AIRCRAFT STRUCTURAL DESIGN & ANALYSIS

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To invent an airplane is nothing
To build one is something
But to fly is everything

Lilienthal

DAY 1

WHAT IS AN AIRCRAFT?

- An aircraft is a vehicle, which is capable of flying through the air (or through any other atmosphere)

KINDS OF FLYING MACHINES

- **Aerostat :** Flying machines (systems), which are lighter than air
  - Balloons

    (Unpowered aerostat)
  - Airships

    (Powered aerostat)

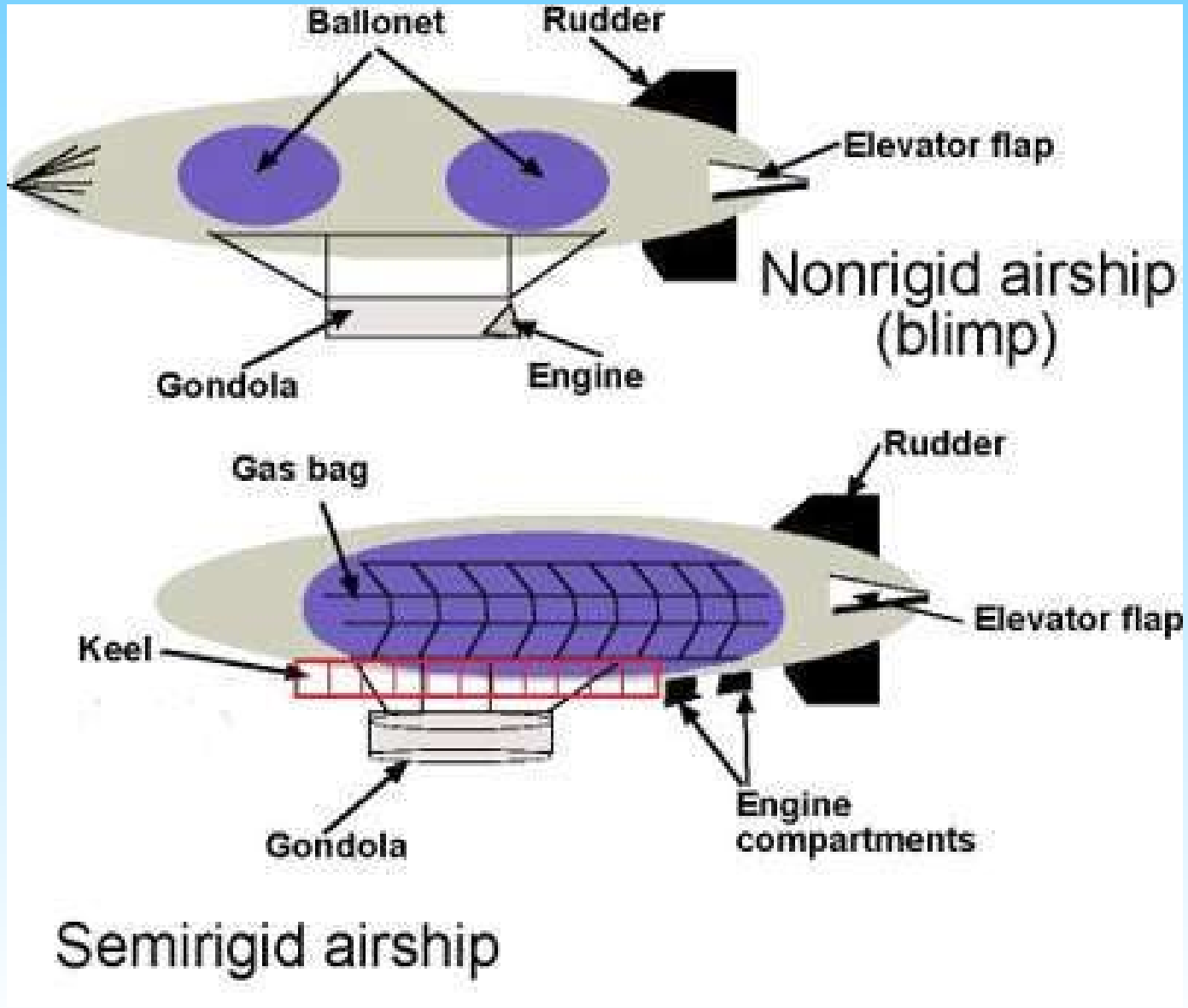
- **Aerodyne:** Flying machines (systems), which are heavier than air
  - Airplanes
  - Helicopter

WORKING PRINCIPLE

- **AEROSTAT**
  Aerostats use the concept of buoyancy to float in the air in much the same manner as ships float on the water.
  - Use lighter than air gases such as hot air, hydrogen, helium

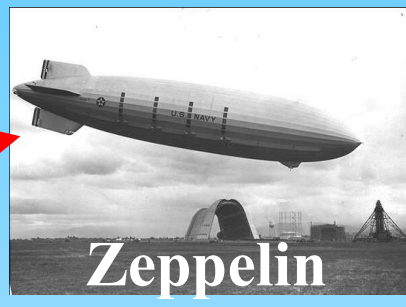
- **AERODYNE**
  Aerodynes use the concept of pushing the air or gas downwards so that due to Newton's law of motion to generate an upward force to push the aircraft upwards

AIRSHIP


Ballonet
Rudder
Elevator flap
Nonrigid airship
(blimp)
Gondola
Engine
Rudder
Gas bag
Elevator flap
Keel
Engine
compartments
Gondola
Semirigid airship

TYPES OF AIRSHIPS

- **Rigid airships** (Airships with rigid frames containing multiple, non-pressurized gas cells or balloons to provide lift)



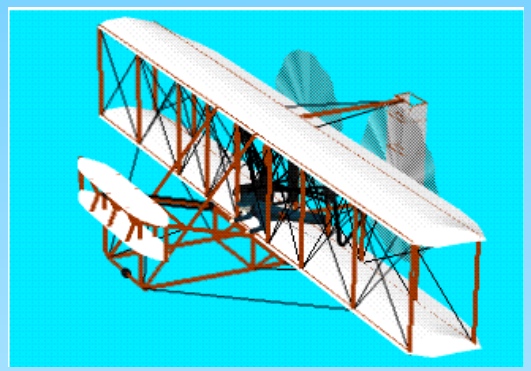
- **Non-rigid airships** (Airships that use pressure level in excess of the surrounding air pressure to retain their shape)

- **Semi-rigid airships** (Airships that use internal pressure to maintain their shape, but having articulated keel frames running along the bottom of the envelope)

- **Metal clad airships** (Airships utilizing a very thin, airtight metal envelope, rather than the usual rubber-coated fabric envelope)

- **Hybrid airships** (is a general term for an aircraft that combines characteristics of heavier-than-air (airplane or helicopter) and lighter than air technology

SOME AIRCRAFTS



Wright brothers (1903)

Aero A10 (1922)

Boeing 247 (1933)

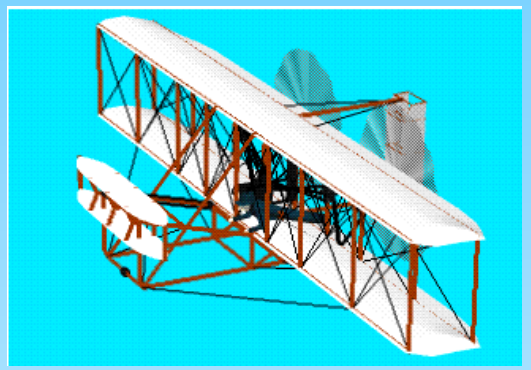
Douglas DC9 (1965)

Airbus 380 (2007)

Boeing 787 (2008)

CLASSIFICATION BASED ON POWER

- Unpowered



- Propeller powered
  (20000 ft)

- Jet engine powered
  (40000 ft)

CLASSIFICATION OF CIVILIAN A/C

- **Airliner**
  - Boeing / Airbus/ ATR / Bombardier / Douglas
- **Cargo**
  - Boeing / Airbus
- **Business aircraft**
  - Gulf stream / Bombardiar / Dassault
- **Agricultural aircraft**
  - Grumman / Transavia / Pacific aerospace
- **General aviation**

