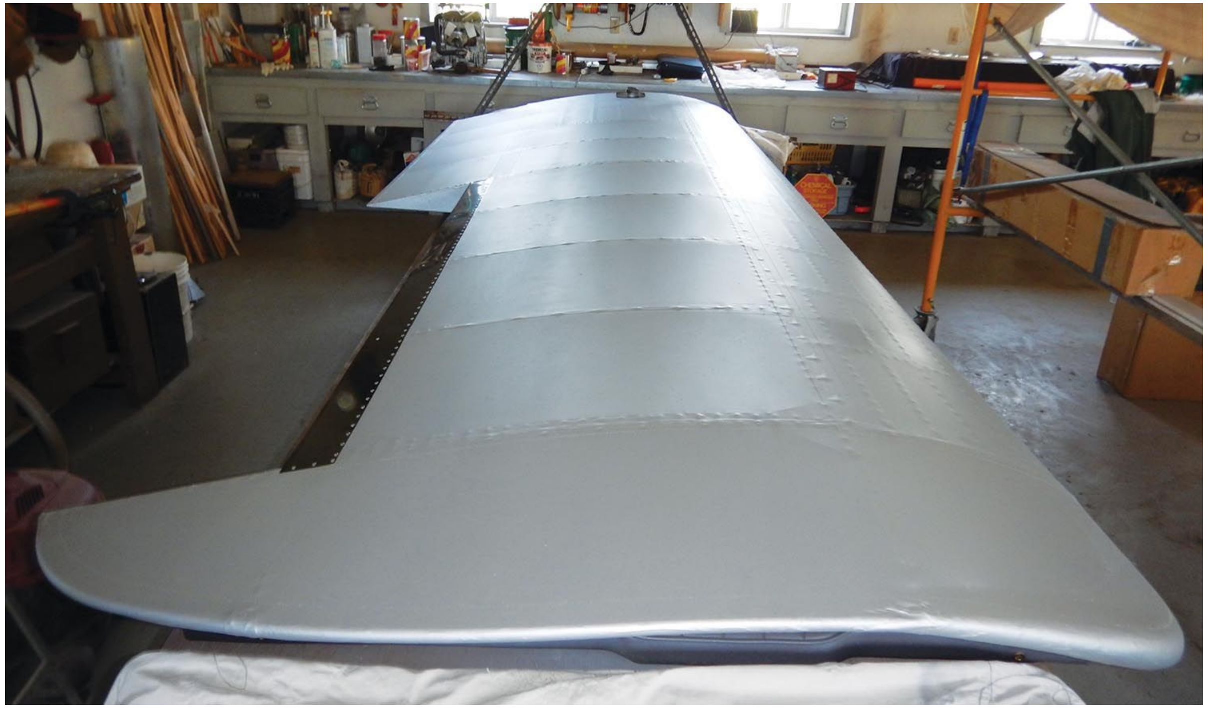
80% of limit load times 1.15 dynamic factor after a structural failure

Each span-wise splice between panels is a tear-stopper which tends to stop the failed panel to continuously crack the adjacent panel.

Skin as primarily bending material

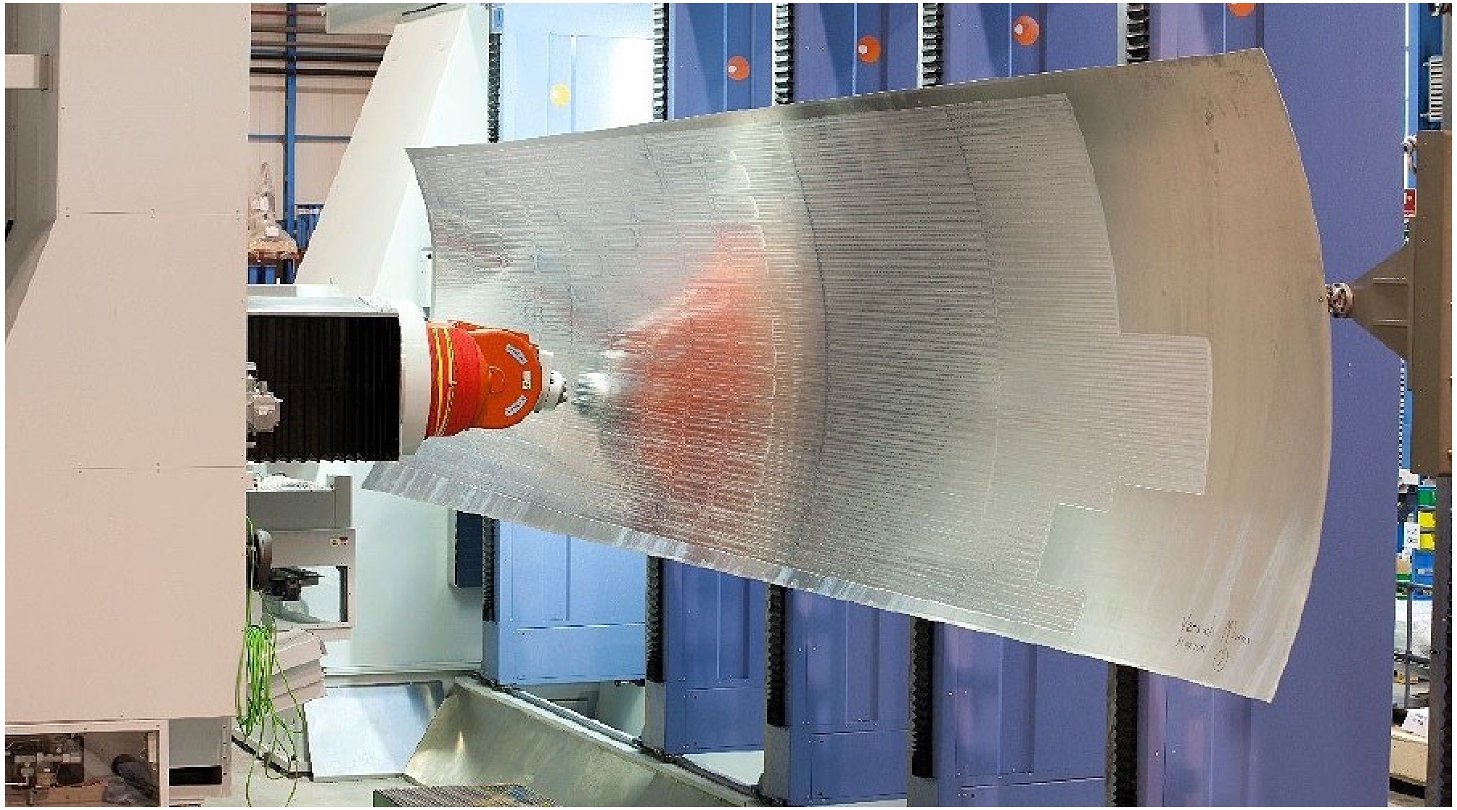
Upper surface panels are also designed to be fail-safe

“Structural separation” can occur during ground operation where tensions loads are small



Skin stringer panels

The machined skins combining with machined stringers are the most efficient structure to save weight.



Skin stringer panels

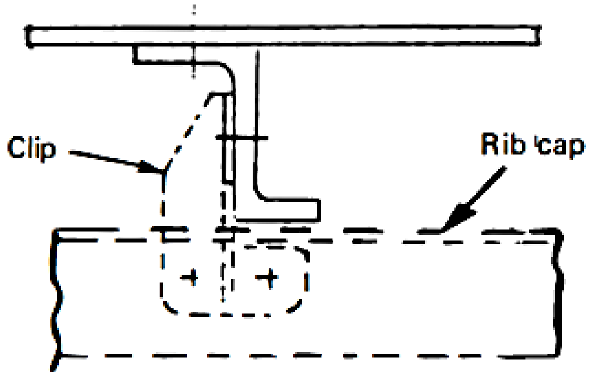
Advantages

- The skin can be tapered spanwise and chordwise
- Thickened skin around holes
- Maintenance

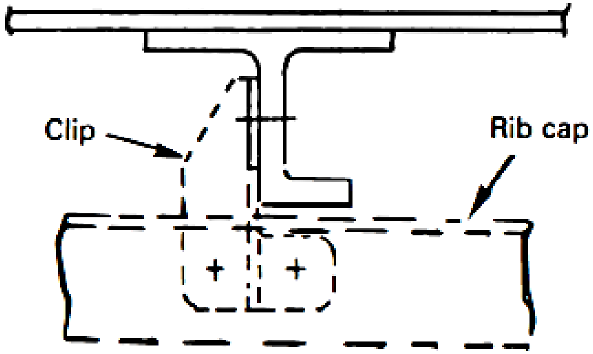
Skin stringer panels

https://www.youtube.com/watch?v=dJr3PMFEPRw&ab_channel=UnitedLaunchAlliance

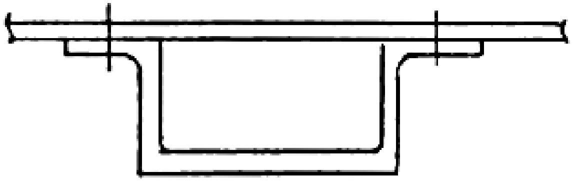
Skin stringer panels



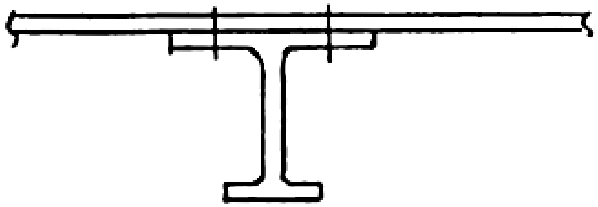
(a)Z-shape
(Widely used)



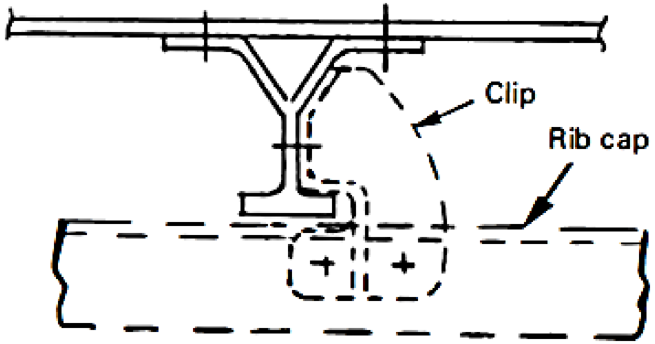
(b)J-shape
(Widely used)



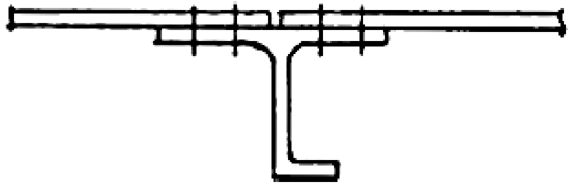
(c)Hat-shape
(Less used except
as vent conduit
at wing upper cover)



(d)I-shape
(Less used)



(e)Y-shape
(Less used)



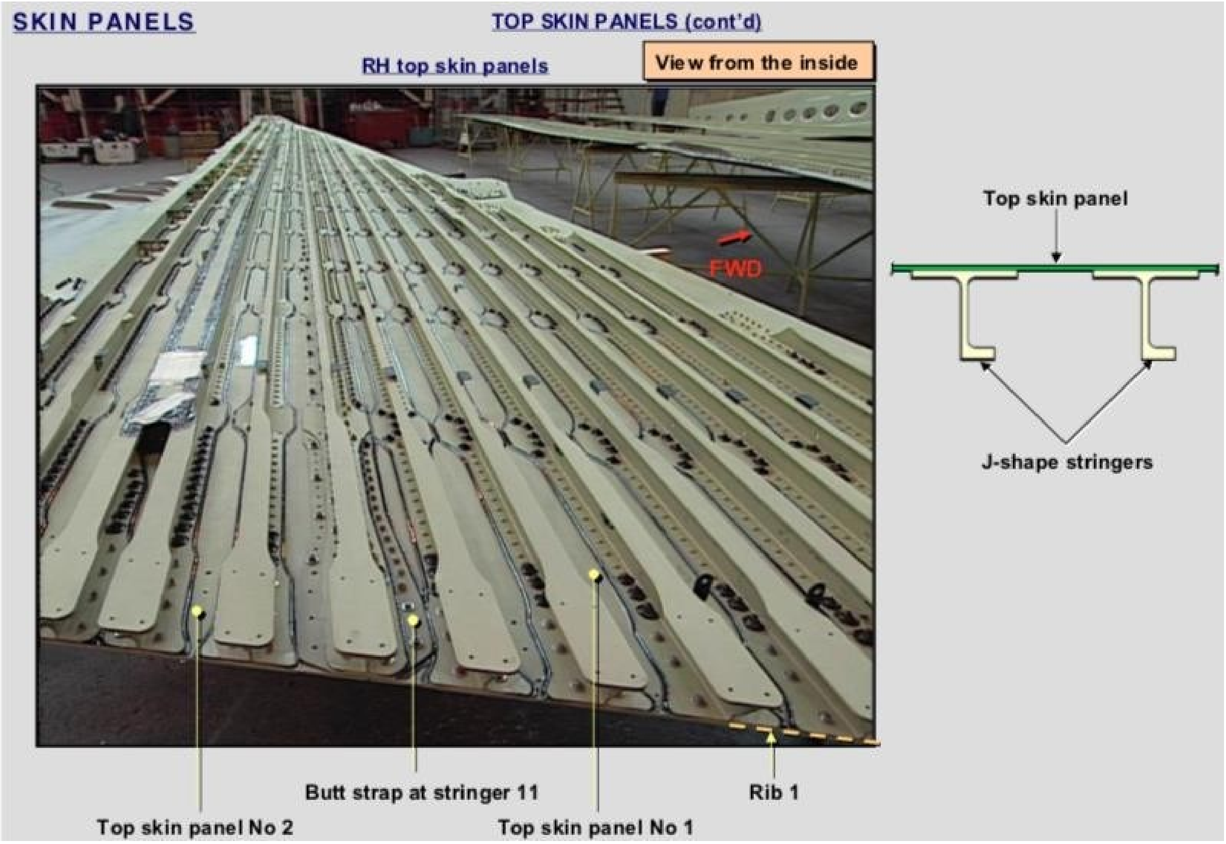
(f)J-shape for panel splice

Skin stringer panels

The optimum distribution of area between skin and stiffener for minimum weight exist:

The optimum ratio of stiffener area to skin area is approximately 1,4 assuming equal buckling stress in the skin and stiffener.

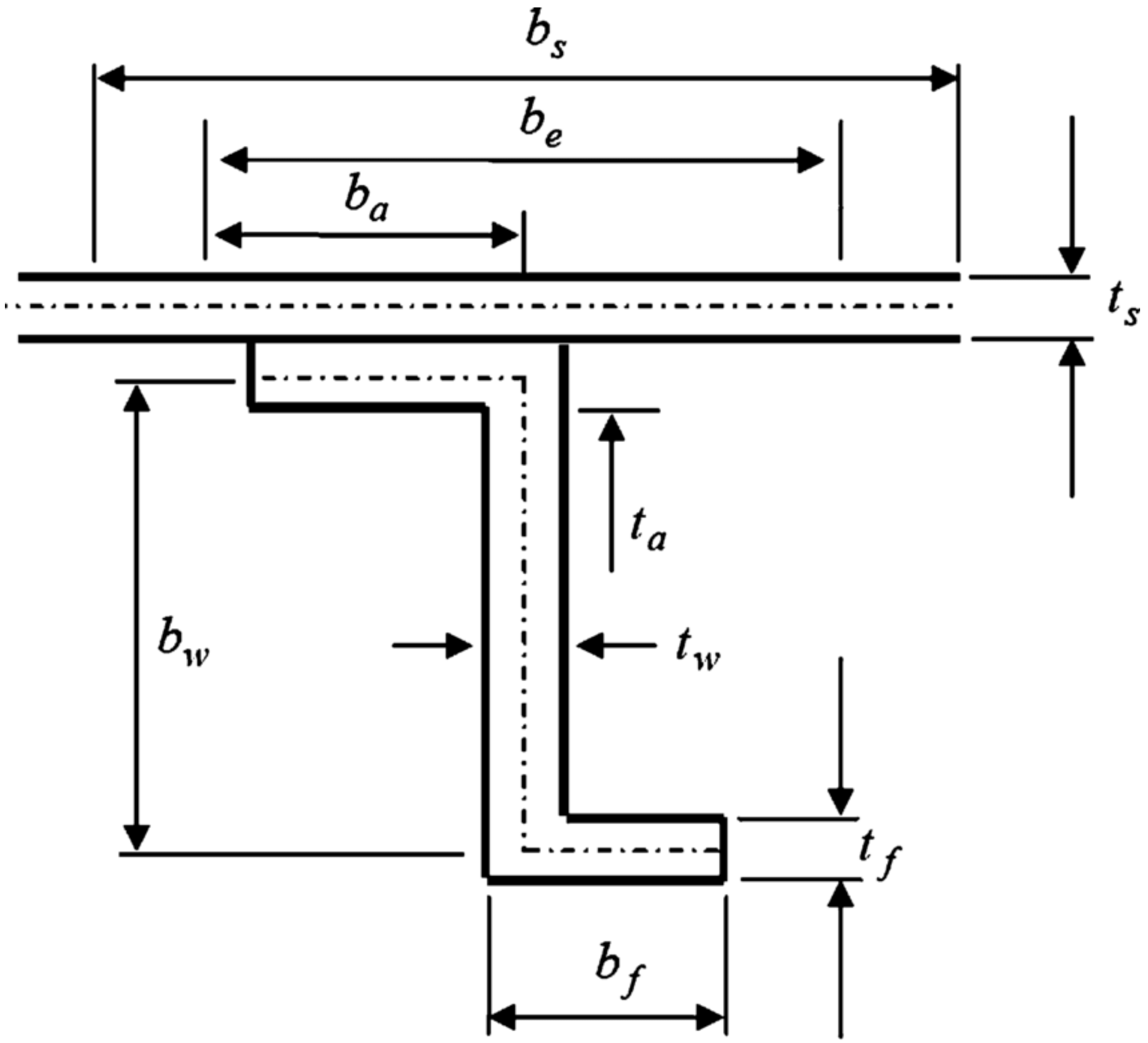
The optimum area for unflanged stiffened panels, is 1,7.



Skin stringer panels

The optimum distribution of area between skin and stiffener for minimum weight is:

For z channel the ratio of stiffener to skin area is 1,5.



Skin stringer panels

It should be noted that in a practical design, the skin area will be a higher fraction of the total weight than indicated in this discussions.

The weight is higher due to the need of interacting with shear loads, fatigue, and stiffness considerations.

The upper and the lower cover wing must be designed to fatigue criteria.

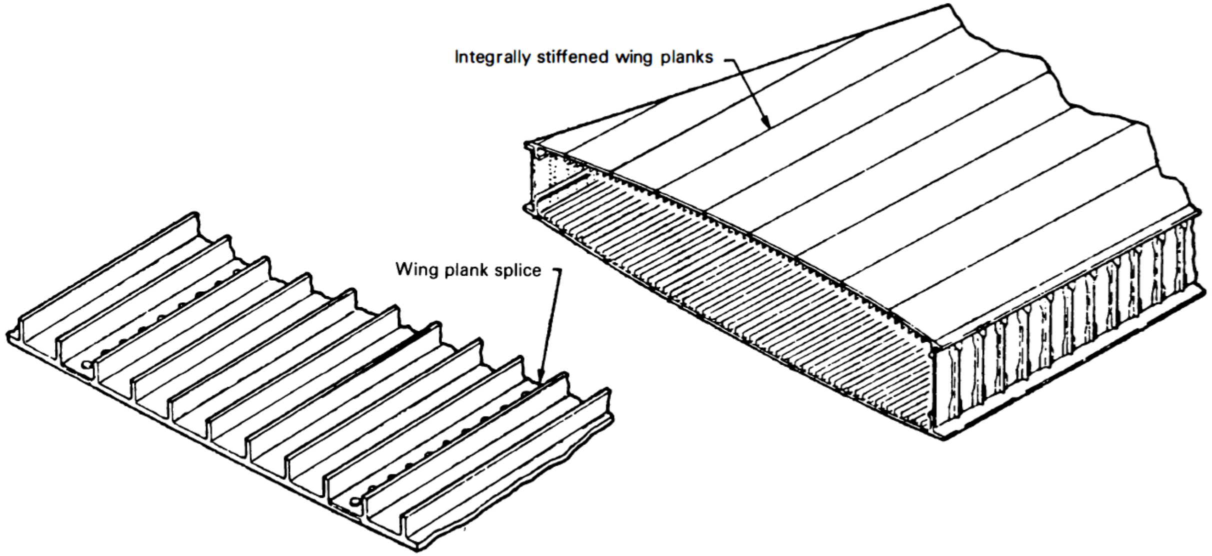
Centroids of sections should be close to the skin as possible for stability of the wing-box and minimum panel eccentricity.

Skin stringer panels

A350
upper wing skin

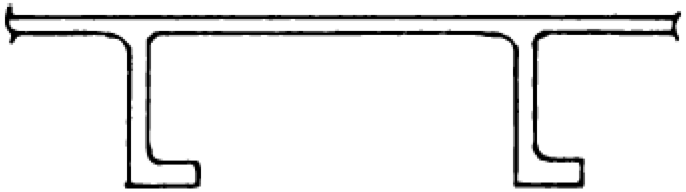
Integrally stiffened panels

In aircraft where weight is always a critical problem, integrally stiffened structural sections have proved particularly effective as a **light weight, high strength construction. OPTIMUM DESIGN.**



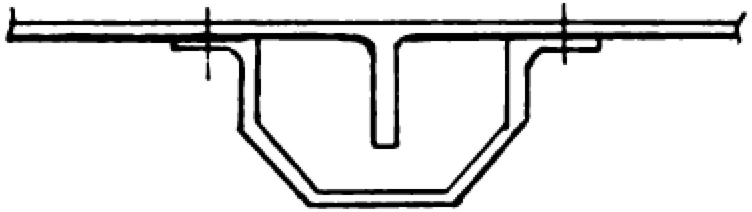
Integrally stiffened panels

(a)Integral blade section
(Widely used)

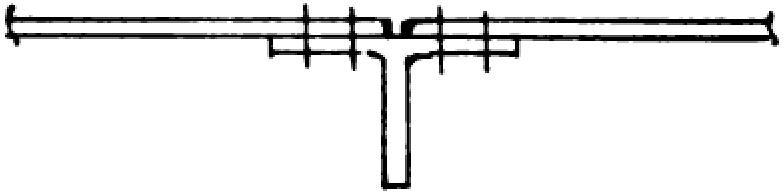


(b)Integral Z-section

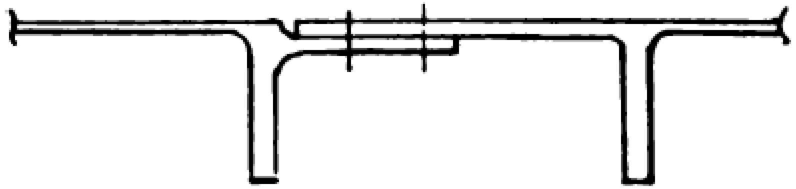
(c)Integral T-section



(d)Blade section with reinforcement



(e)Splice configuration



(f)Splice configuration (avoid)

Integrally stiffened panels

These one-piece panels can be produced by several techniques. **Size and load requirements** are usually the important considerations.

Composites and metallic extrusions or machined panels are the most employed sections.

Integrally stiffened panels

From a structural point of view:

- Appreciable weight saving are possible.
- High resistance to buckling loads.
- The reduction in the number of assembly attachments gives a smooth exterior skin surface improving the performance.

Integrally stiffened panels

Other advantages:

- Reduction of amount of sealing material for pressurized fuel tanks.
- Increase in allowable stiffener compression loads by elimination of attachment flanges.
- Increased joint efficiencies under tension loads by means of integral doublers.
- A weight reduction of 10% to 15% can be achieved by integral panels.