Boeing 747

Airbus A300

Bombardiar BD700

Fletcher FD25

CLASSIFICATION OF MILITARY AIRCRAFT

- Bombers

- Fighters

- Patrol

- Reconnaissance

- Transportation

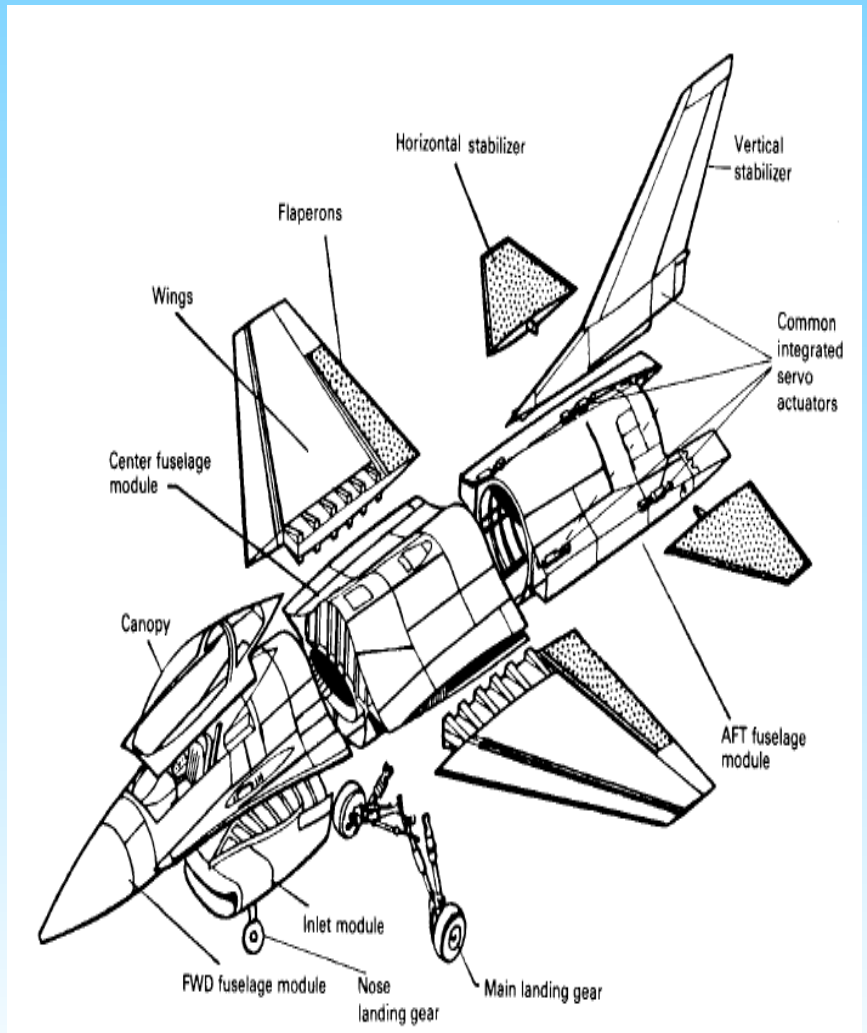
- Air support / counter insurgency

- Military trainers

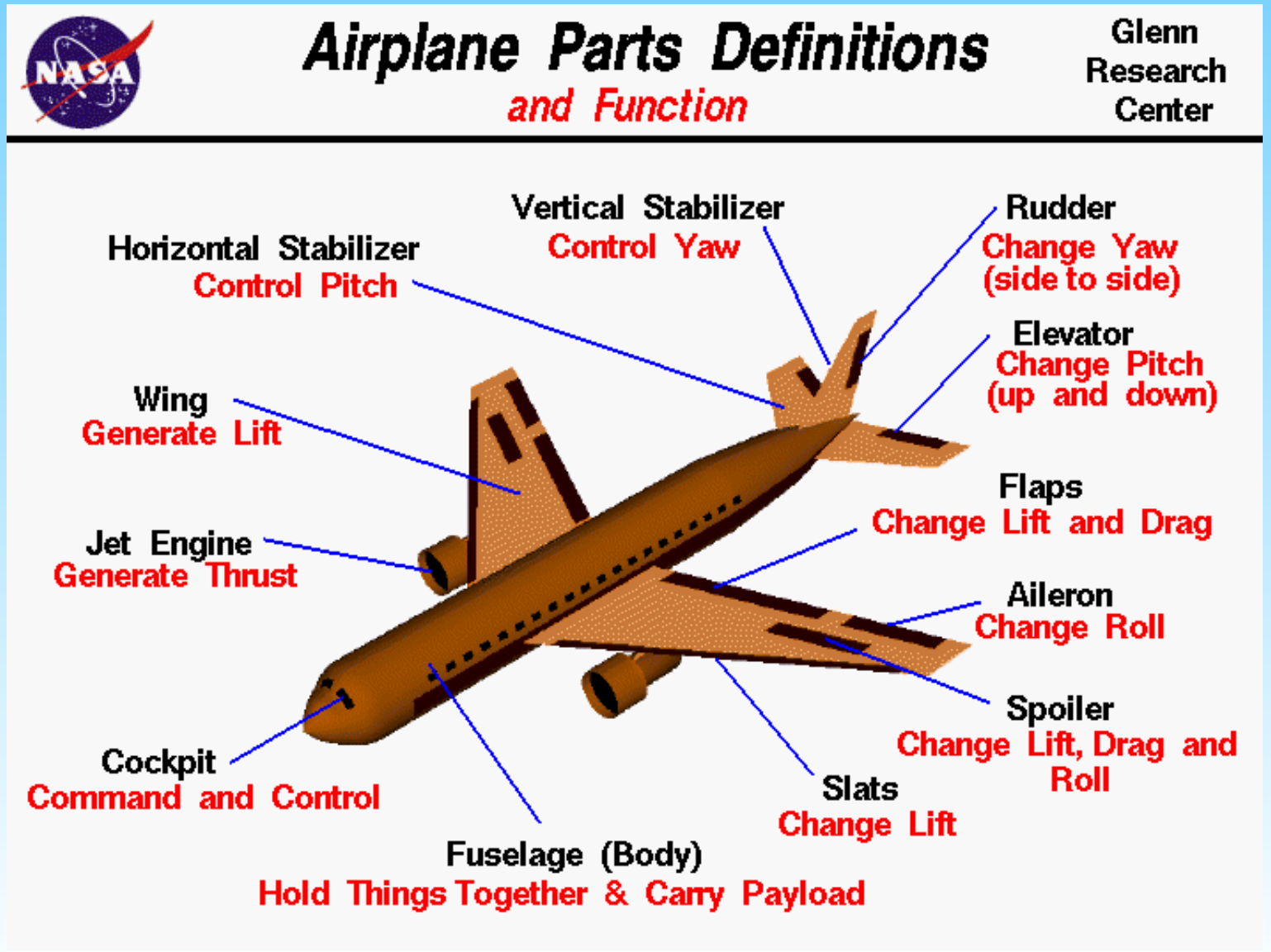
PARTS OF AN AIRCRAFT

MAJOR COMPONENTS OF AN AIRCRAFT

- Wings (to provide lift)
- Fuselage (to carry payload)
- Empennage (Directional stability)
- Landing gear (to land / takeoff /Taxiing)
- Flaps (High lifting devices)
- Ailerons (to control roll)
- Elevators (to control pitch)
- Rudders (to control yaw)



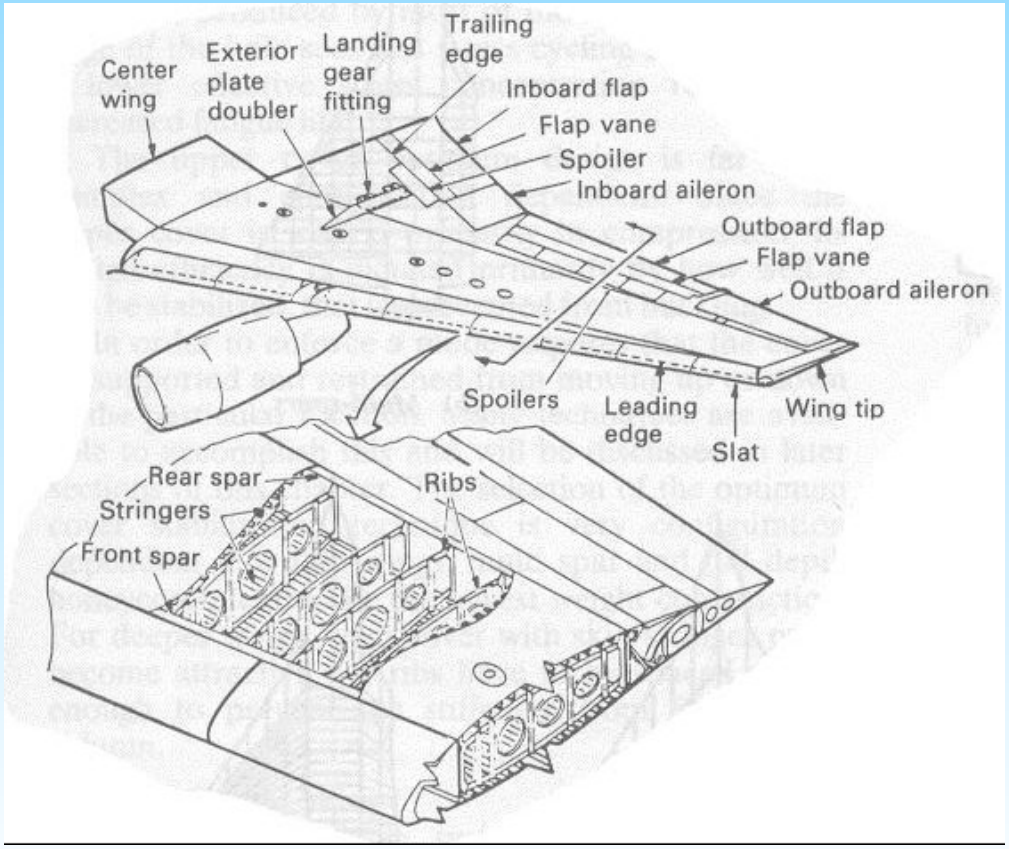
PARTS OF AN AIRCRAFT

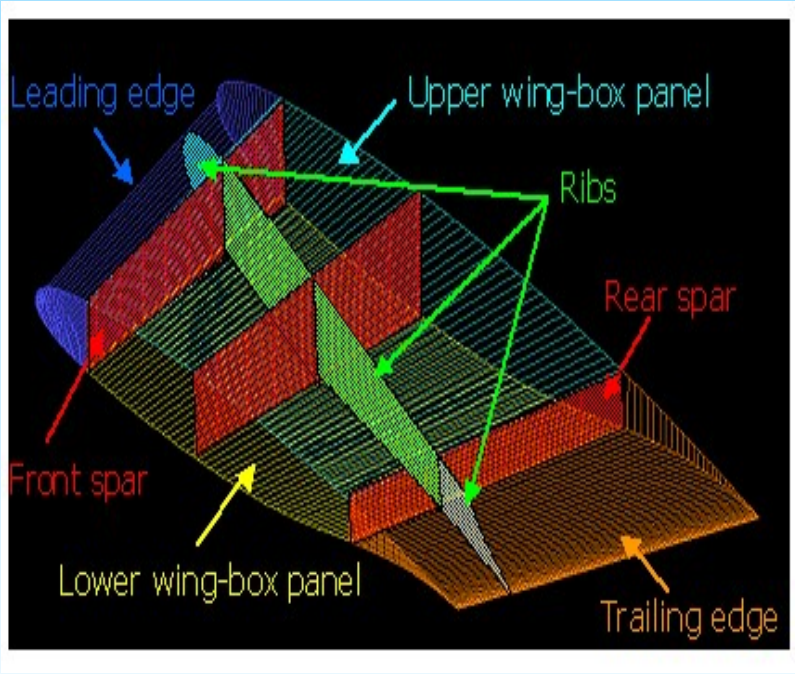


WINGS

WINGS

- **Wing is essentially a beam which gathers and transmits all the aerodynamic loads to the central fuselage attachment**