Spars

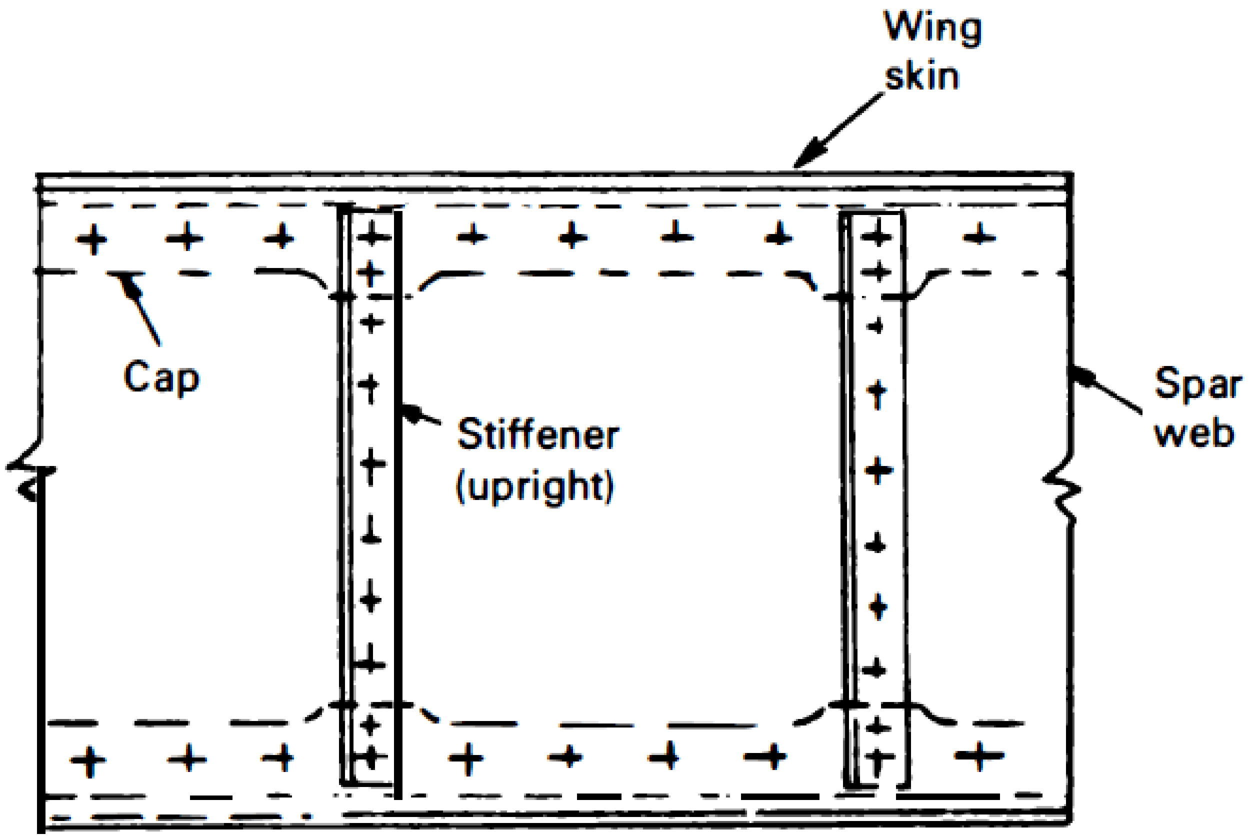
Mid spar 747-8

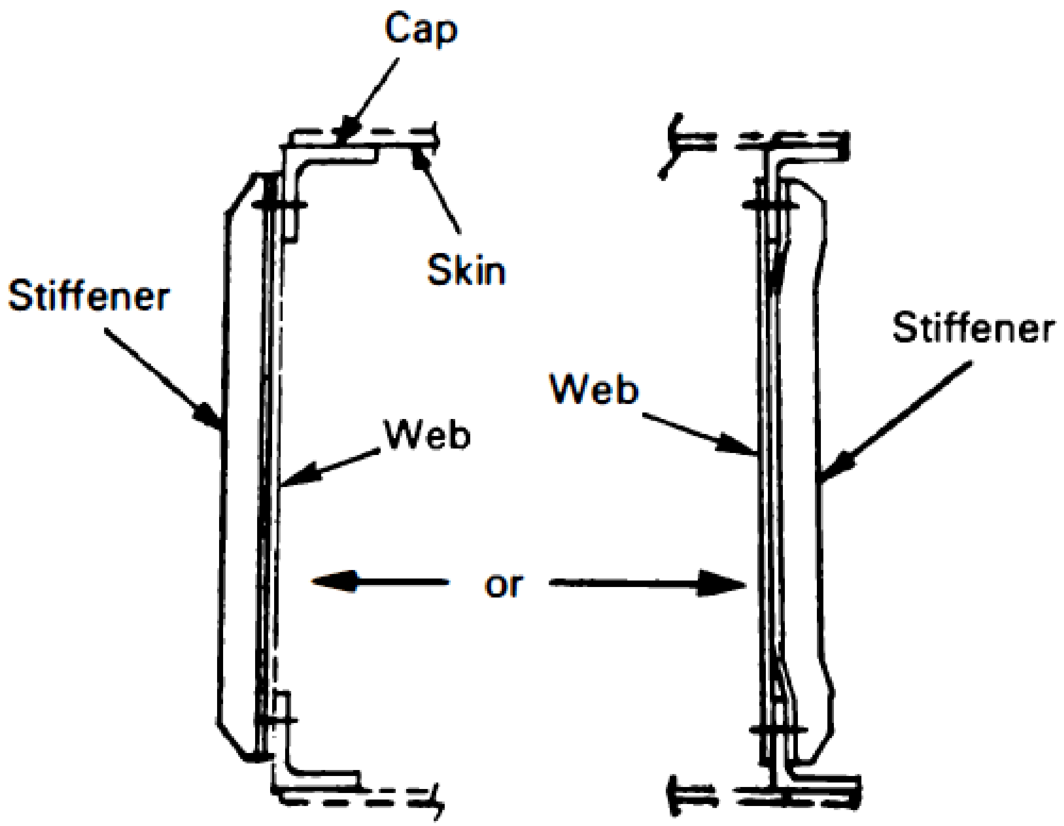
Spars

Wing box

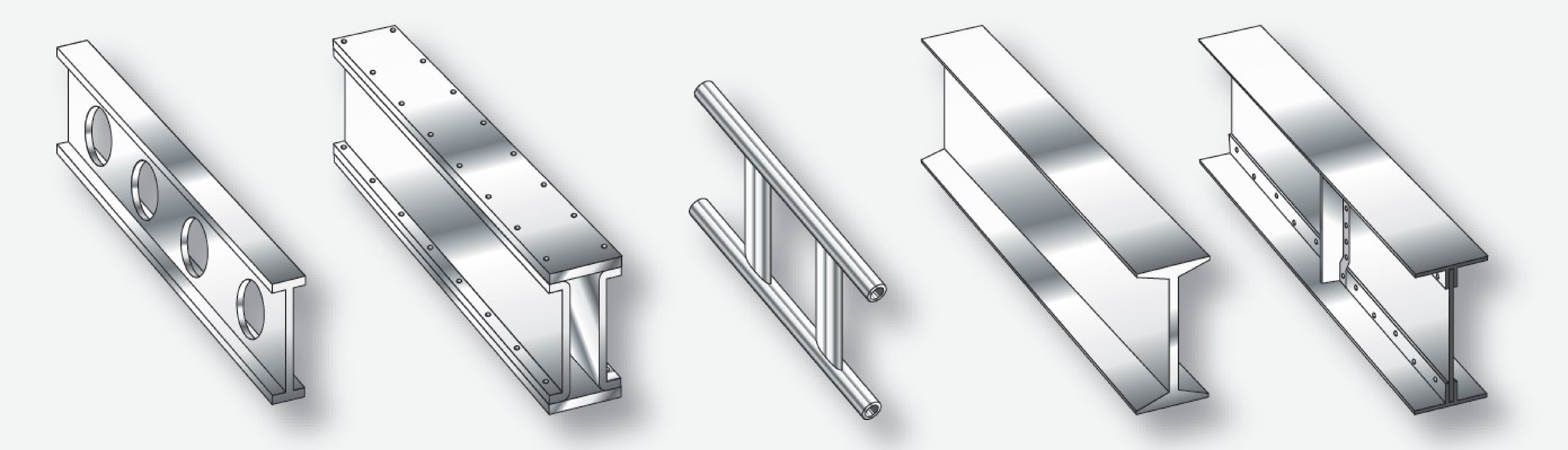
Irkut MC-21

Spars


Wing
skin
Cap
Stiffener
(upright)
Spar
web

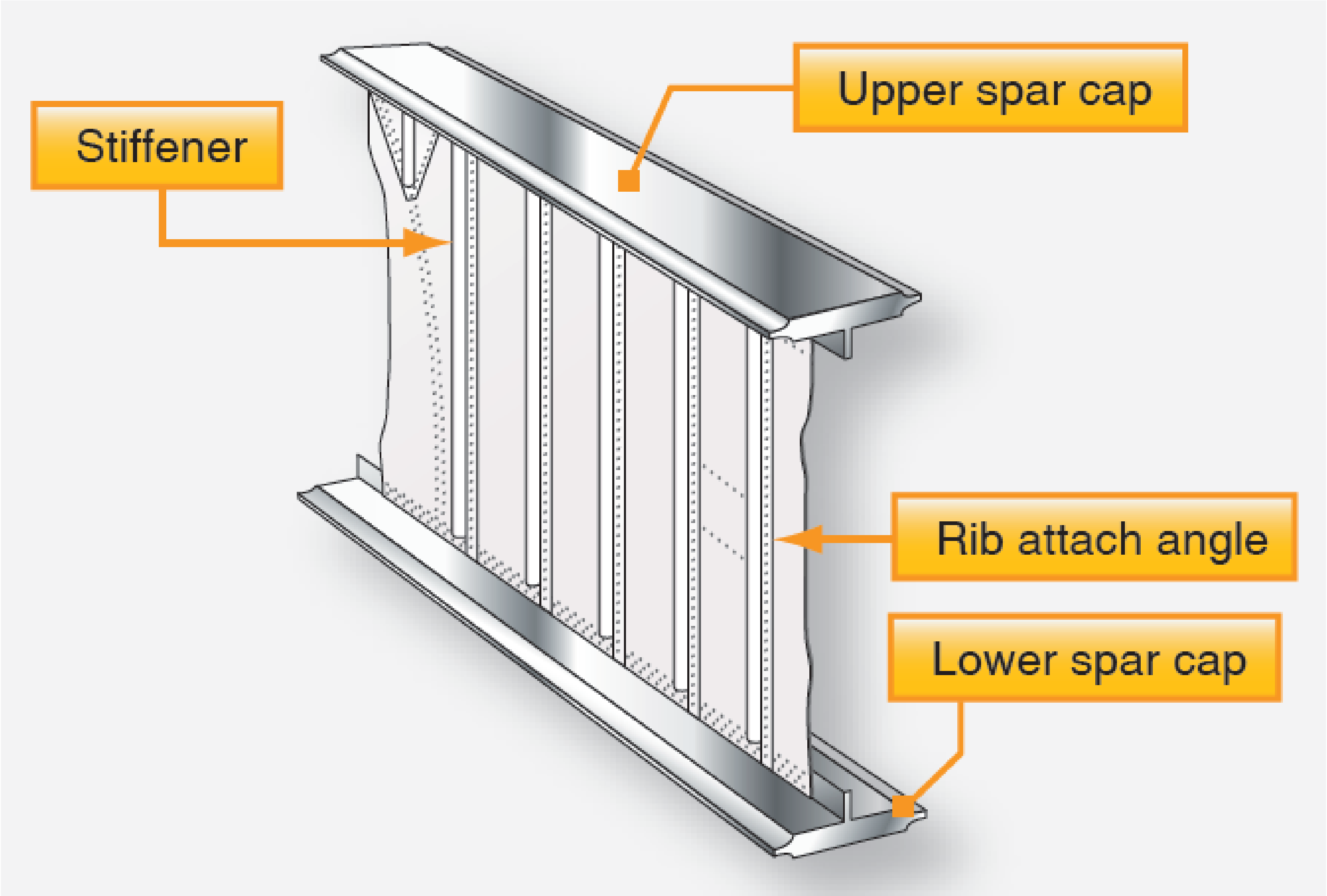

Cap
Skin
Stiffener
Web
or
Web
Stiffener

Spars

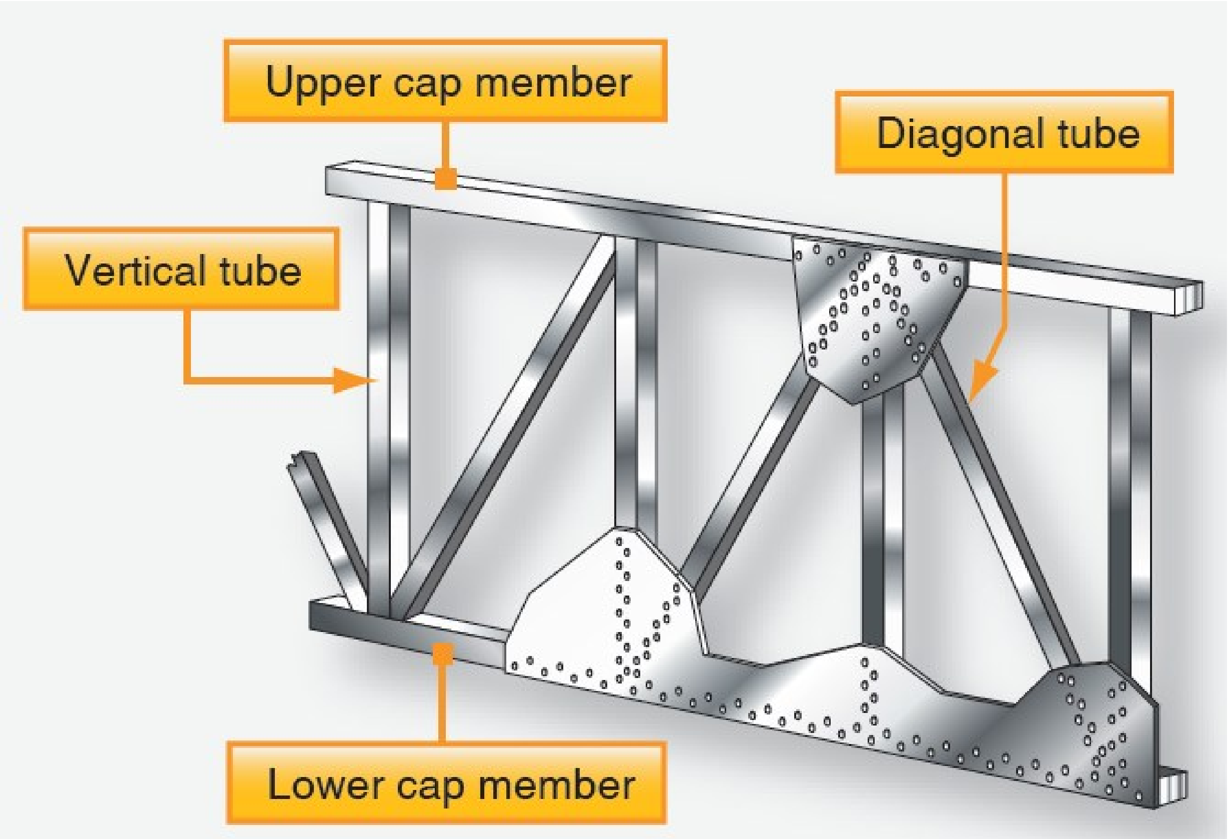


Spars

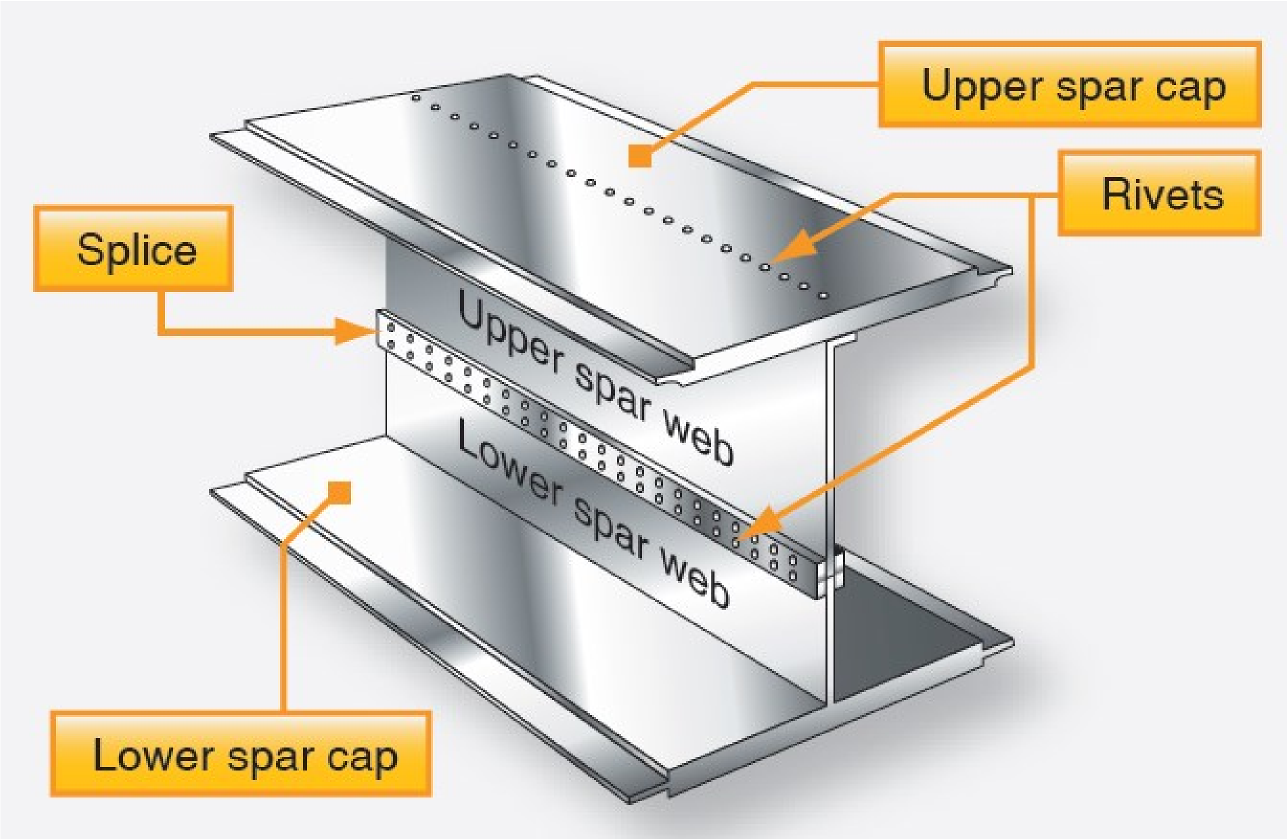
Common stiffened web spar



Spars



Truss spar

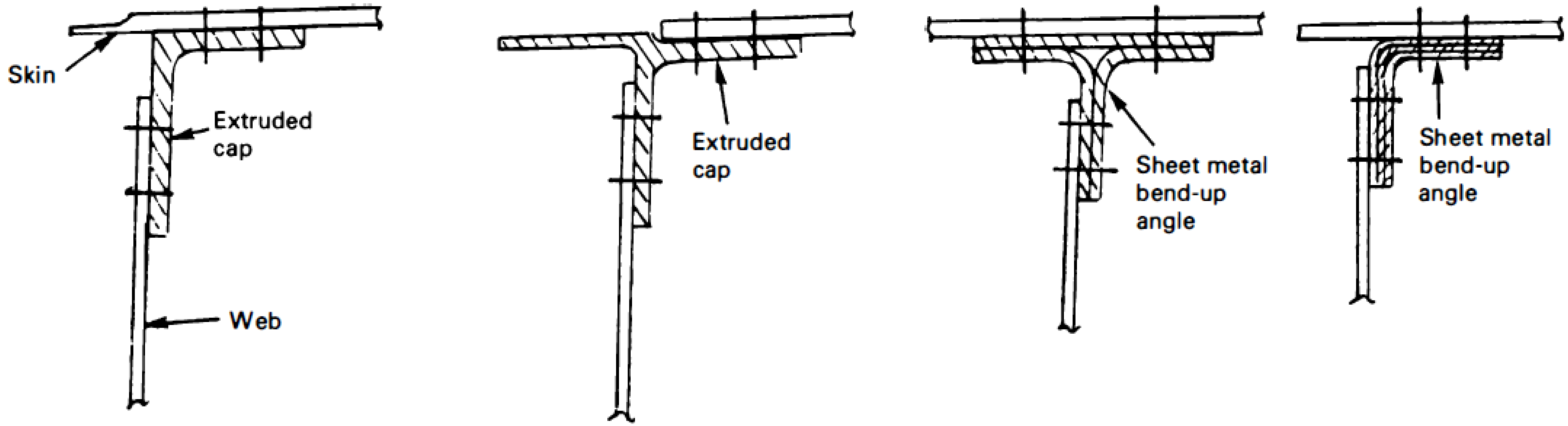


Fail-safe spar

Spars

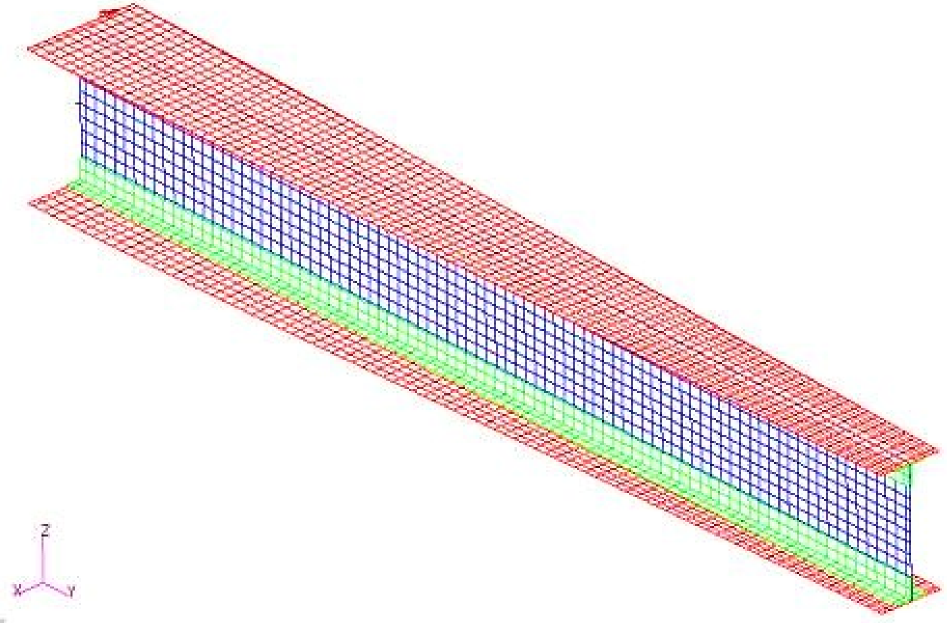
The beam cap should be designed to:

- Make the **radius of gyration** of the beam section as large as possible
- Caps with high crippling (buckling) local stress



Spars

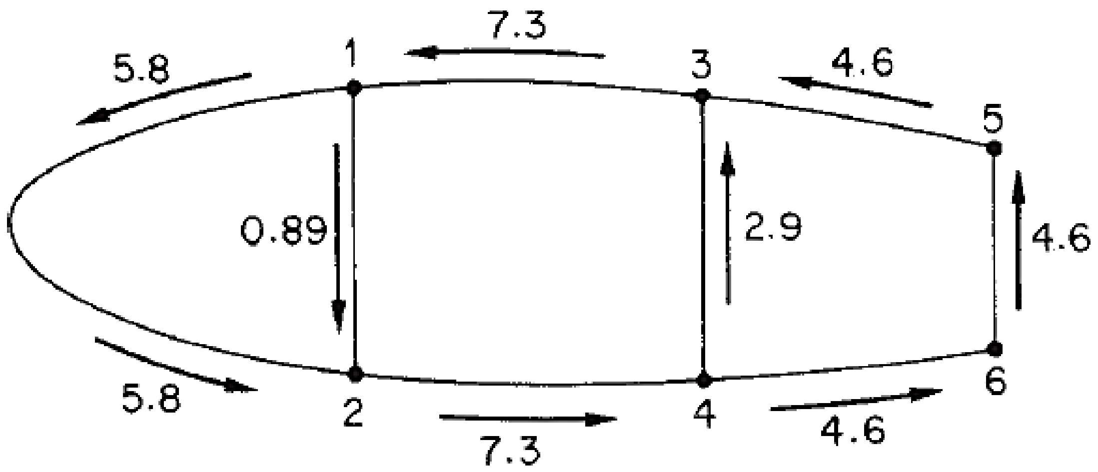
The cap sections for large cantilever beams which are frequently used in wing design should be of **such shape as to permit an efficient tapering**, reducing of the section as the beam extends outboard



Spars

1. The air load act directly on the wing cover which transmits the load to the ribs

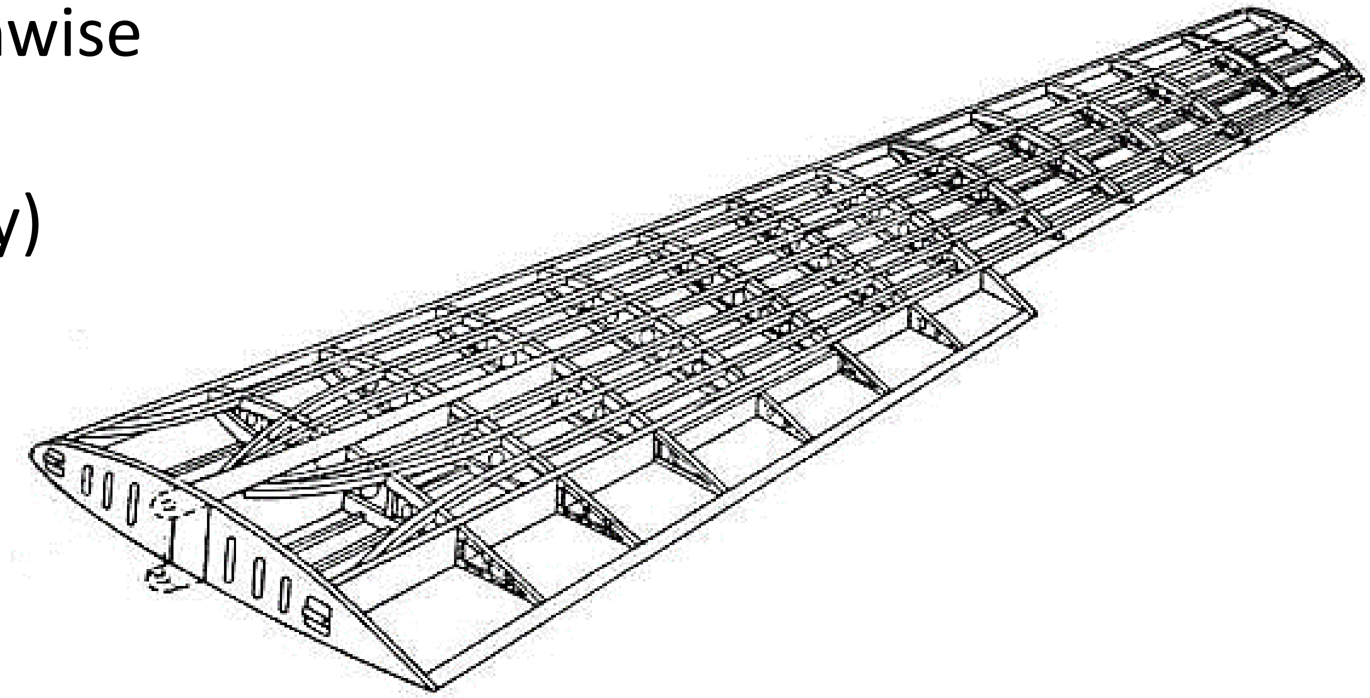
2. The ribs transmit the loads in shear to the spar webs and distribute the load between them in proportion to the web stiffness.



Spars

The use of several spars permit:

- Reduction in rib stresses.
- **Better support** for the spanwise bending material.
- Design for **fail-safe** (redundancy)



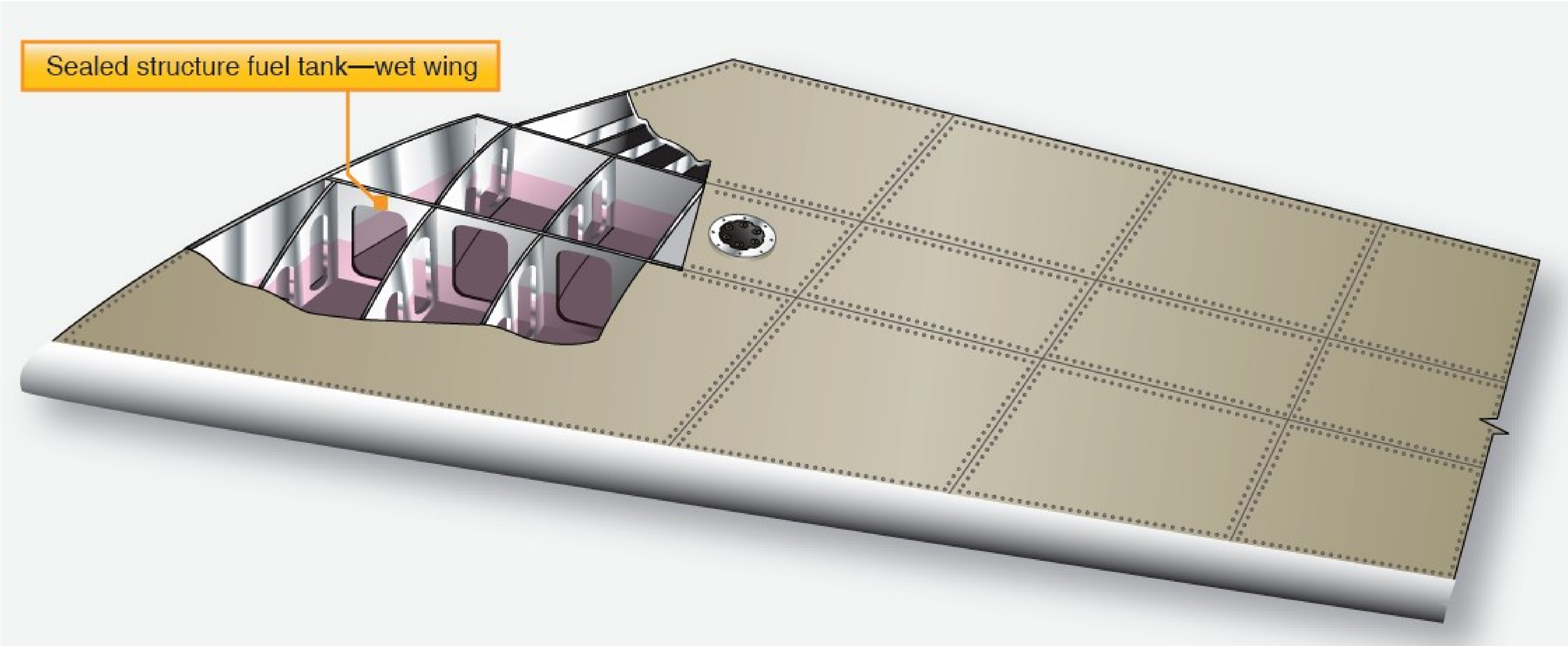
Spars

The use of several spars permit:

Space requirements for **housing fuel tanks and landing gears** is the main reason for at least considering two spar wing box construction.