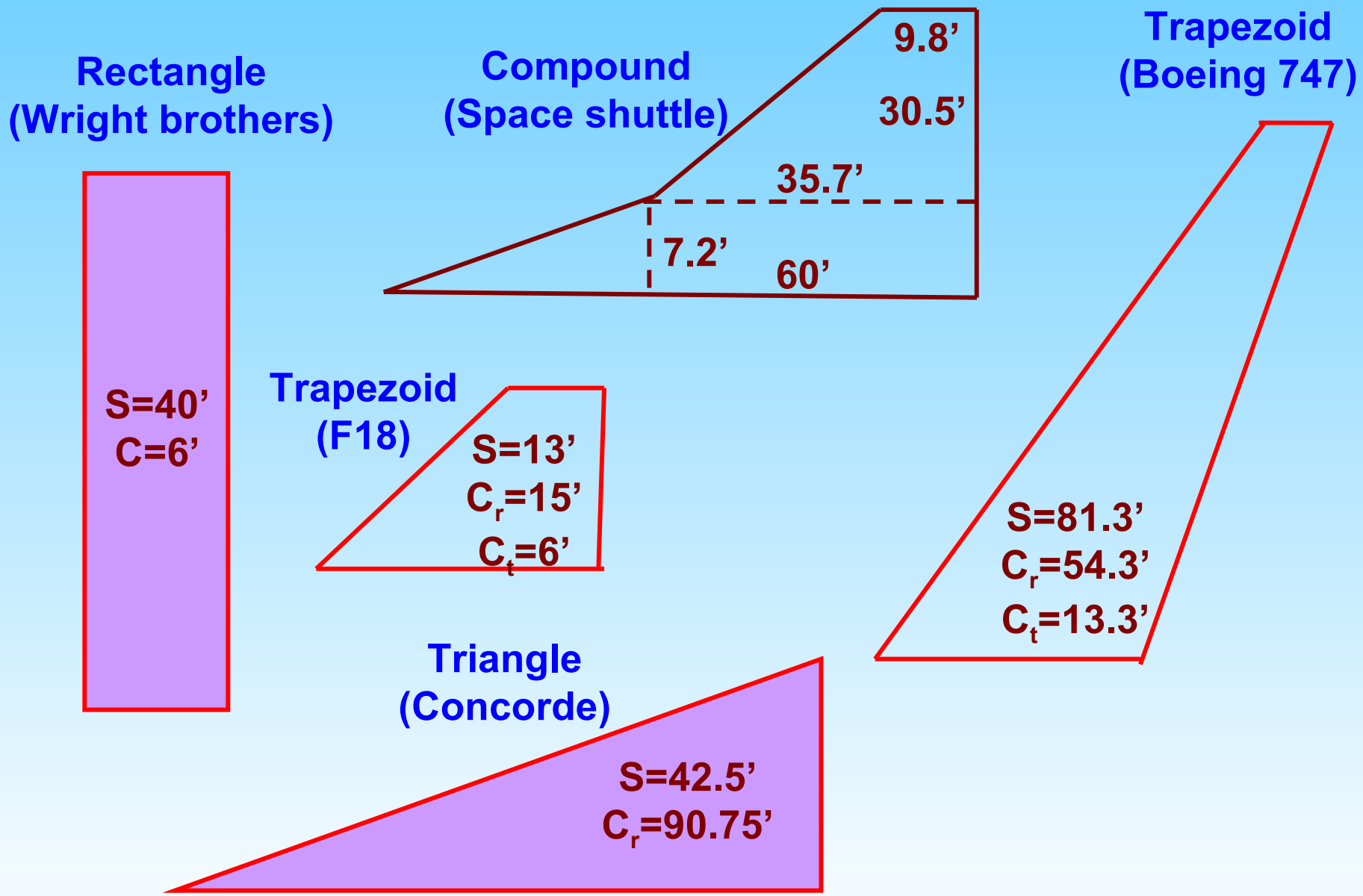
WING TYPES

- **Straight wing :**
  - **If the leading edge of a wing is perpendicular to the airflow, it is called a straight wing**
- **Swept wing :**
  - **If the leading edge of a wing meets the airflow at an angle, it is called a swept wing**

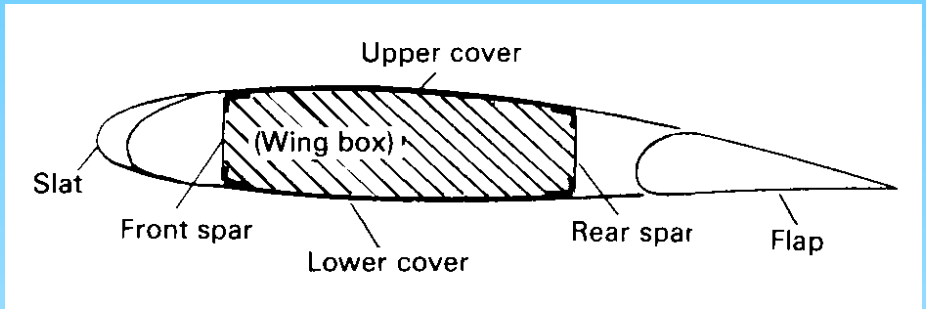
Straight wing

Swept wing

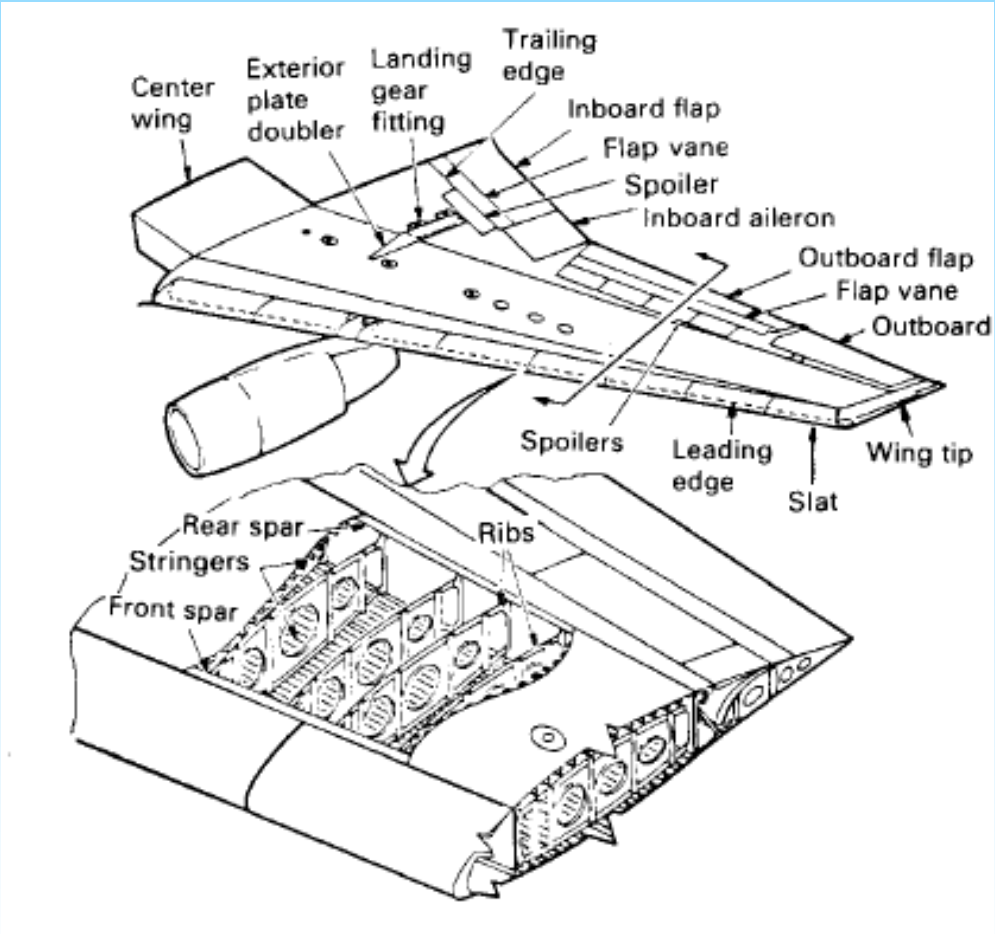
TYPICAL WING FORMS



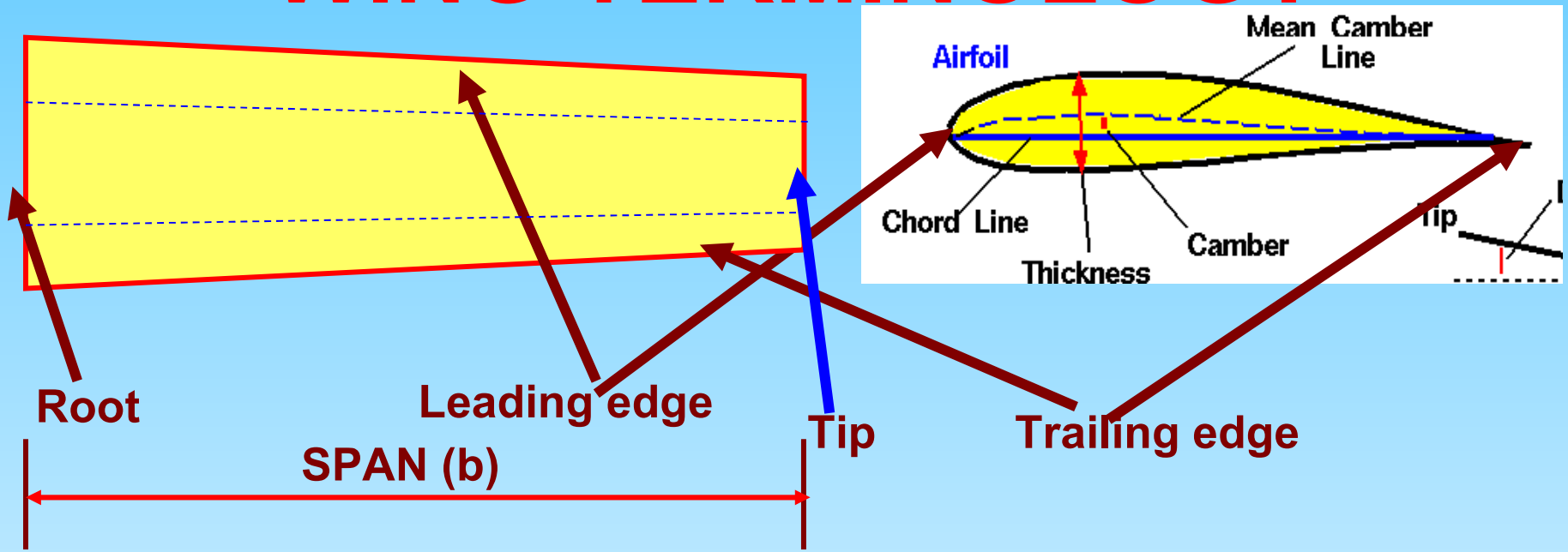
PARTS OF A WING



- Wing box
- Fixed leading edge
- Fixed trailing edge
- Ailerons
- Spoilers
- Flaps
- Slats