Spars

The front and rear spar combined with wing skin panels form as the closing member of the torsional-resistant box and serves as integral fuel tank



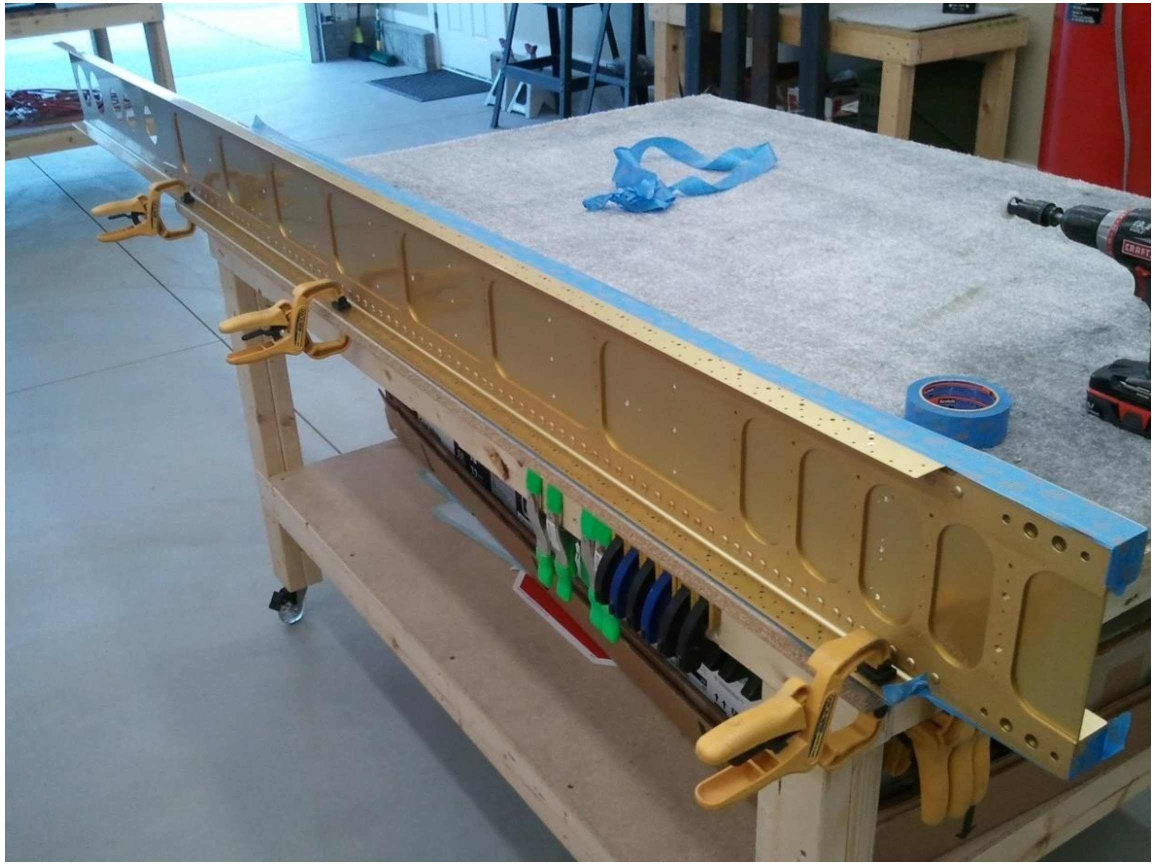
Spars

The design of metal beam composed of **cap members joined** (riveted or welded) **to a web member** is a common airplane structural design.

Shear based constructions:

- **Shear resistant beam** (non-buckling type).
- **Diagonal tension field beam** (buckling type).

Spars



Spars

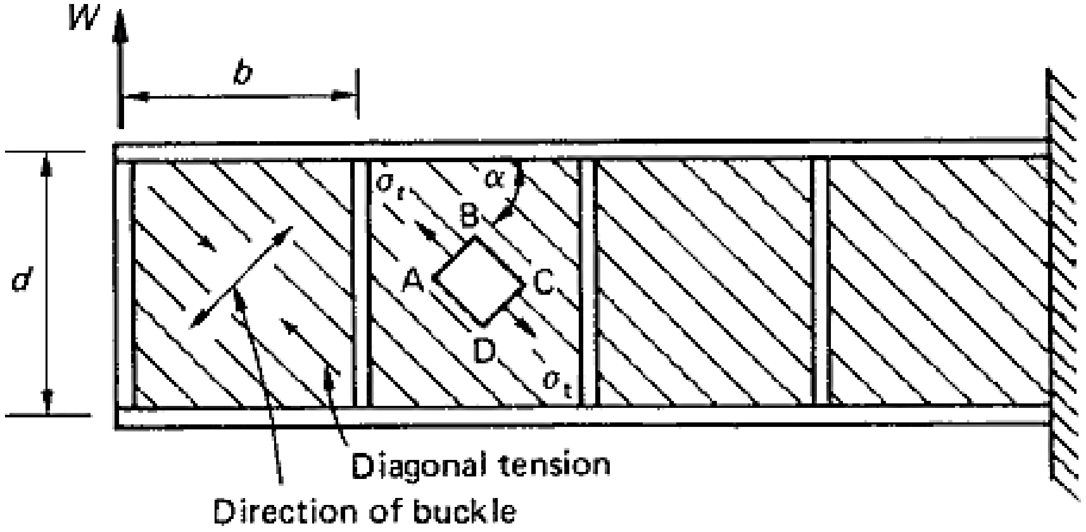
Integral spar (machined, composites)

https://www.youtube.com/watch?v=_MeyM_jyG0E&ab_channel=HawthornComposites

Tension field beam

Tension field beam is particularly adaptable to mass production because of its component's parts:

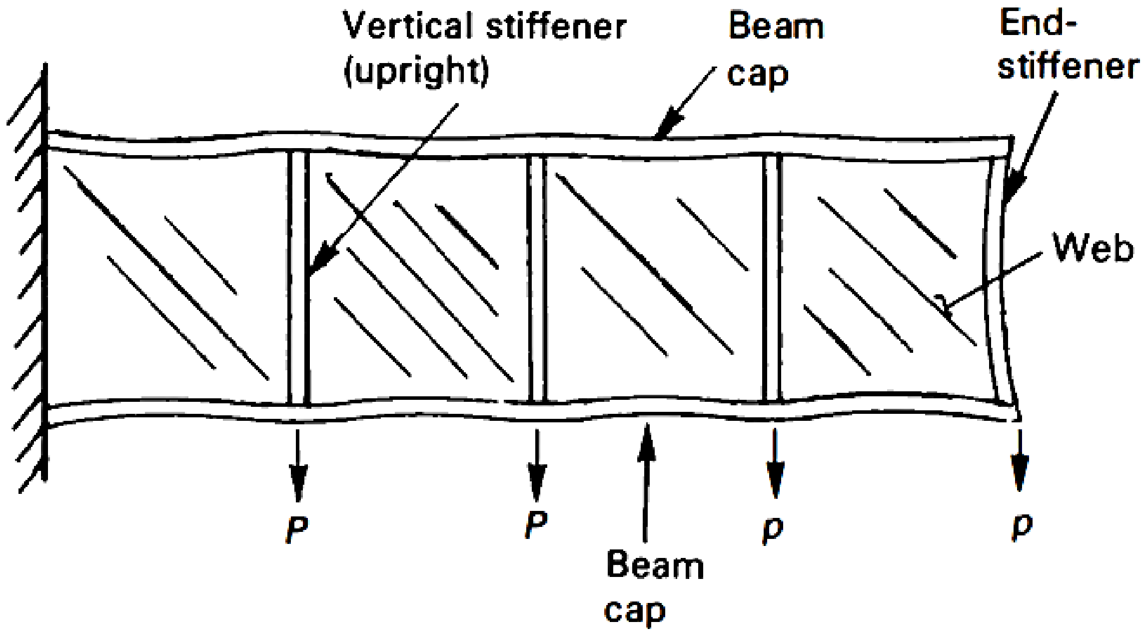
- Webs require simple cutting operations.
- Spar caps and vertical stiffeners are extrusion parts.



Tension field beam

Because of the high degree of redundancy, it will carry load even when severely damaged.

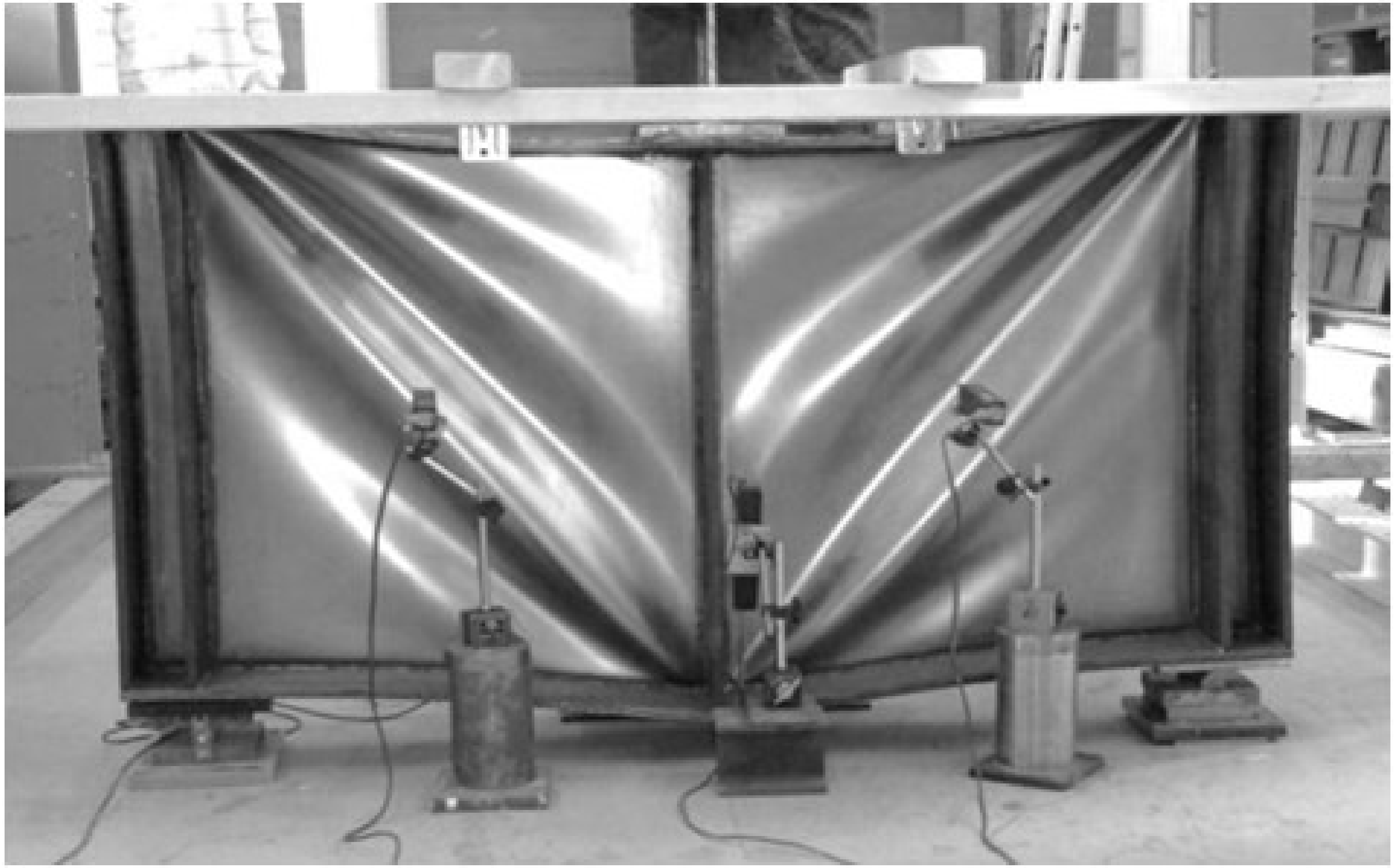
- They have a remarkable strength to weight ratio
- Stiffness



Tension field beam

https://youtu.be/cM1mVXSFnq0?si=hI5dooXHp5R6JqZc&t=35

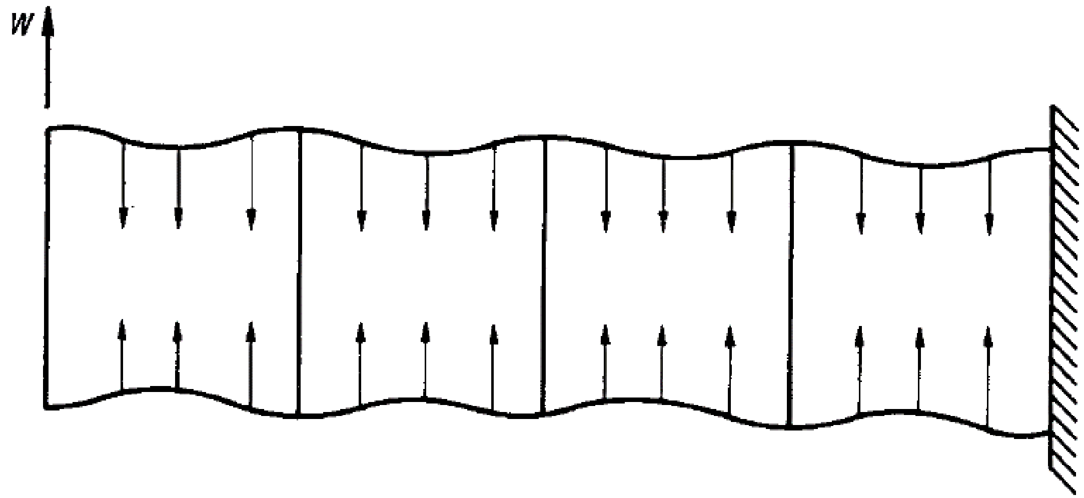
Tension field beam



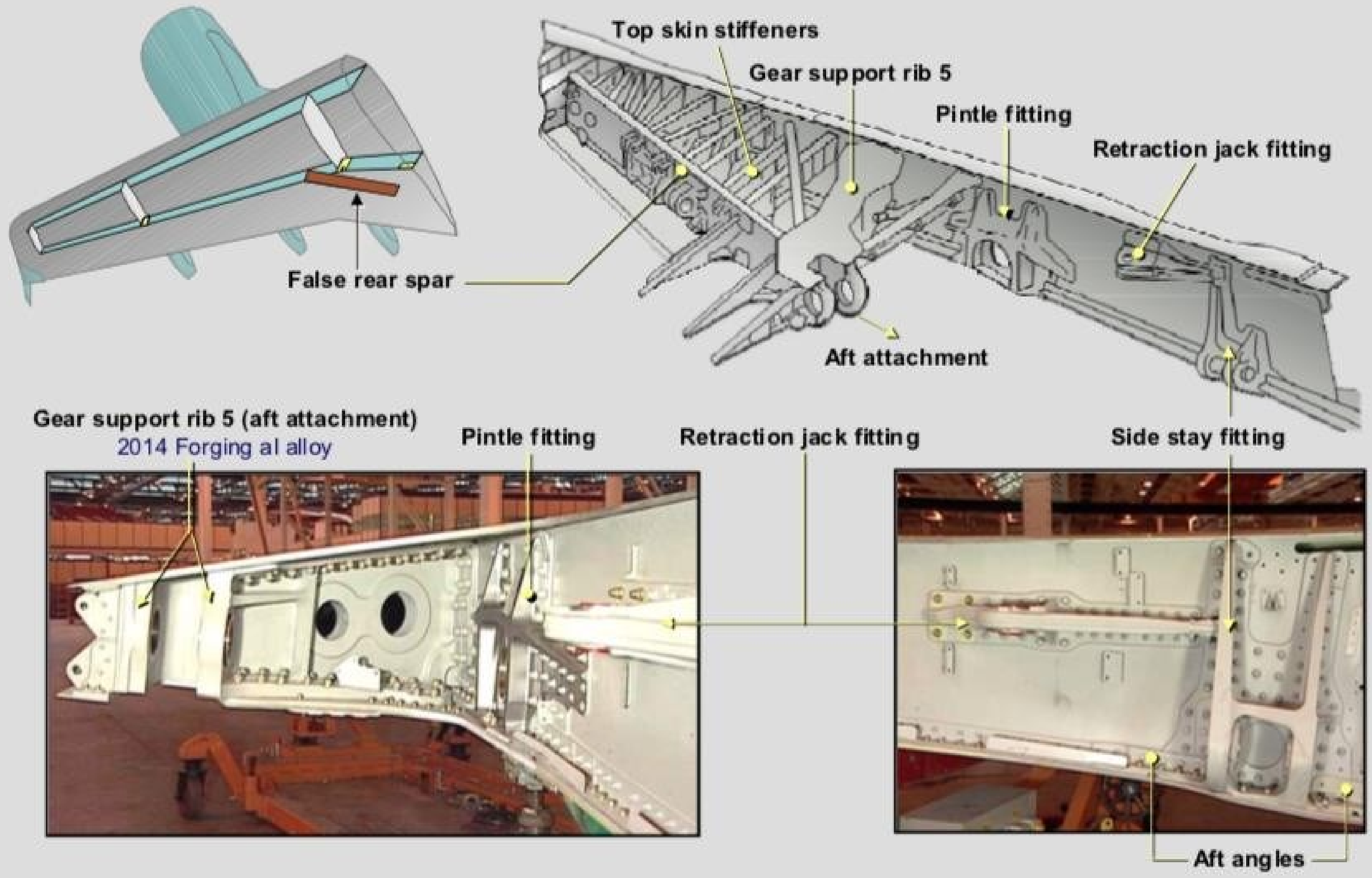
Tension field beam

The effect of the vertical component of web tension is to compress the vertical stiffeners and bend the caps in the plane of the webs.

The horizontal component of web tension compresses beam caps.