WING TERMINOLOGY



- Leading edge is the portion of the wing front of the front spar
- Trailing edge is the portion of the wing back of rear spar
- The *chord* is the distance between the leading edge and trailing edge
- Wing box is portion of the wing between the front spar and rear spar
- Ribs are the airfoil shaped members from leading edge to trailing edge
- Span is the distance between the root and tip of the wing
- Aspect ratio AR = B^2/A

WING STRUCTURE

- Wing structure consists of
  - Internal structure
    - Spars
    - Ribs
    - Stringers
  - External structure
    - Upper skin
    - Lower skin

- Wing structure should posses
  - Sufficient strength
  - Stiffness
  - Light weight
  - Minimum manufacturing problems

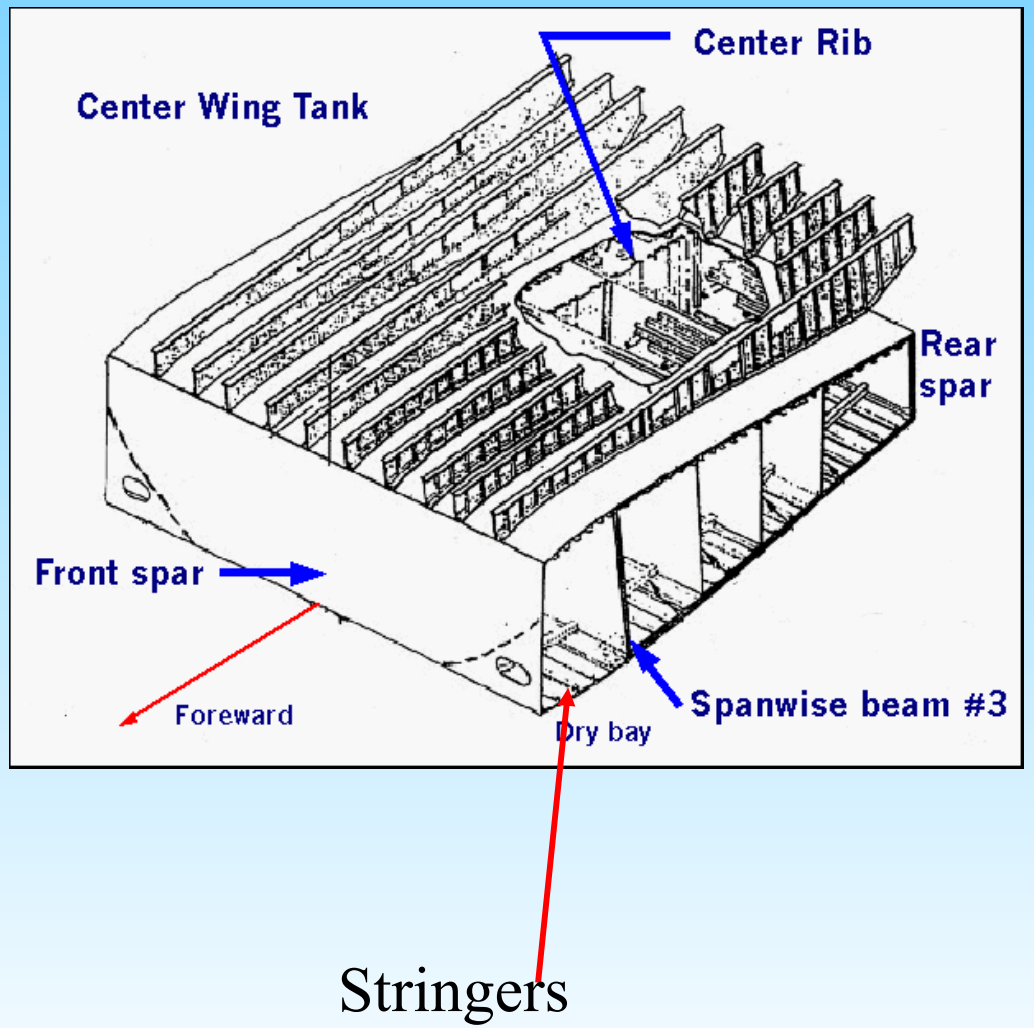
WING BOX DESIGN

PRIMARY ISSUES

- **Rib direction**
  - **Perpendicular to rear spar**
  - **Parallel to flight path**
- **Bending load carrying members**
  - **Spar only**
  - **Spar and skin**

WING BOX

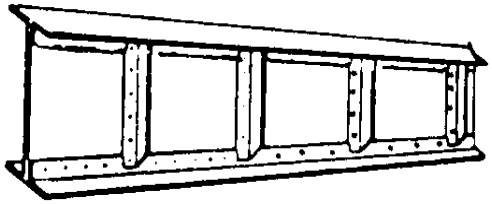
- Front spar
- Rear spar
- Ribs
- Stringers
- Span wise beam
- Fuel tank
- Wing skins



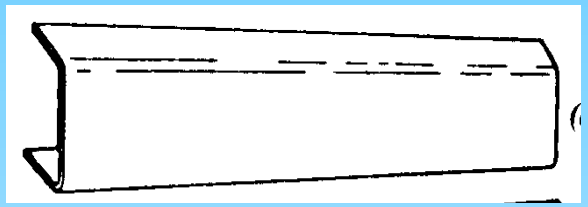
SPARS

- Spars are generally a beam running from root to the tip of the wing
- There are two spars
  - Front spar
  - Rear spar
- Multi-spar designs are used on larger wings and on military aircraft
- Spars carry the aerodynamic loads developed on a wing
- Spars consists of spar cap (flange) and web
- Spar cap carries bending loads and web carries shear loads
- Spars are generally I beams, some times C beams are also used
- All the structural parts of wing are attached to the spars
- Spars are of two types namely
  - Shear web
  - Truss type

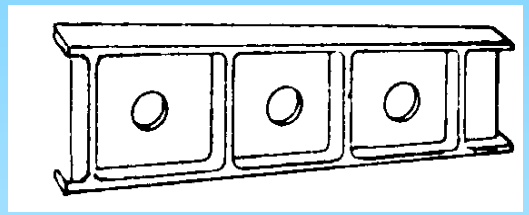
TYPES OF SPAR



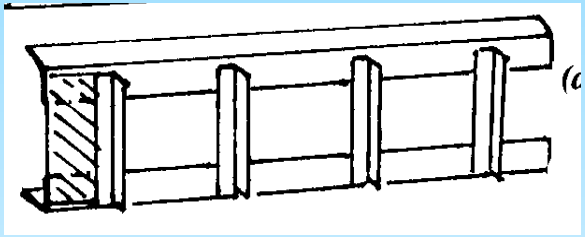
a) Built up spar



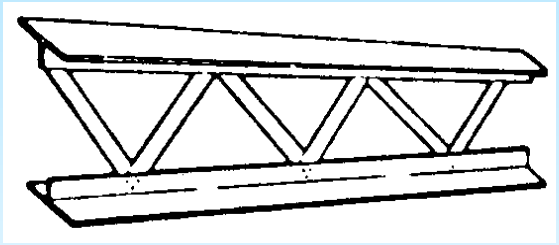
c) Bent up channel



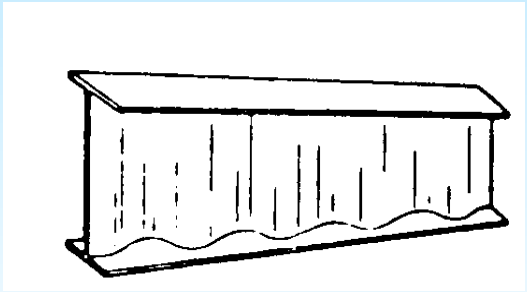
f) Integrally machined web



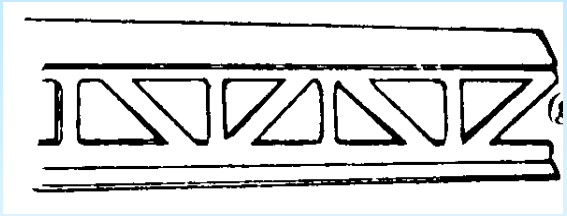
d) Frame truss



b) Truss type



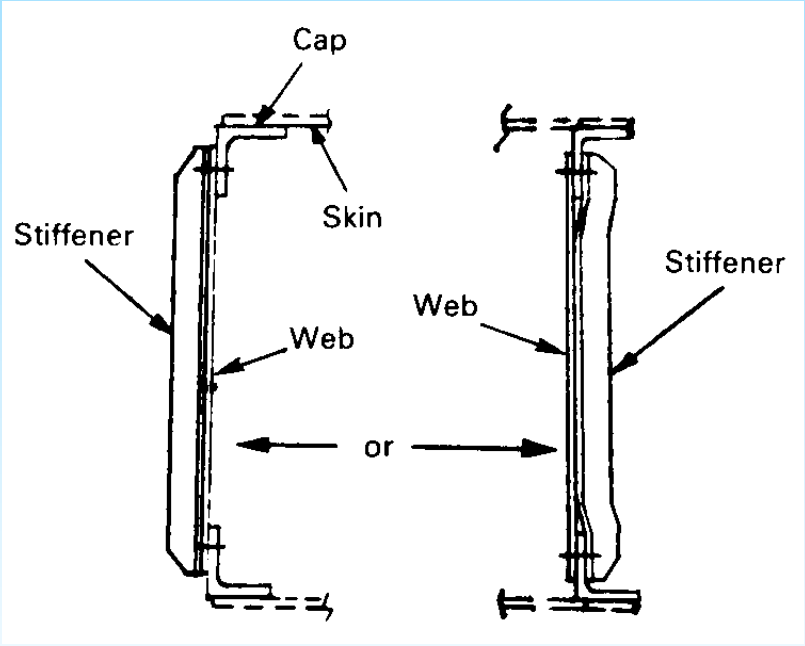
e) Sine wave web



g) Integrally machined truss

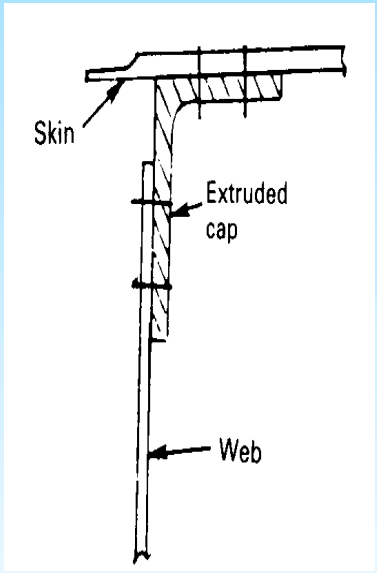
SPARS

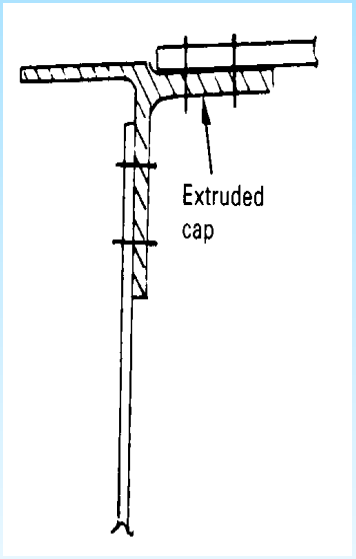
- Spars consist of
  - Spar cap
  - Spar web
  - Web stiffener

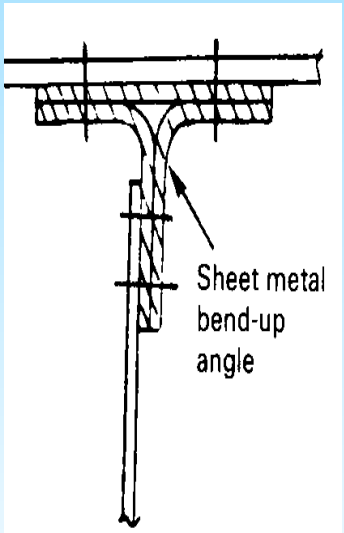


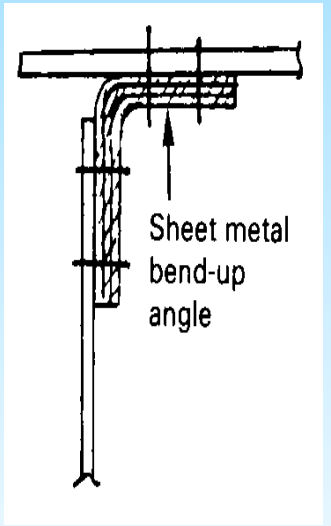
SPAR CAPS

- Spar caps are nothing but the flange of a beam
- Spar caps carry the bending load as axial load
- Spars caps are designed to have maximum radius of gyration
- High local crippling stress





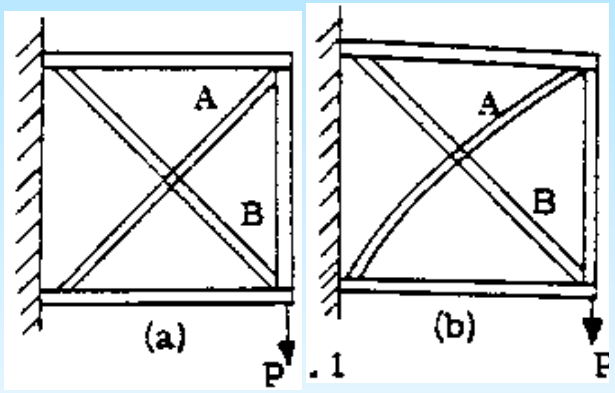


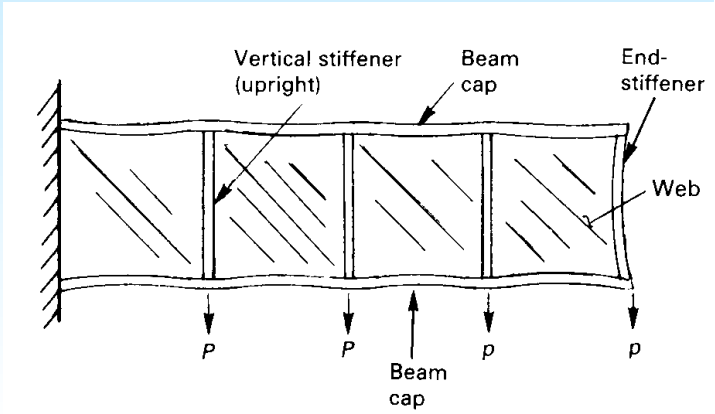


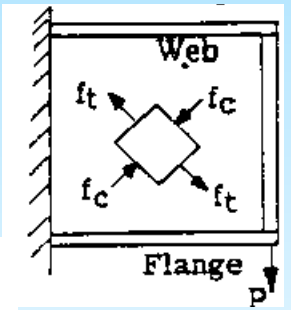
Typical spar caps

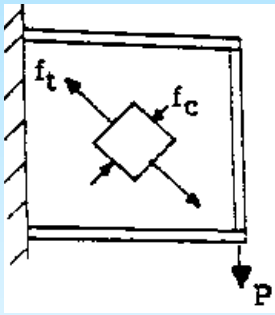
SPAR WEBS

- Spars webs are of two types
  - Shear resistant type (No buckling of the web takes place)
    - i.e The shear stress acting on the web is not more than the buckling shear of the web
    - Web stiffeners are designed to resist overall instability
  - Diagonal tension field type
    - In this type of web construction, a diagonal member can take the excess load by tension



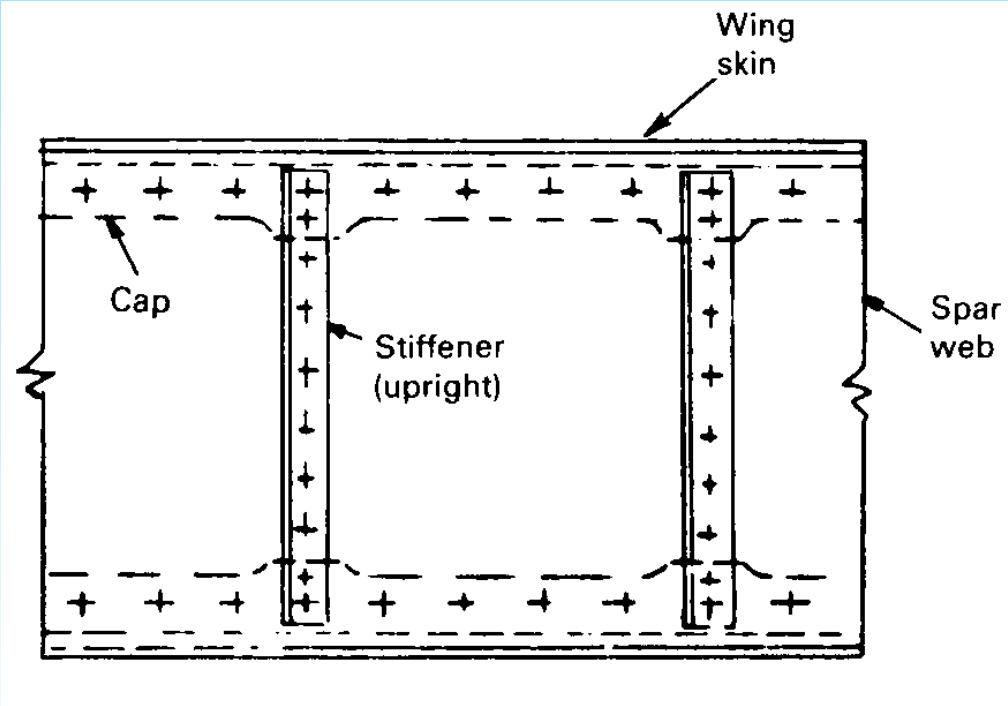






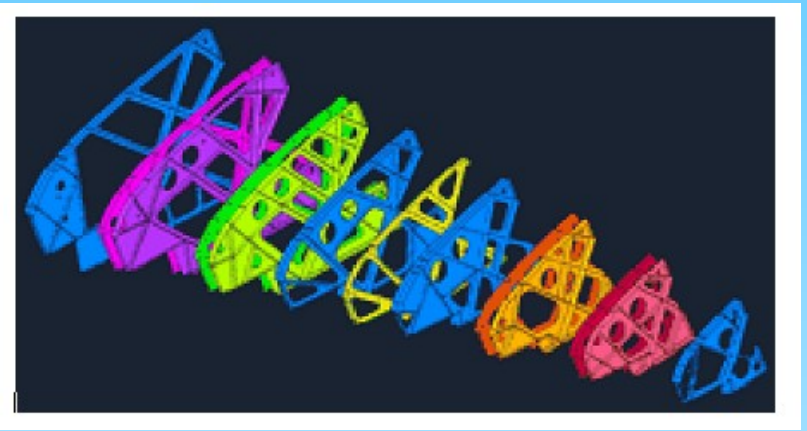
WEB STIFFENER

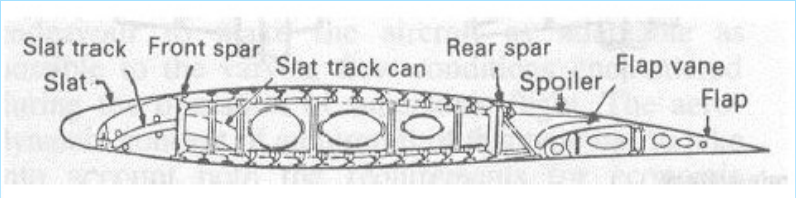
- **Webs stiffeners are provided to**
  - **Prevent the overall instability of the web**
  - **Increase the buckling strength of web**