MAIN LANDING GEAR ATTACHMENTS



Ribs and bulkheads

Ribs are used to:

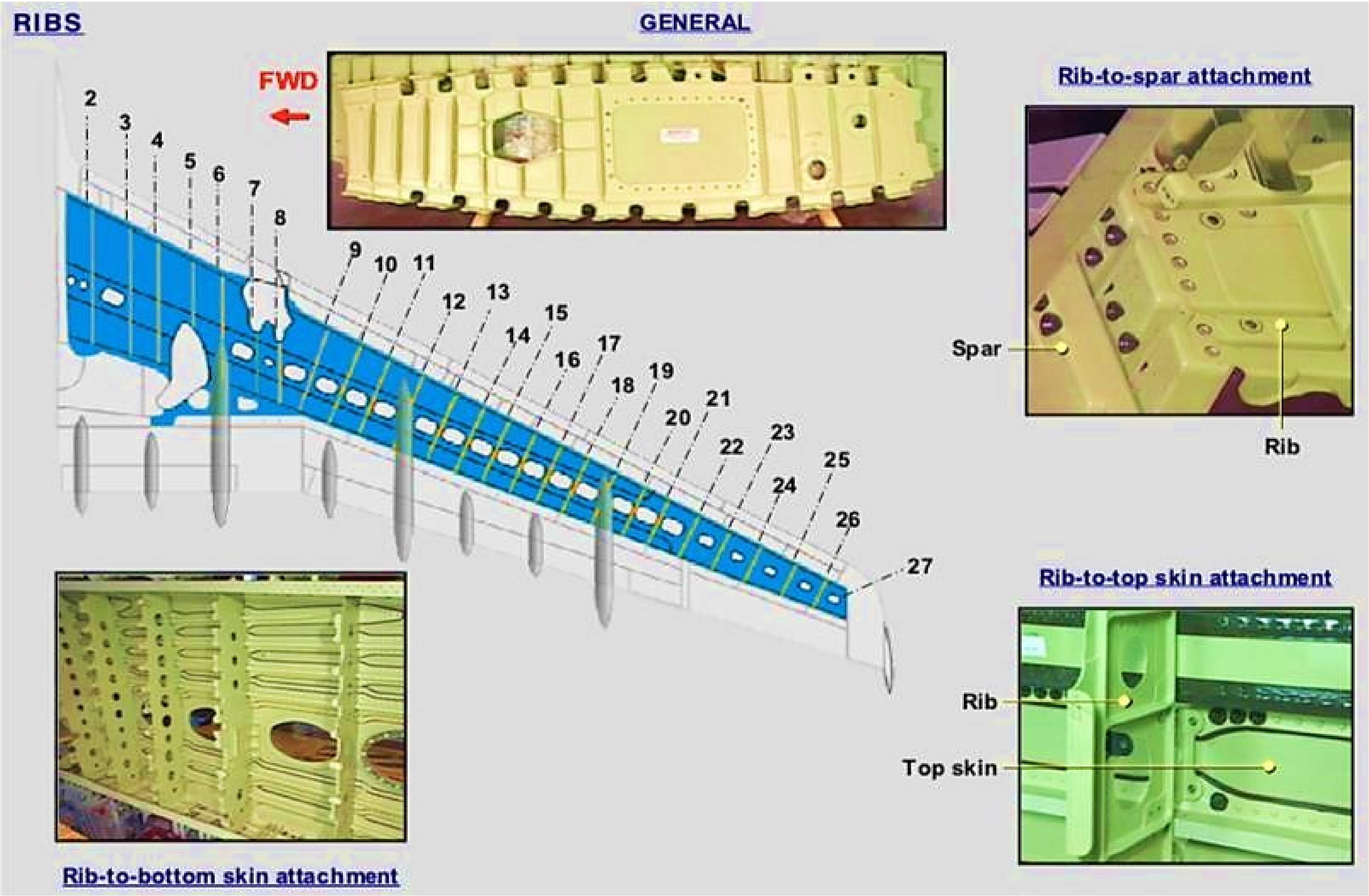
Hold the cover panels

Contour shape

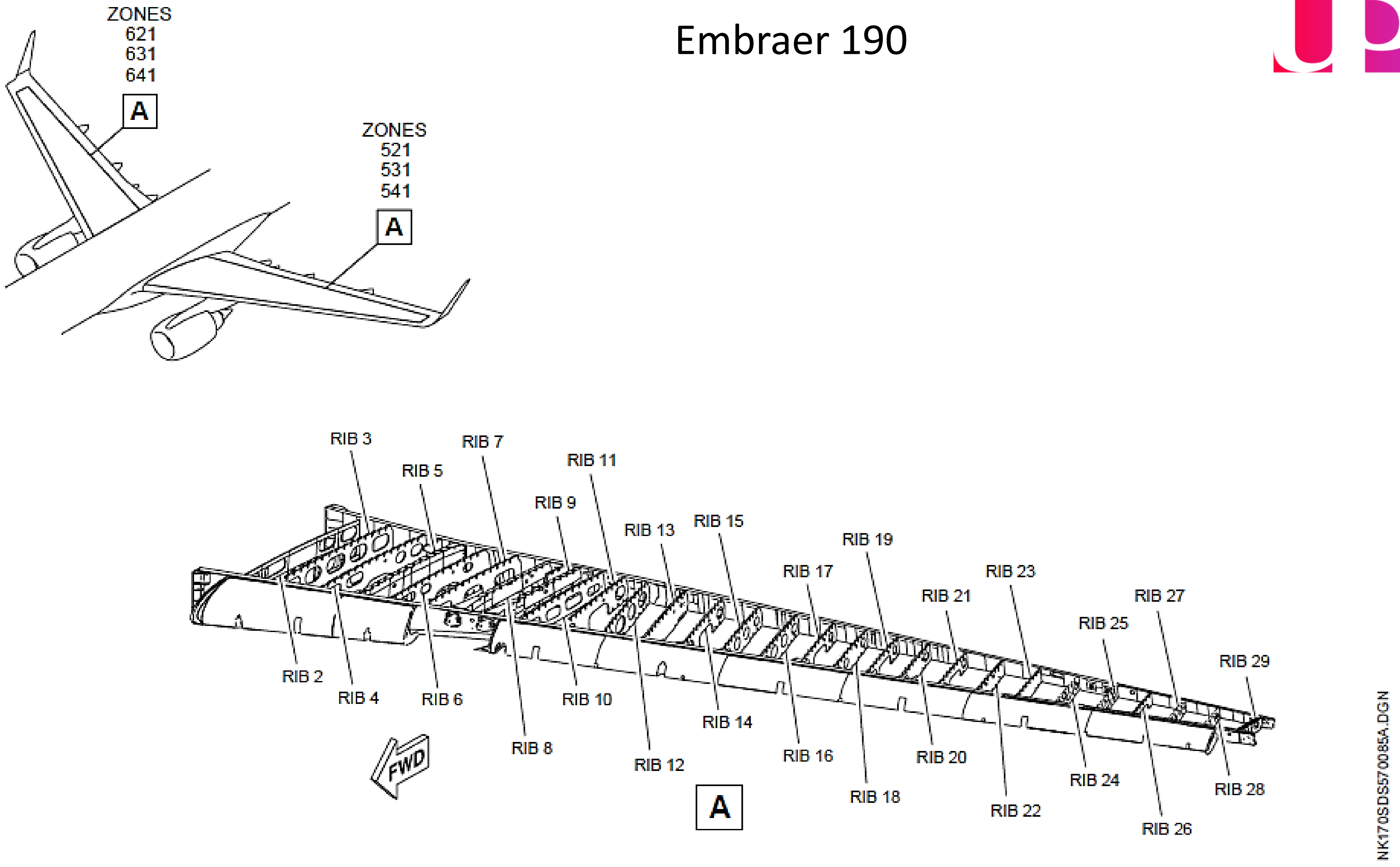
Limit the length of skin-stringer or integrally stiffened panels to an efficient column compressive strength.