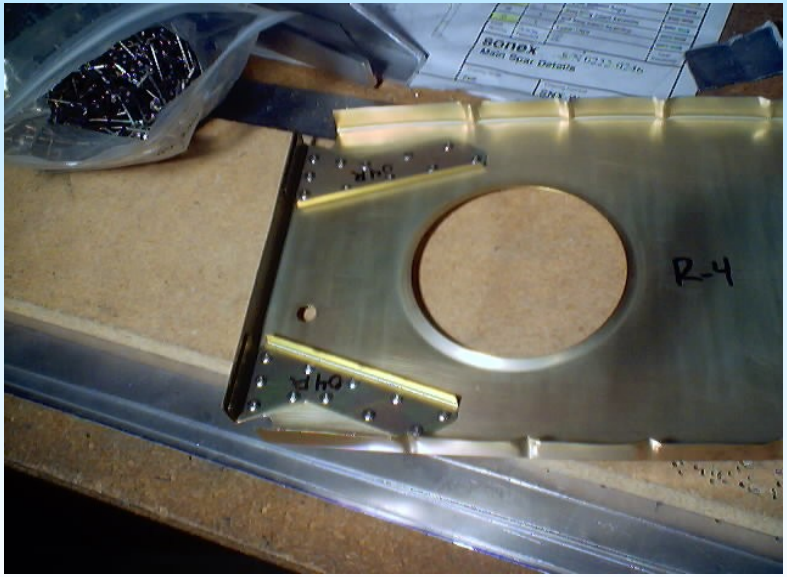


RIBS

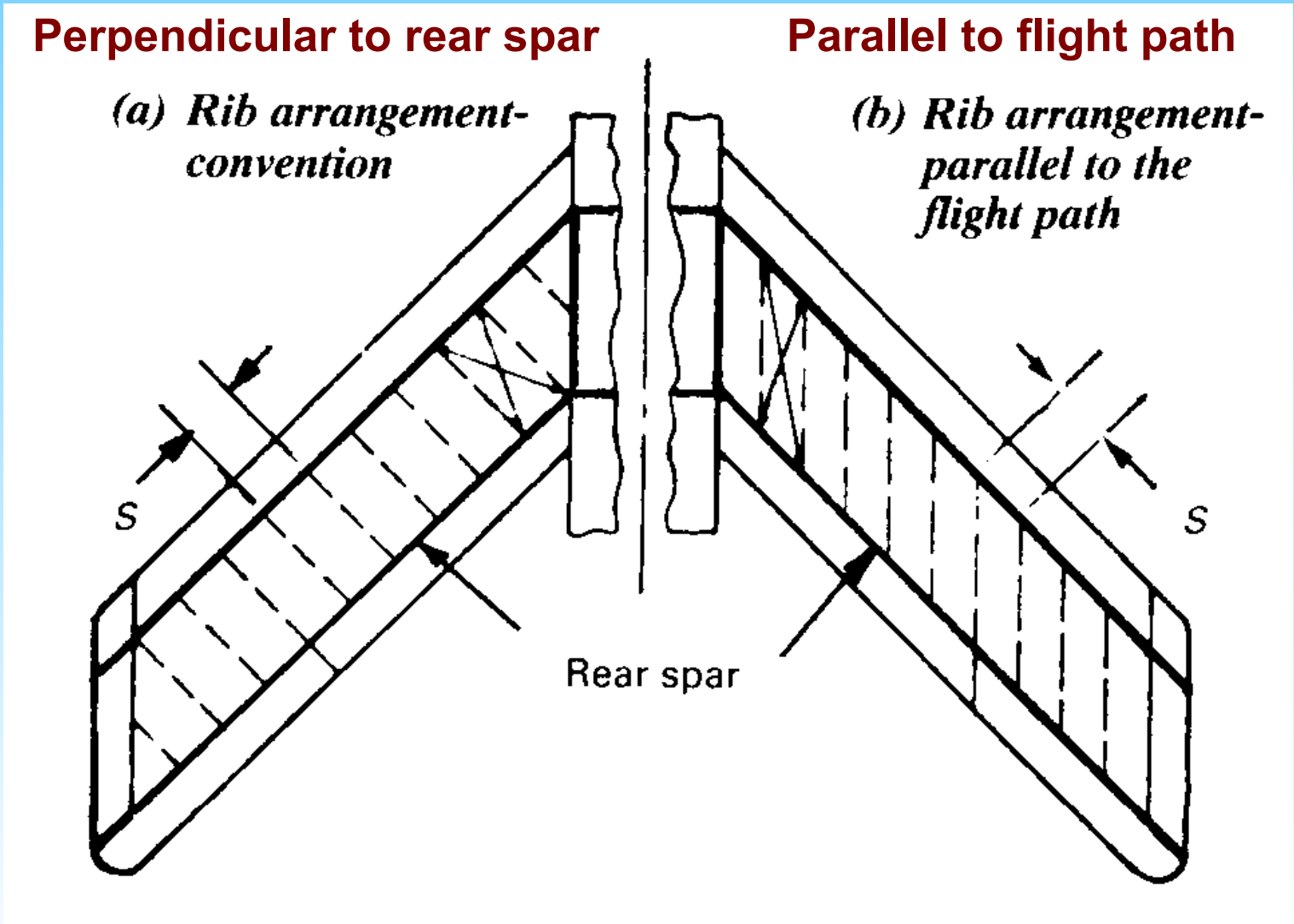
- Ribs are used to define and produce the airfoil shape
- Carry inertial loads (fuel, equipment, missiles, rockets)
- Support skin-stringer panel in compression and tension
- Prevents wing skin buckling
- Transfers primary loads from the control surfaces and undercarriage to the spars







WING RIB DIRECTIONS



WING RIB DIRECTIONS

Advantages

- Perpendicular to rear spar
  - Rib length is less
  - Connection is easy
- Parallel to flight path
  - Provides better aerodynamic shape

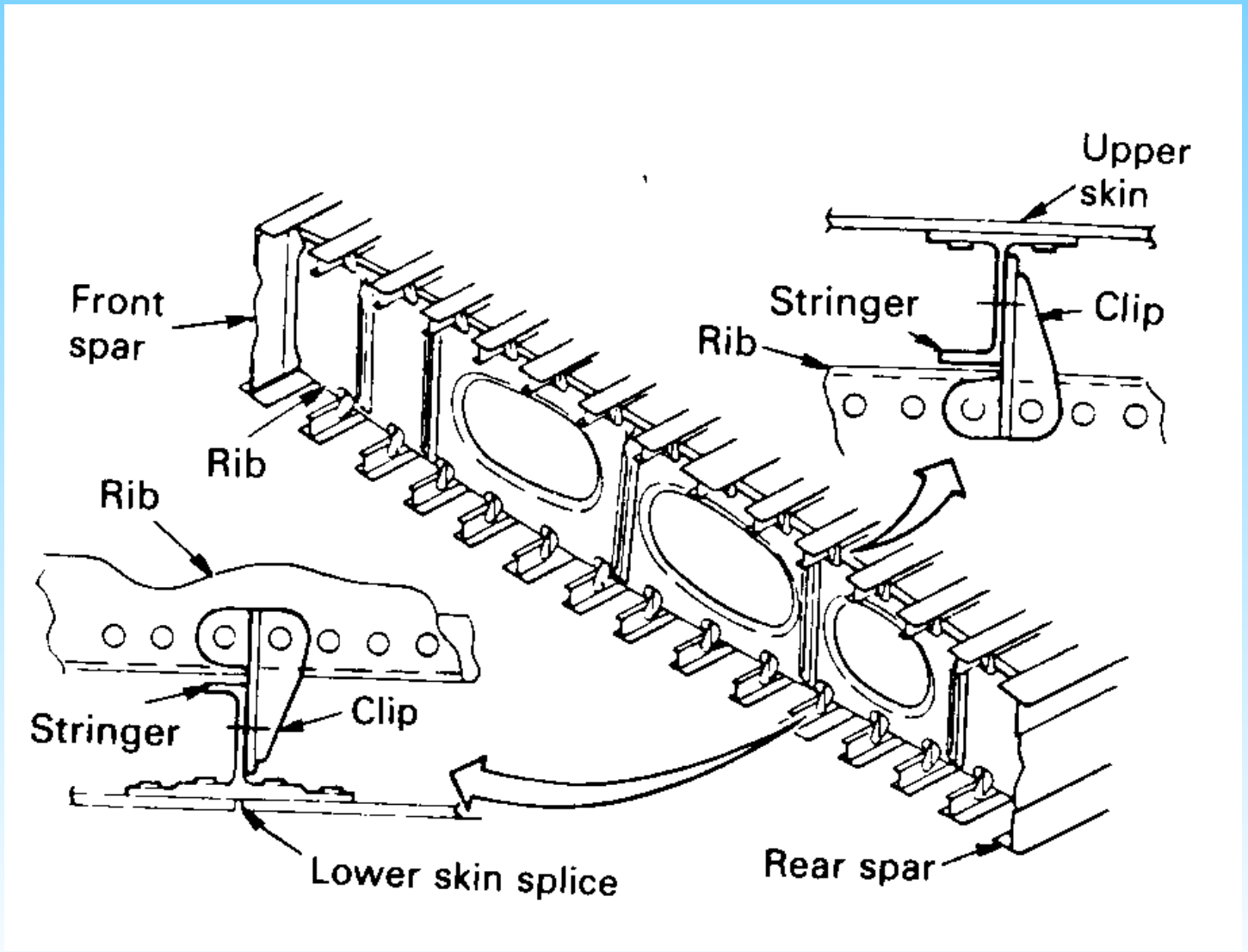
Disadvantages

- Parallel to flight path
  - Rib length is more (nearly 28%)
  - Maintaining 90° at joints
  - Skin gauge is more

TYPE OF RIBS

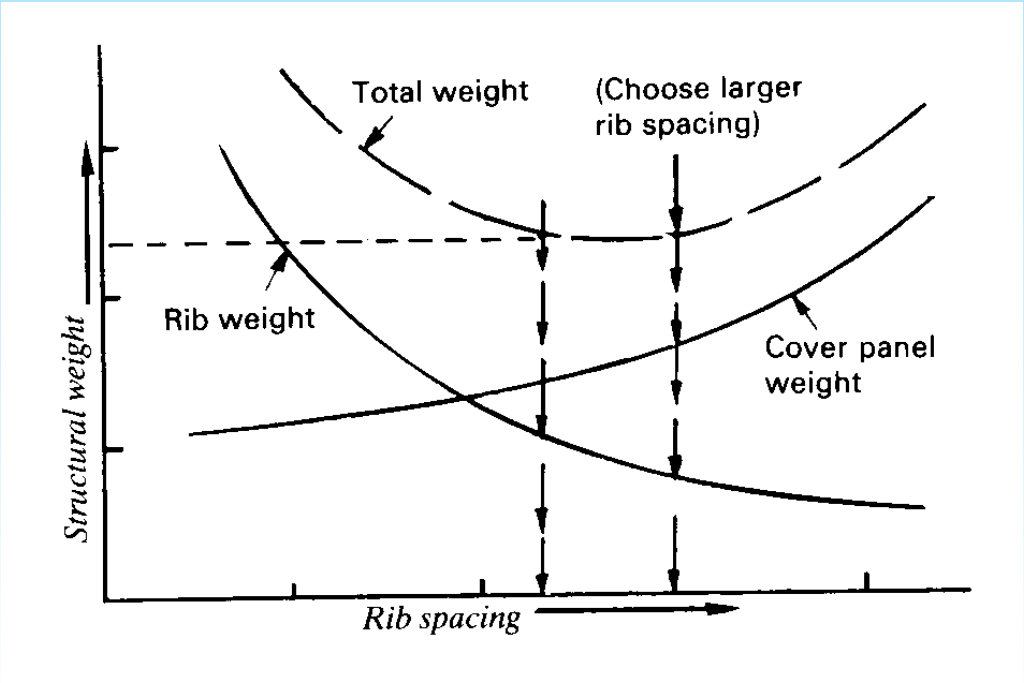
- **Shear type rib**
  - **Web acts as fuel slosh inhibiter**
  - **Eliminates stress concentration by having a gradual cross section change from rib cab to shear web**
  - **Continuous support for the wing panels**
- **Truss type rib**
  - **Heavier**

WING RIB CONSTRUCTION



RIB SPACING

- Preliminary rib spacing is arrived based on the structural weight
- The location of control surface and heavy weight location, ribs are provided to support
- Larger rib spacing leads to cost saving and less fatigue hazards
- The final rib spacing is arrived based on wing skin buckling



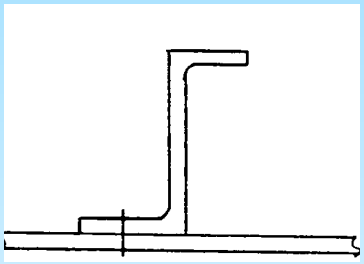
RIB LOADS

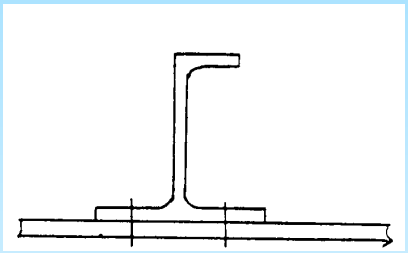
- Air loads
- Inertial load due to fuel, equipment, structure
- Crushing loads due to wing bending
- Concentrated loads (nacelle, landing gear)
- Diagonal tension loads from skin

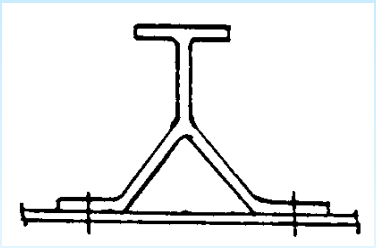
STRINGERS

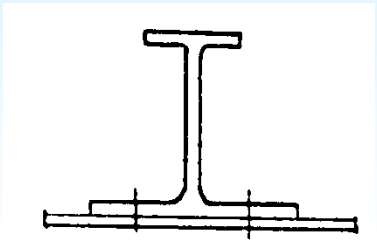
- Stringers are stiffening members in the wing which run from root to the tip
- Stringers are made from forming or extrusion