Ribs and bulkheads

Airbus A320

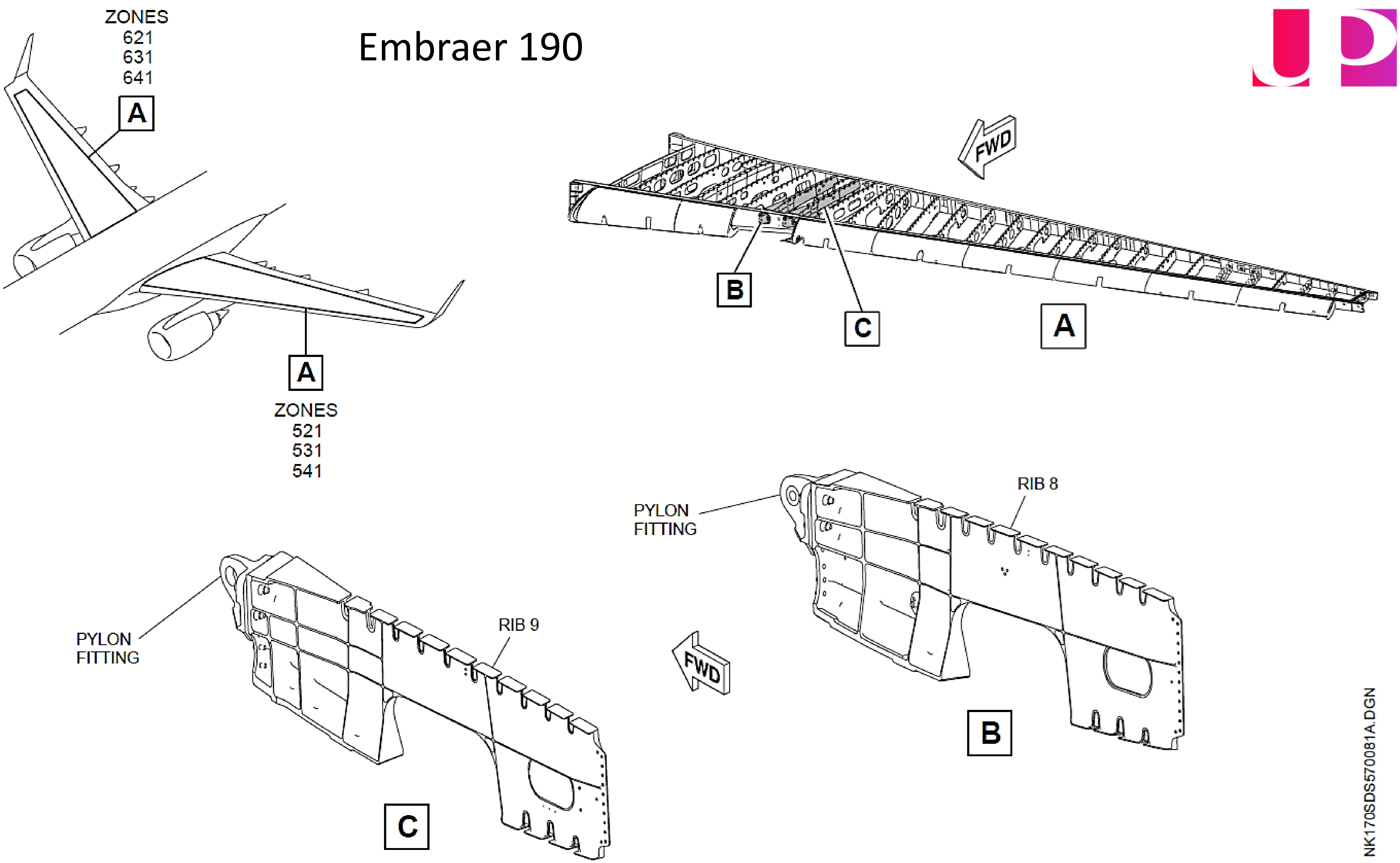


Embraer 190

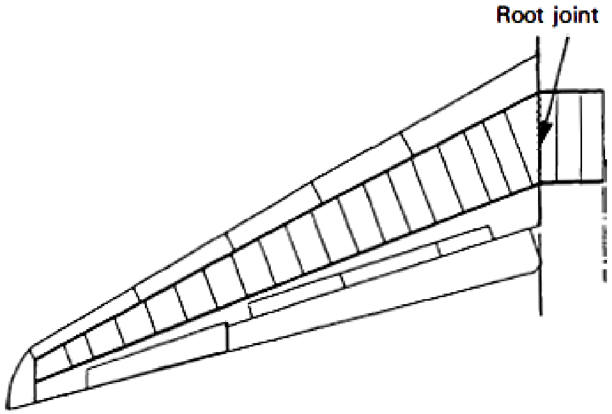


WING MAIN BOX - WING MAIN BOX RIBS

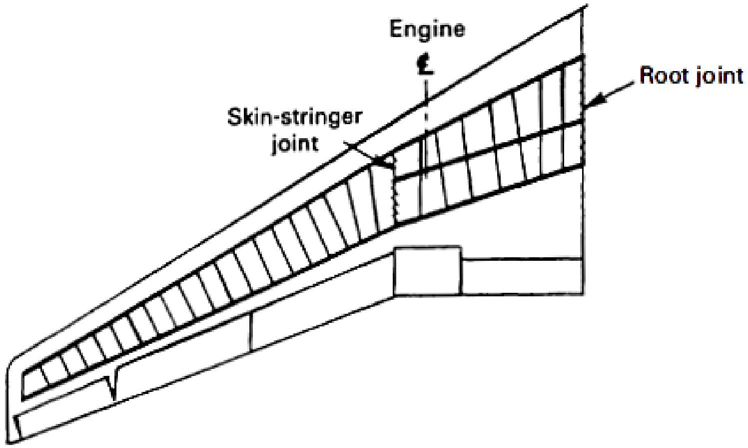
Embraer 190



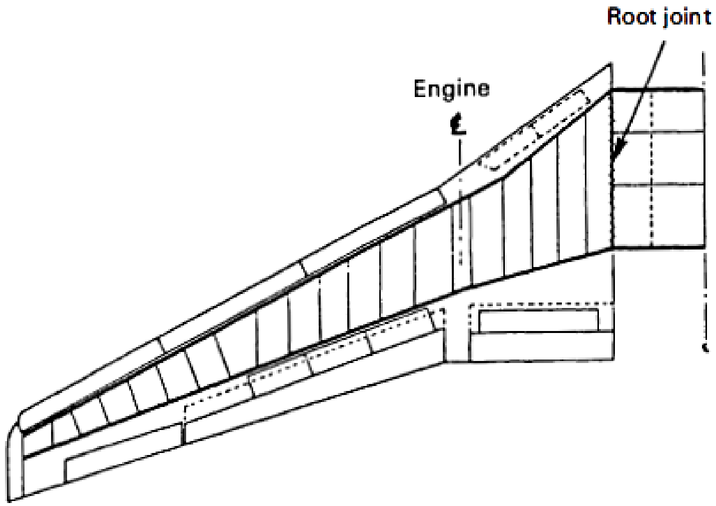
WING MAIN BOX - PYLON FITTINGS



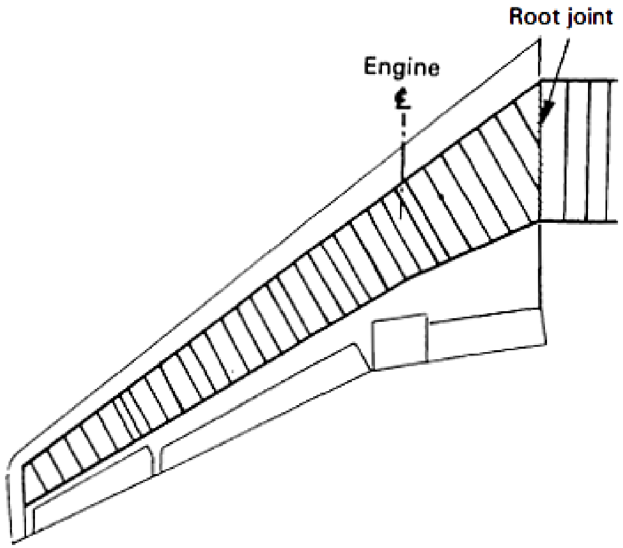
(d)DC-9



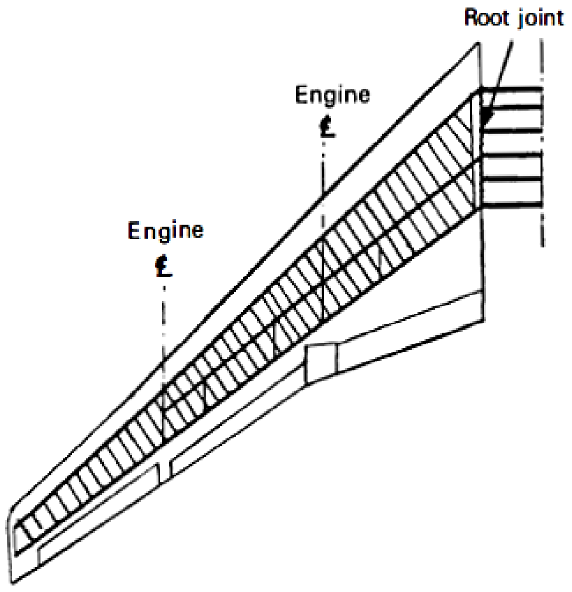
(g)A300



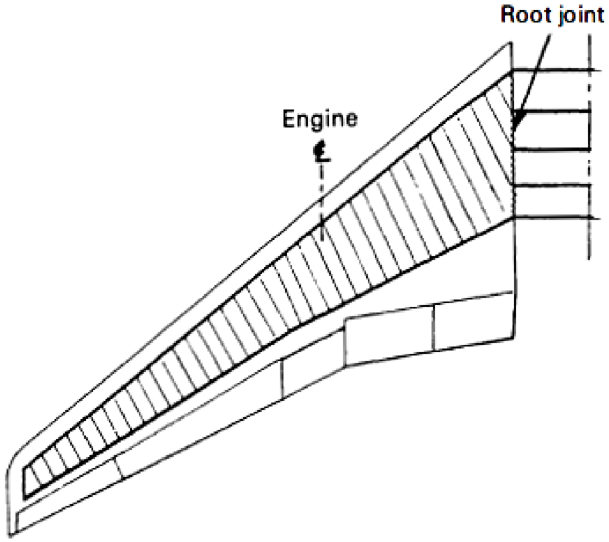
(e)B737



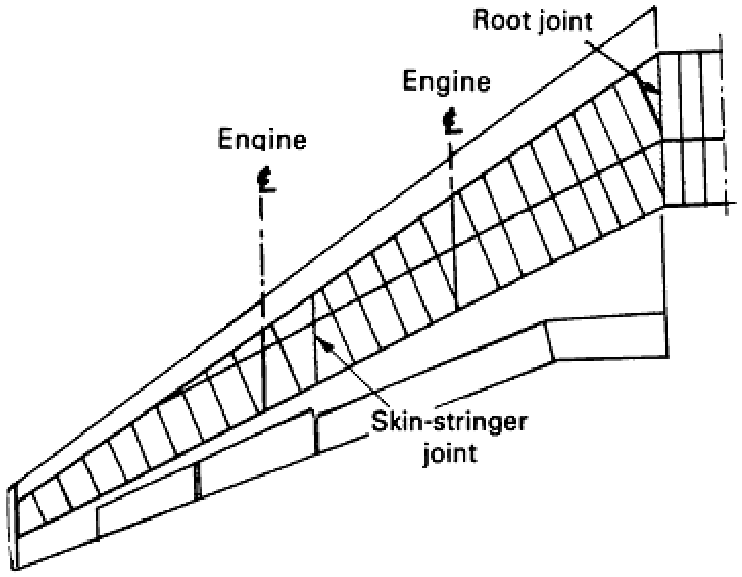
(h)DC-10



(f)B747



(i)L-1011

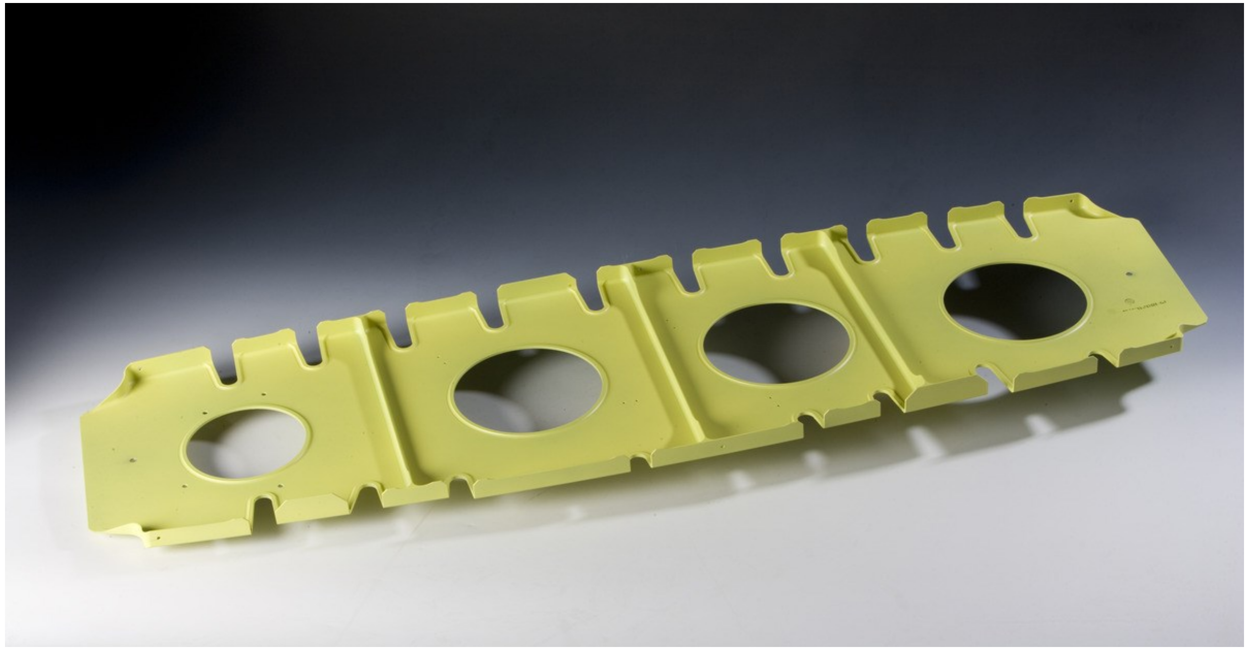


(a)DC-8

Ribs and bulkheads

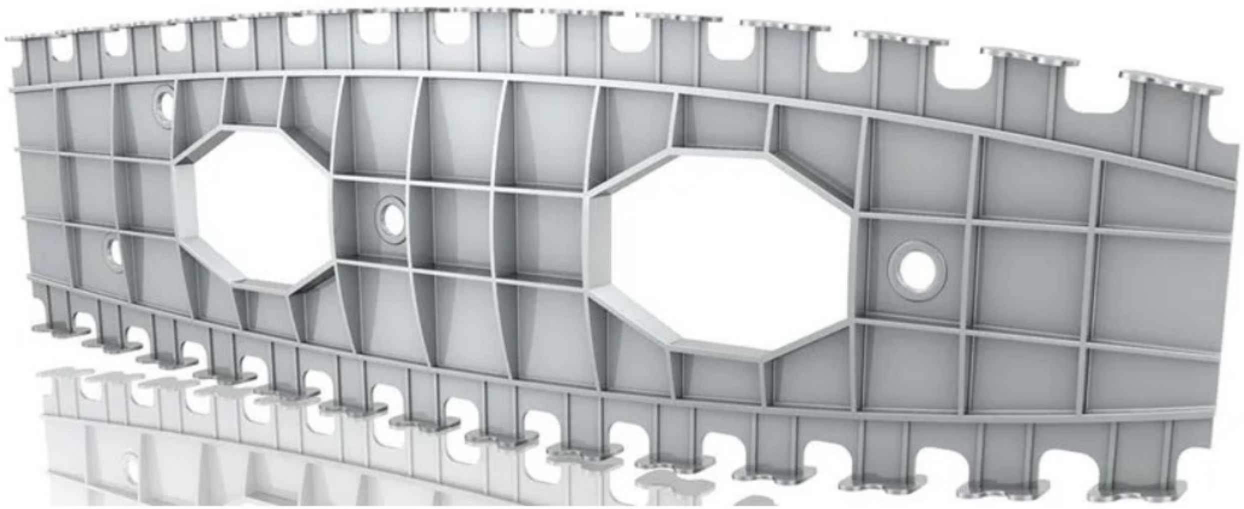
Ribs are used also for transfer and distribute loads.

The applied loads may be only **primary loads** (air loads) and/or **inertia loads** (fuel, equipment) which require relatively light internal ribs to **carry through or transfer these lads to main spar structures**



Ribs and bulkheads

Shear web ribs



Truss web

Ribs and bulkheads

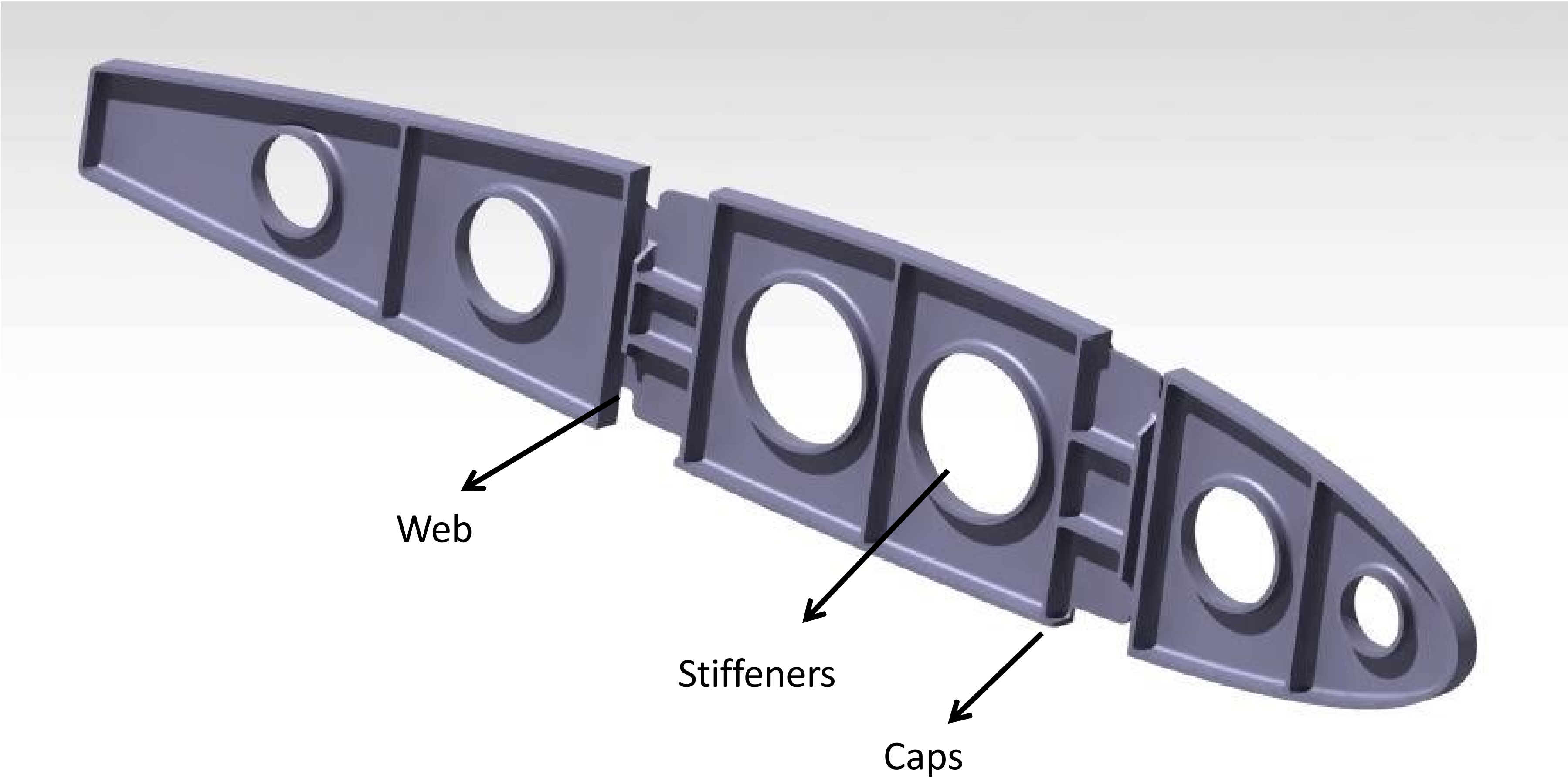
The way the rib structure resists external loads and reaction forces acting on the ribs depends on the **type of construction**.

- In the **truss-type** ribs the distributed external loads and forces are applied as **concentrated loads at joints**
- **Shear web type ribs** are usually employed either to **distribute concentrated loads** (air loads, nacelles, landing gears)

Webs with lightening holes and stiffeners are applied to resist **bending moments by rib cap** members and **shear by the web**.

Ribs must cause a **redistribution of shear flows** in a wing where concentrated loads are applied.

Ribs and bulkheads



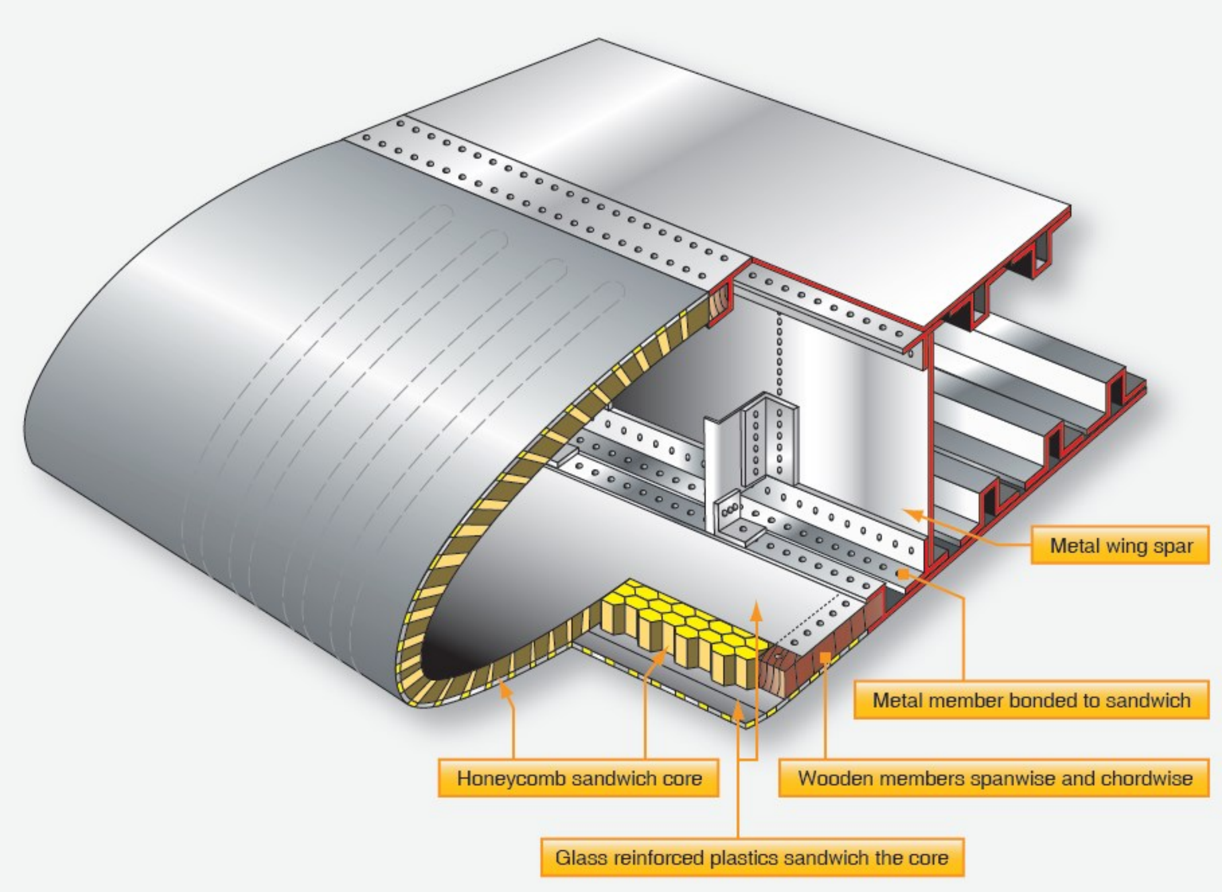
Ribs and bulkheads

Wing bulkheads are frequently constructed as **solid webs**, although **webs with access holes** or **trussed** may be used.

Wing ribs carry the following loads:

- Primary loads
- Inertial loads
- Crushing loads (due to bending)
- Redistributes concentrated loads (nacelles, landing gears)
- Supports members
- Diagonal tensions from skin

Leading edge



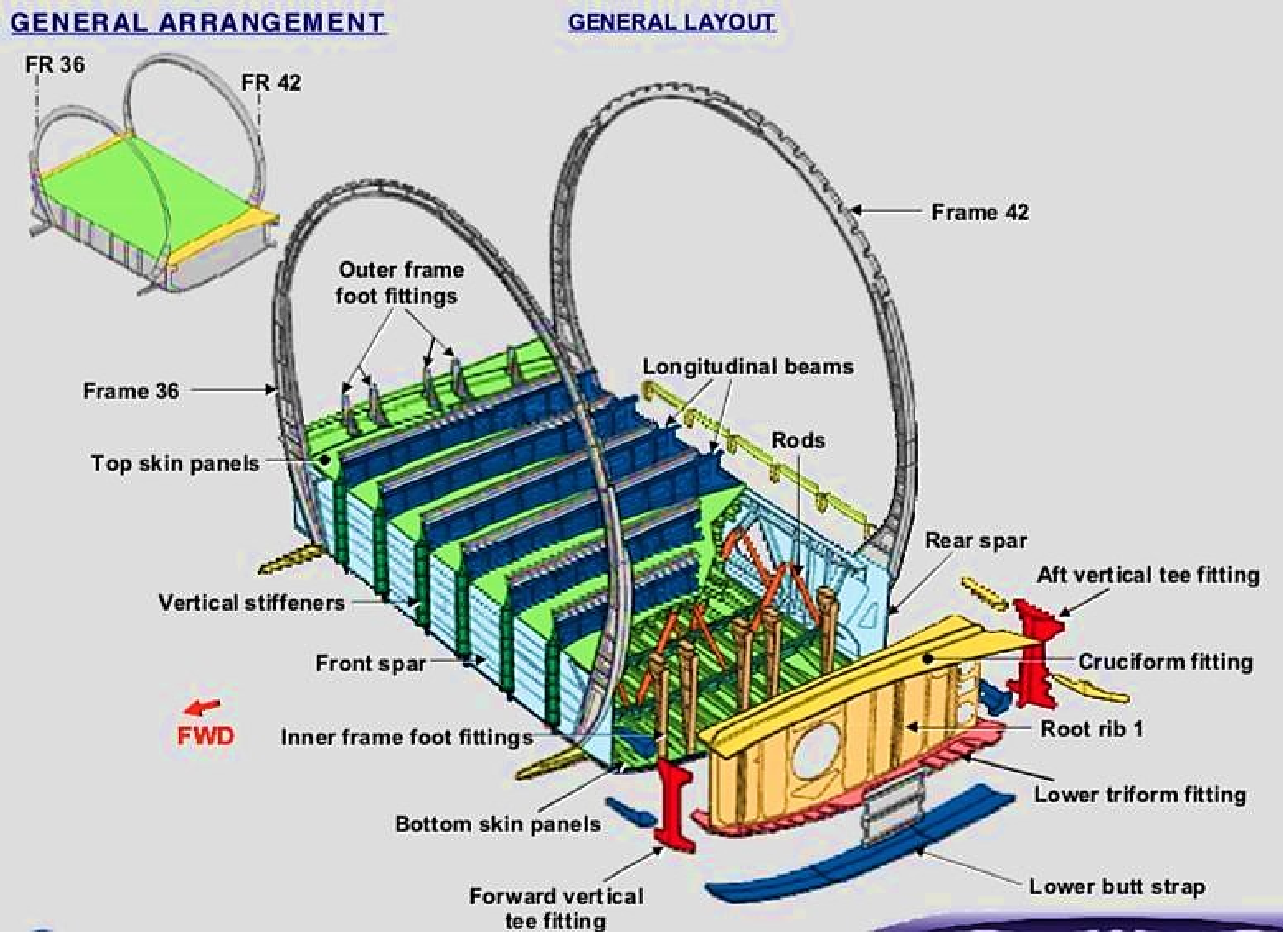
Wing to body joint

The **wing-to-body joint is the highest loaded joint** in an aircraft.

For fail-safe reasons, it is not a single joint but is comprised of many splices and joints that transfer loads from the outboard wing to the wing center section.

The **three primary loads that need to be transferred** at this joint are the vertical shear loads from the spars, the spanwise loads from the wing skins and the fore/aft horizontal shear loads from the wing skins.

Wing to body joint

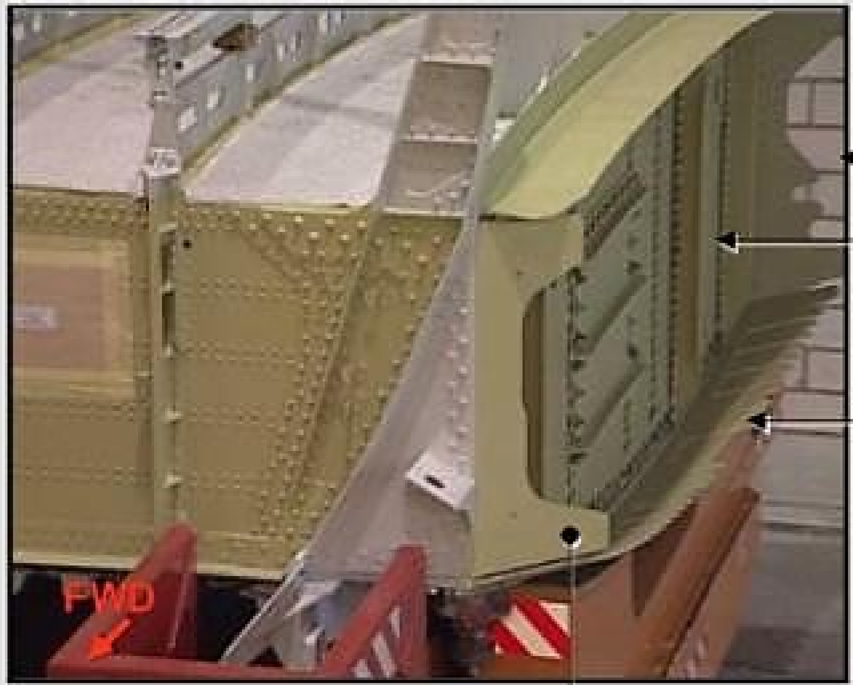


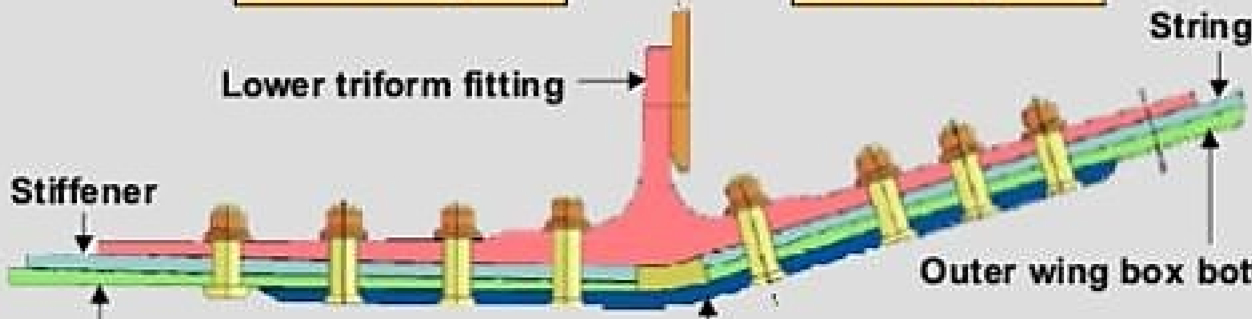
Wing root attachments

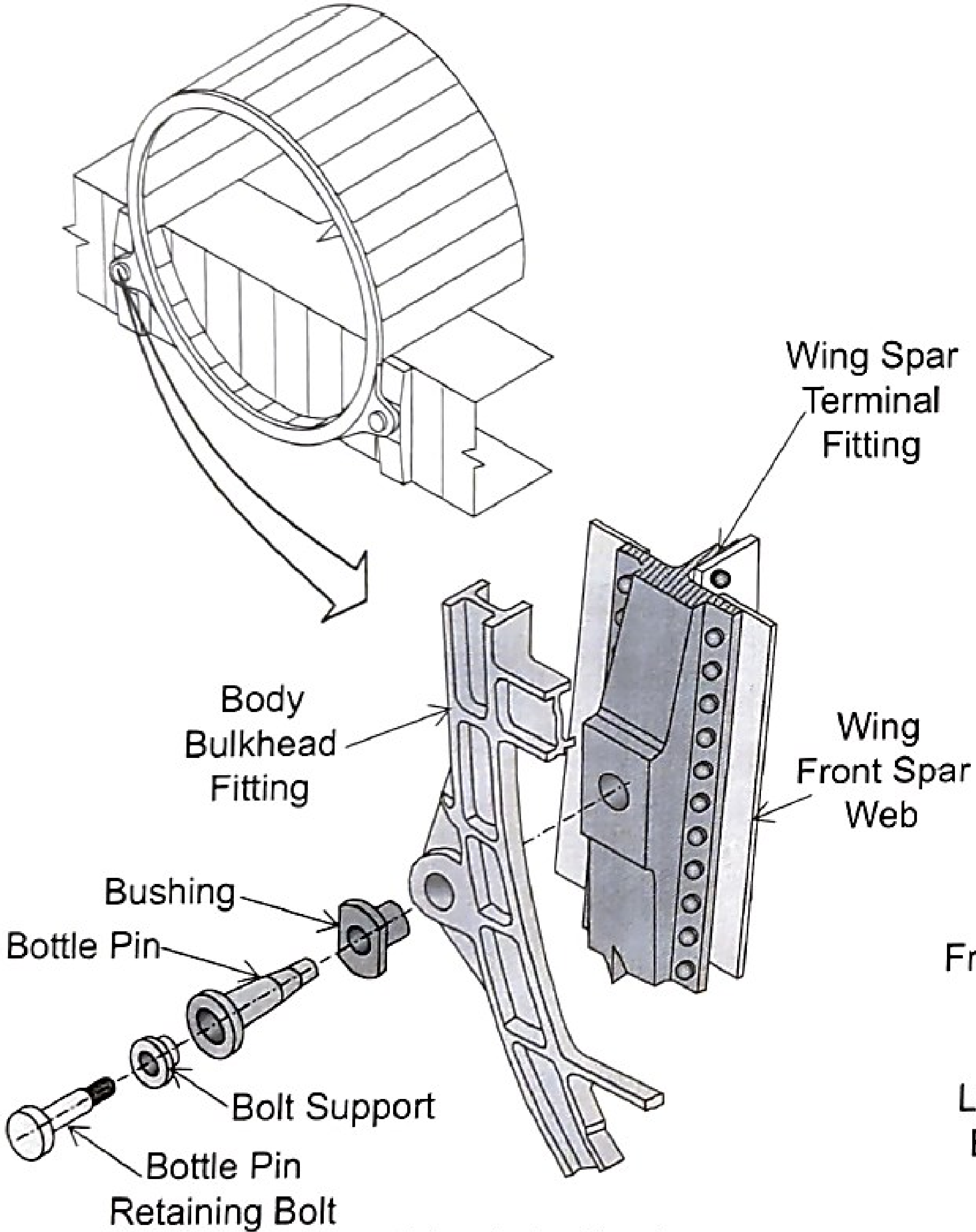
Joint	Ref. Fig.	Advantages	Disadvantages
Spliced plates	8.6.3	Widely used due to its light weight and more reliable and inherent fail-safe feature.	Slightly higher cost, manufactural fitness
Tension bolts	8.6.4	Less manufactural fitness required, easy to assemble or remove. More economic for military flighter with thin airfoil.	Heavy weight penalty
Lug (shear type)	8.6.5	(Same as above)	(Same as above)
Combination of spliced plates and tension bolts	8.6.6	Reliable and inherent fail-safe feature, and less manufactural fitness required.	Heavy weight penalty

ROOT ATTACHMENT

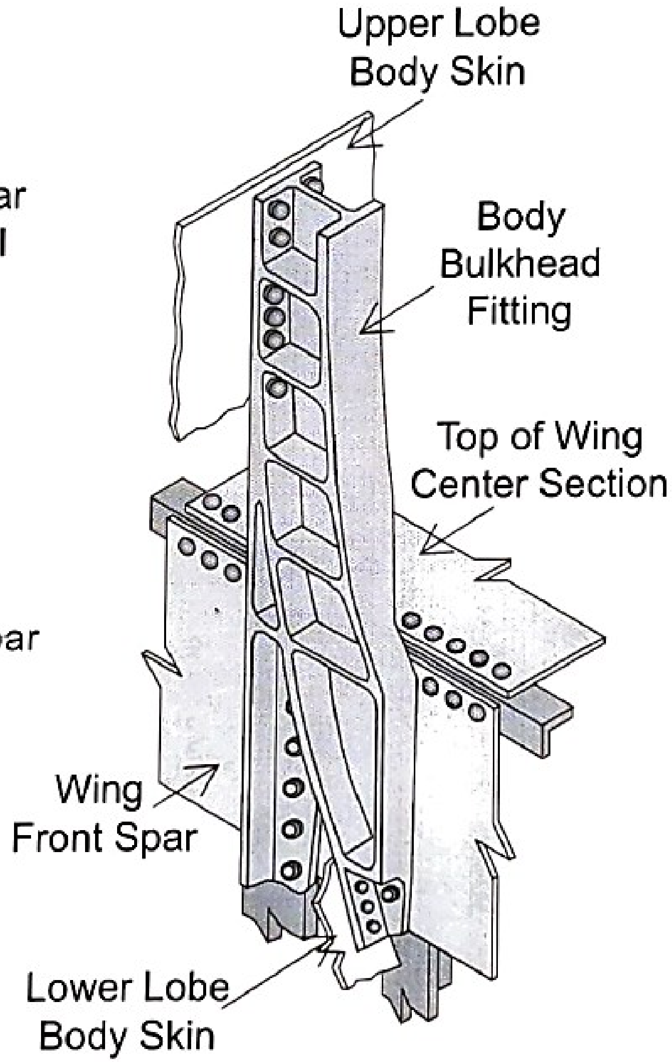
LOWER JUNCTION



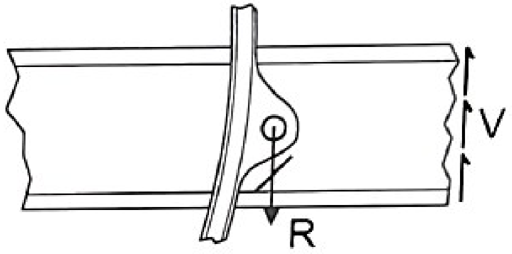




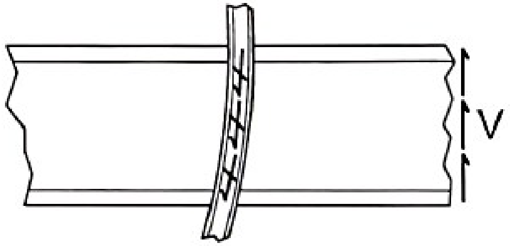
<u>Obsolete Design</u>
(707 and 727)



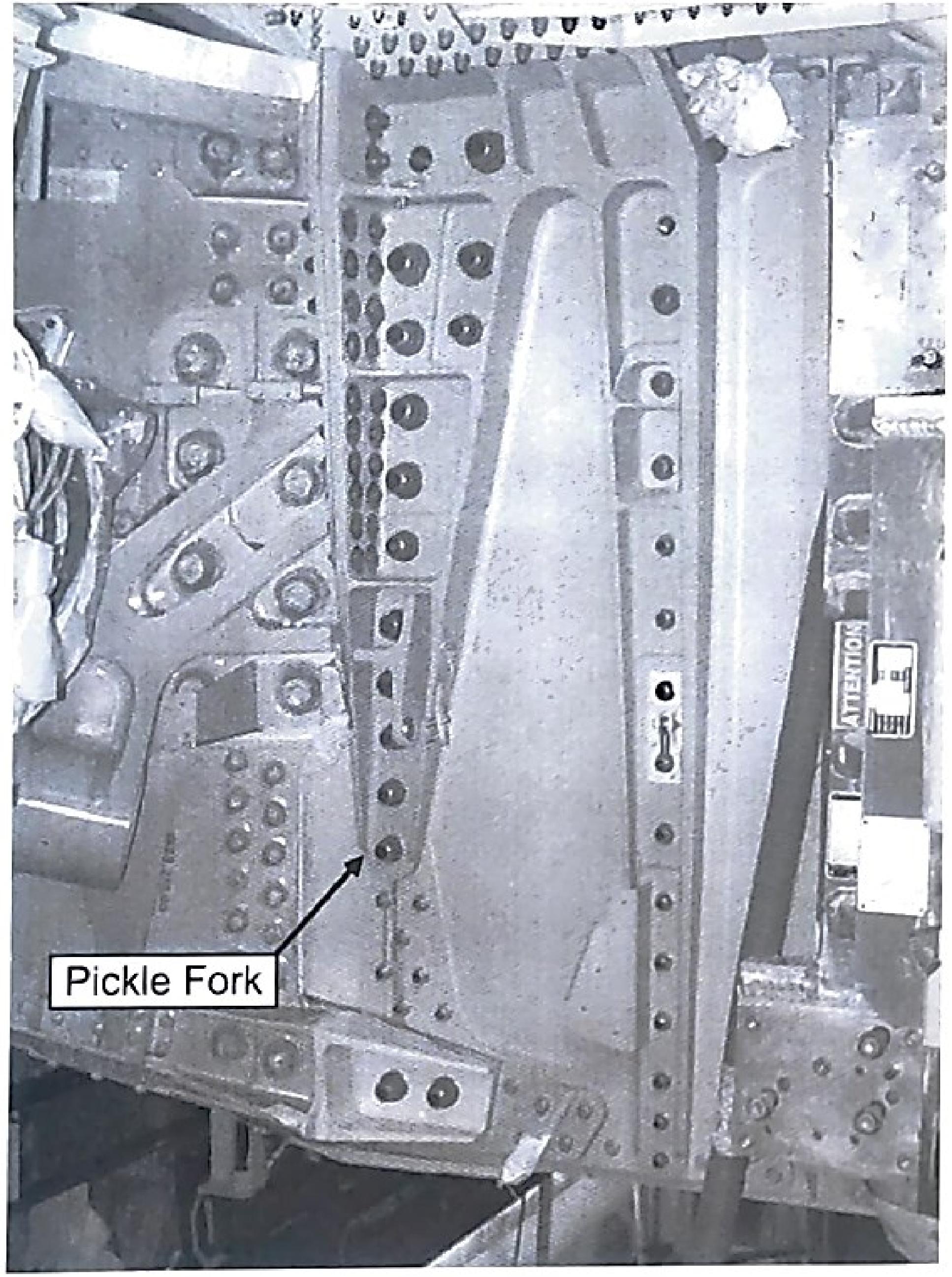
<u>Current Design</u>
(737 and on)



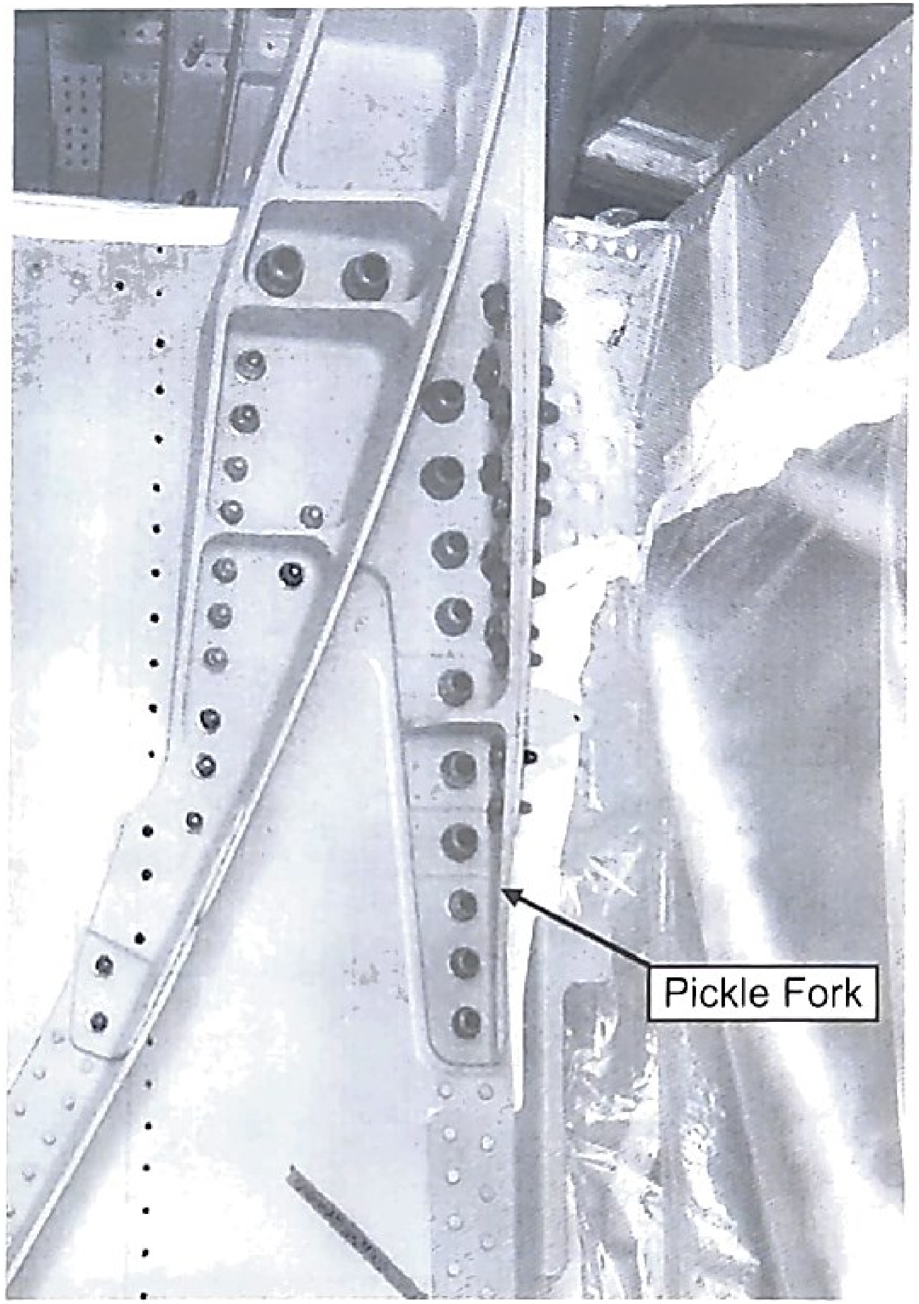
Bottle Pin Joint
Load Distribution
(Obsolete Design)



Continuous Joint
Load Distribution
(Current Design)



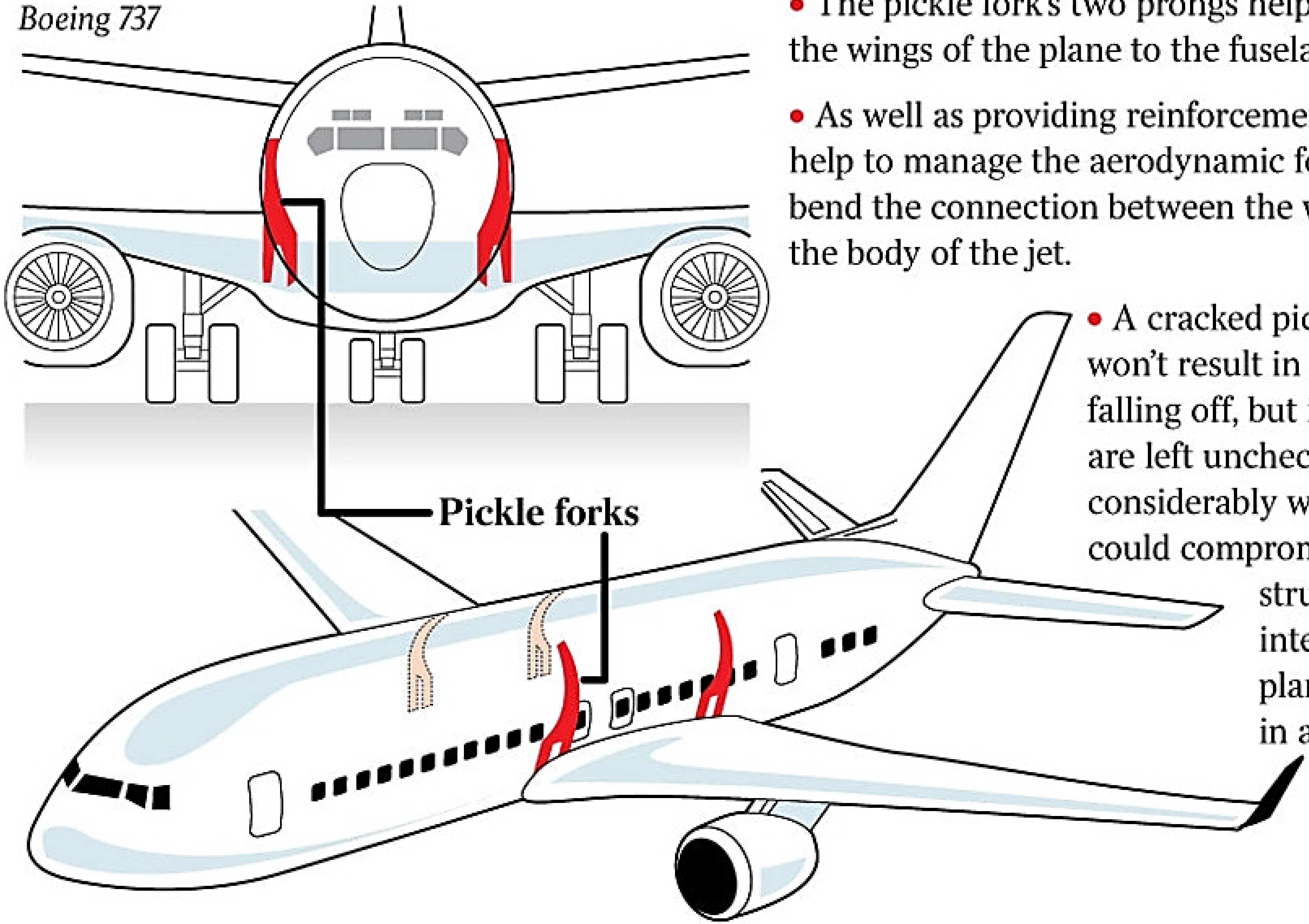
777 Aft Body Buckhead Fitting (Pickle Fork)



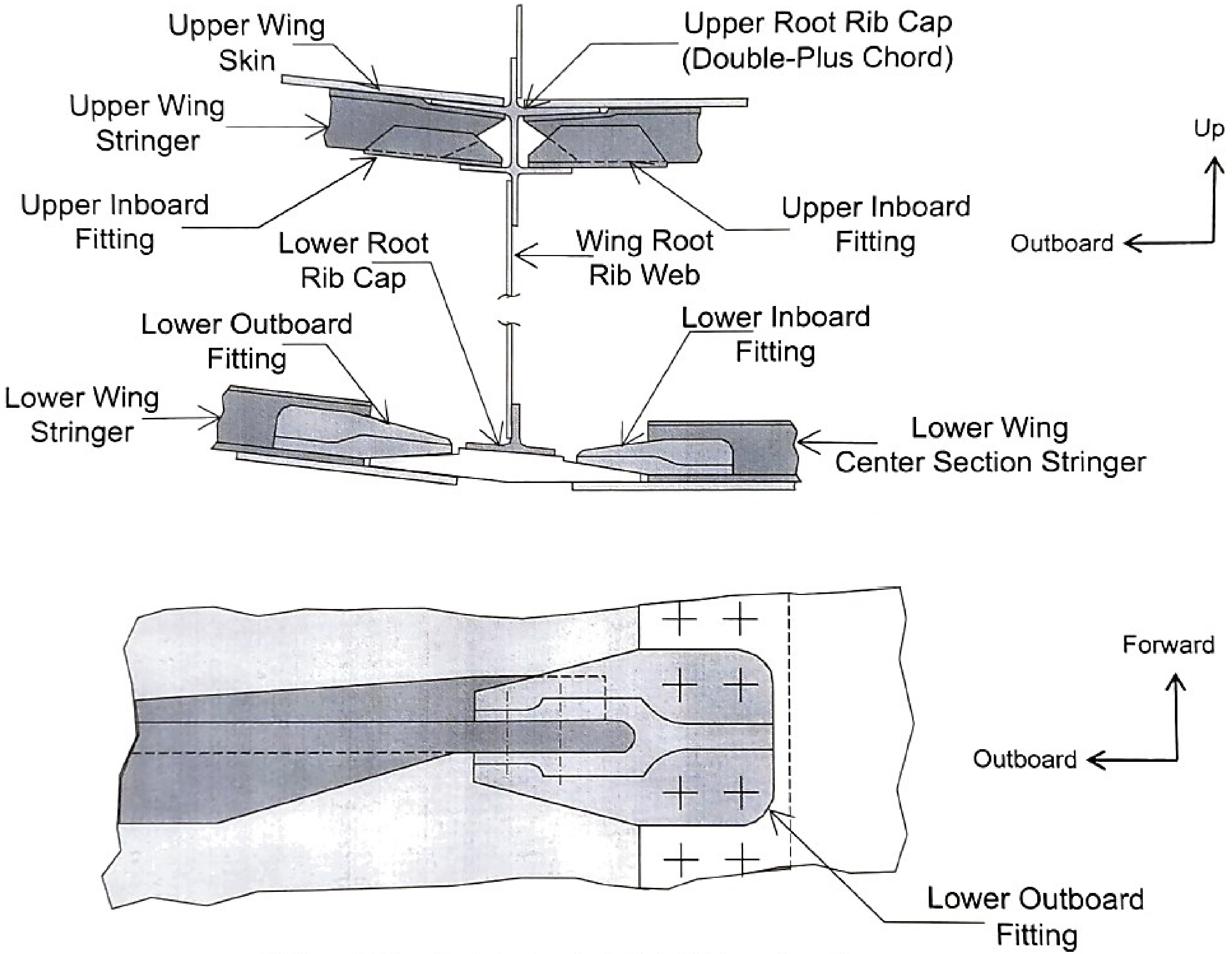
777 Forward Body Buckhead Fitting (Pickle Fork)

BOEING IN A PICKLE

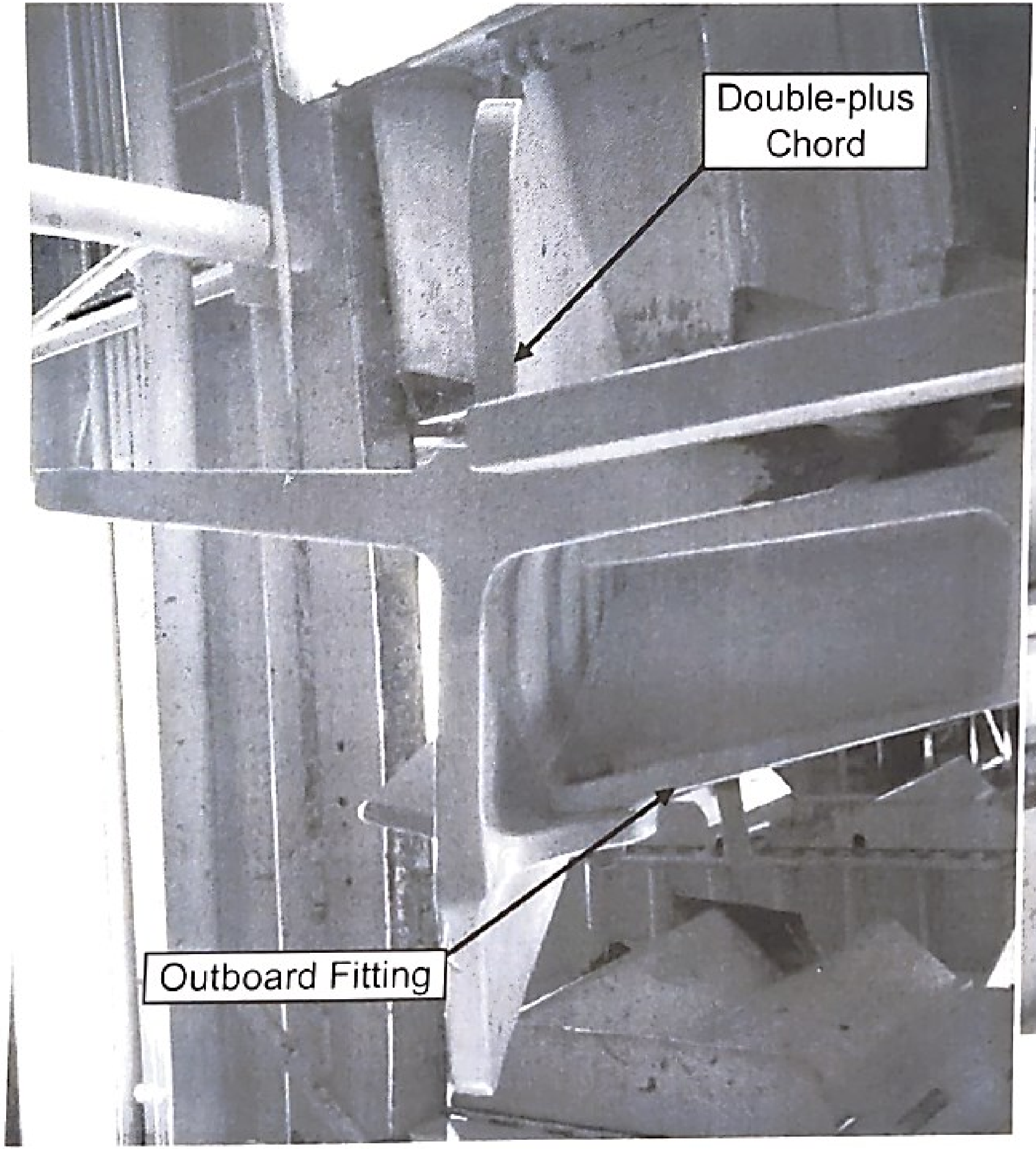
Boeing 737



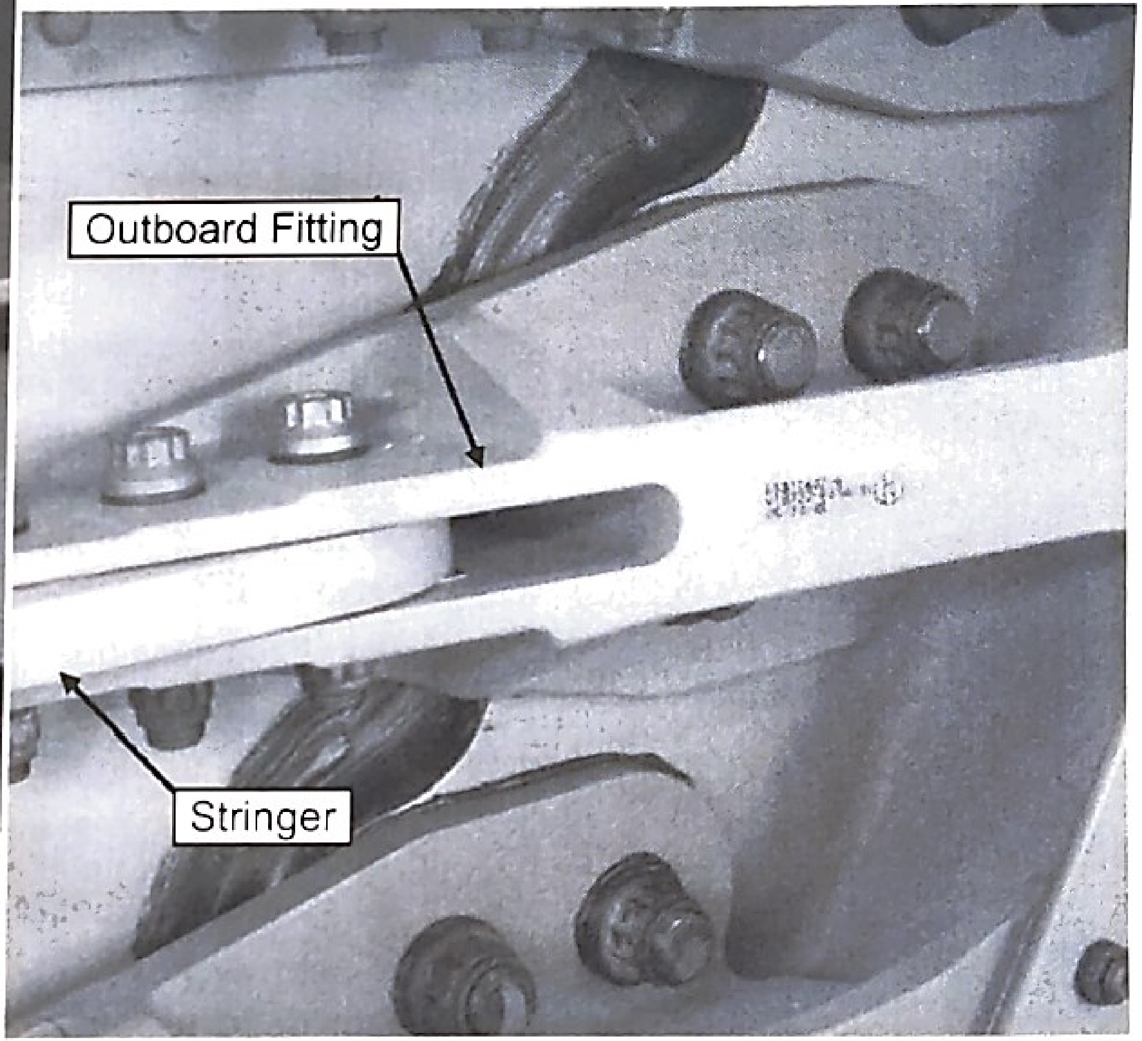
- The pickle fork's two prongs help attach the wings of the plane to the fuselage.
- As well as providing reinforcement, they help to manage the aerodynamic forces that bend the connection between the wings and the body of the jet.
- A cracked pickle fork won't result in a wing falling off, but if the cracks are left unchecked and considerably worsen, that could compromise the structural integrity of the plane, resulting in a loss of control.



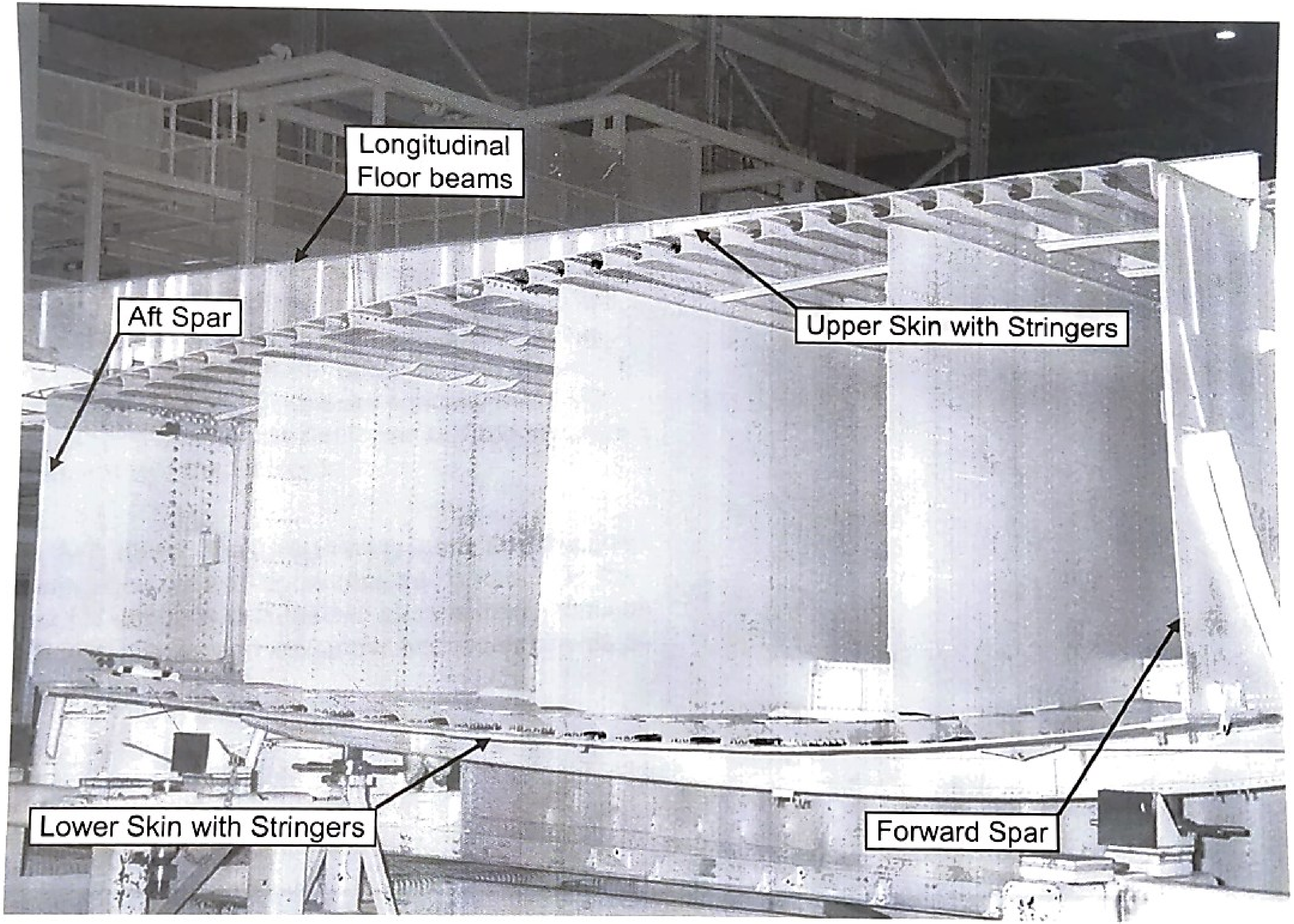
Wing Skin To Body Joint (737 and on)



747 Double-plus Chord



747 Upper Outboard Fitting



777 Wing Center Section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