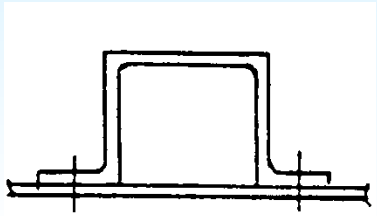
Extrusion



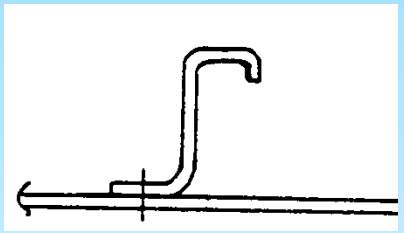


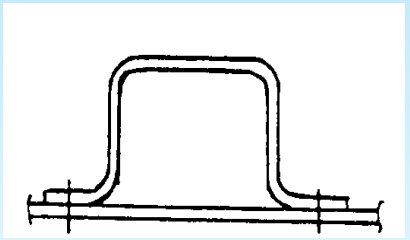


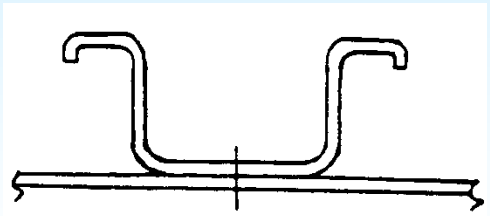




Forming

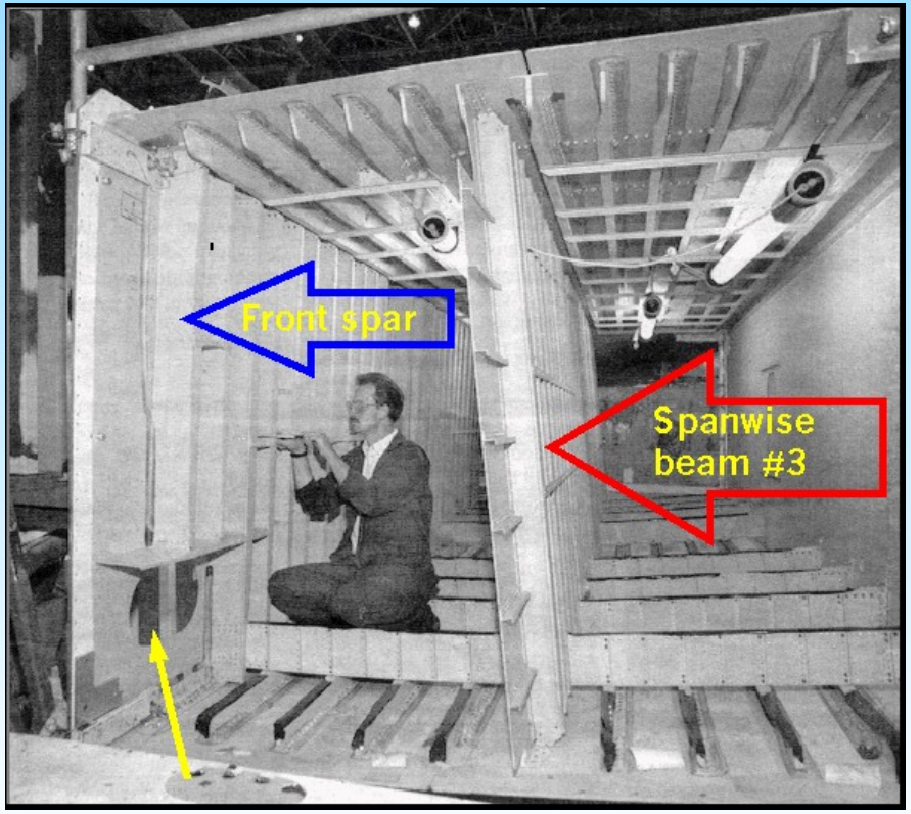




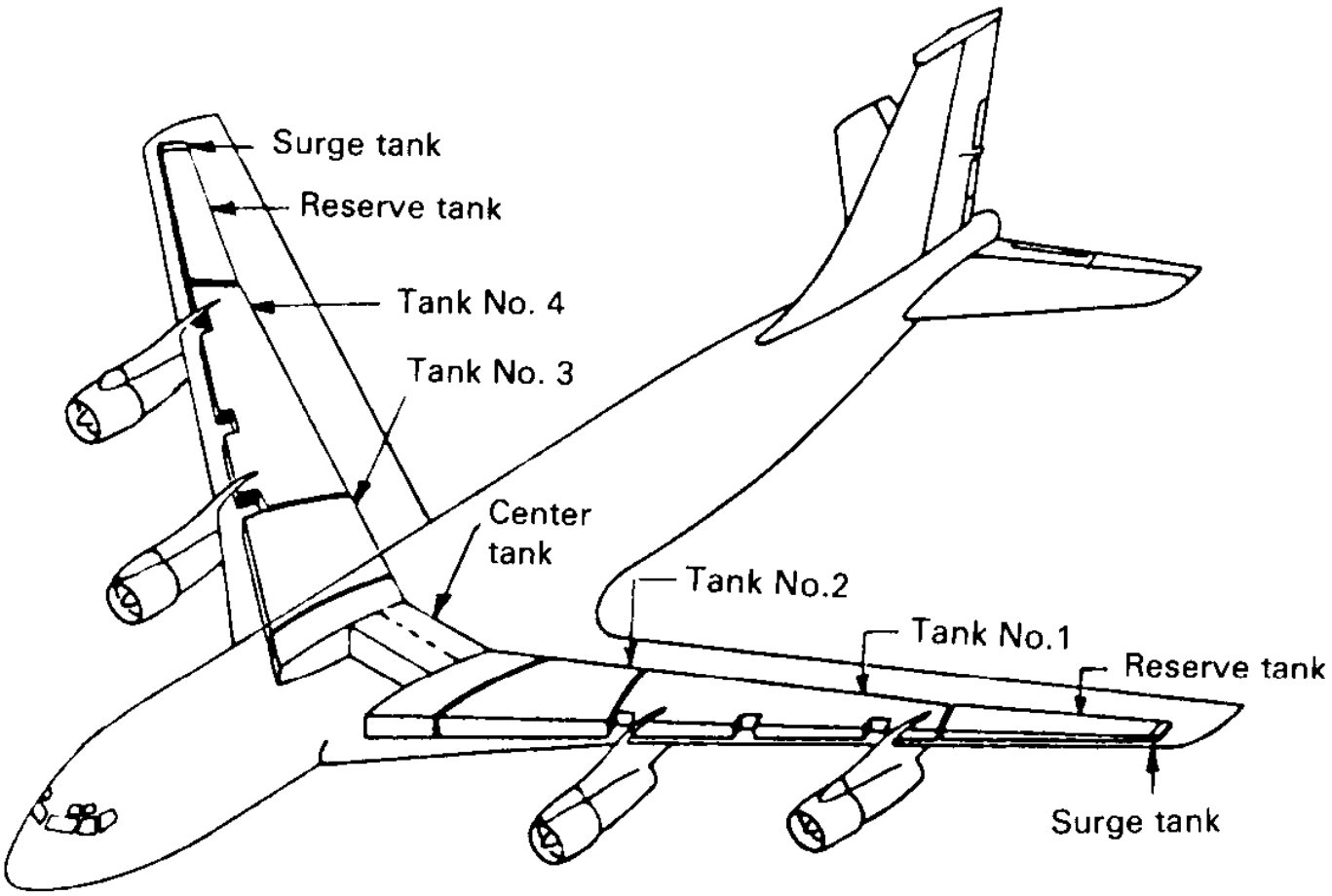


SPAN WISE BEAMS

- Span wise beams are members in the wing which run from root to the tip
- Span wise beams are provided for additional support as well as to support the fuel tank



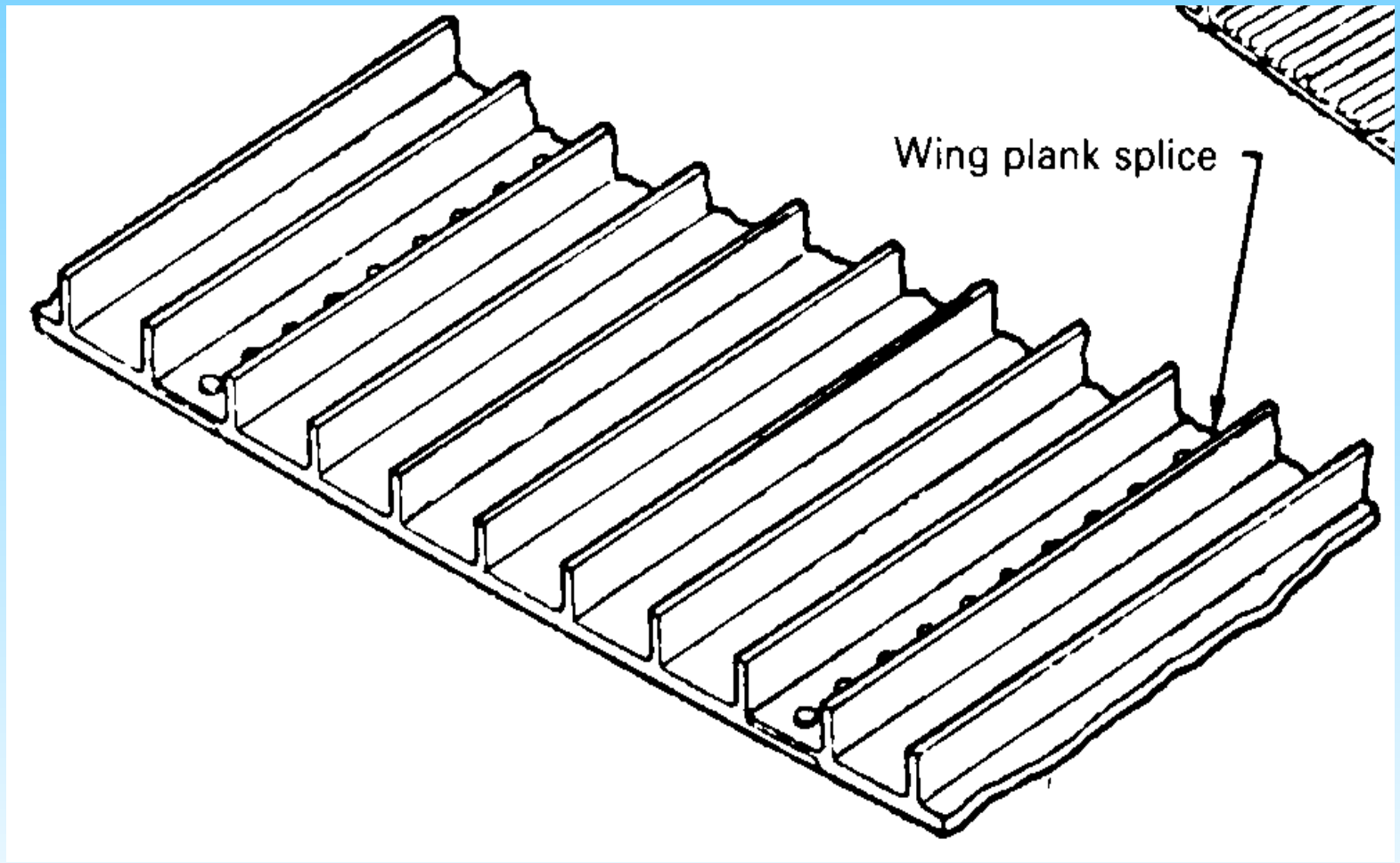
FUEL TANK ARRANGEMENT



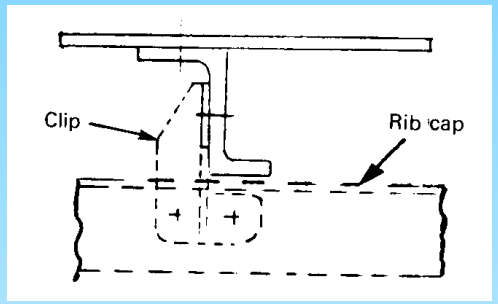
WING SKIN

- Gives the wing it's shape
- Carries loads
  - – Bending and shear loads
  - – Torsional loads caused by control surfaces and other features attached to the wing
- Creates walls for the wing mounted fuel tanks

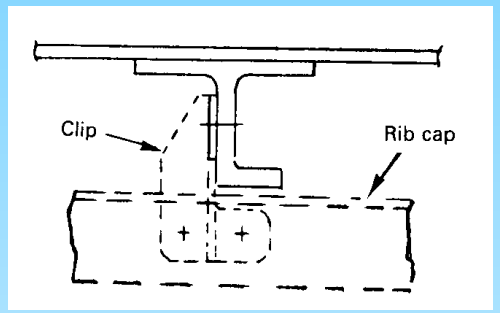
WING SKIN PANEL



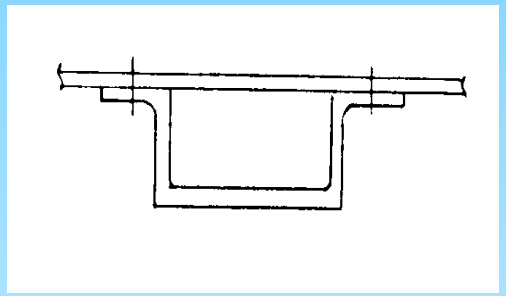
WING SKIN STRINGERS



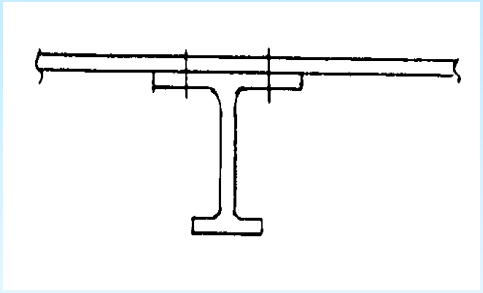
Z- Type



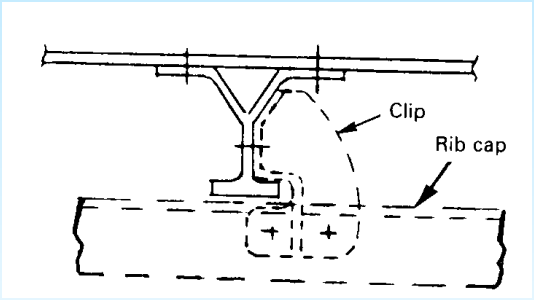
J- Type



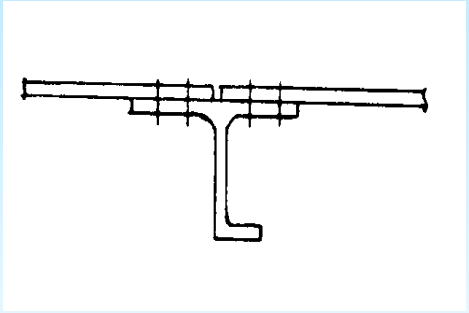
Hat Type



I- Type

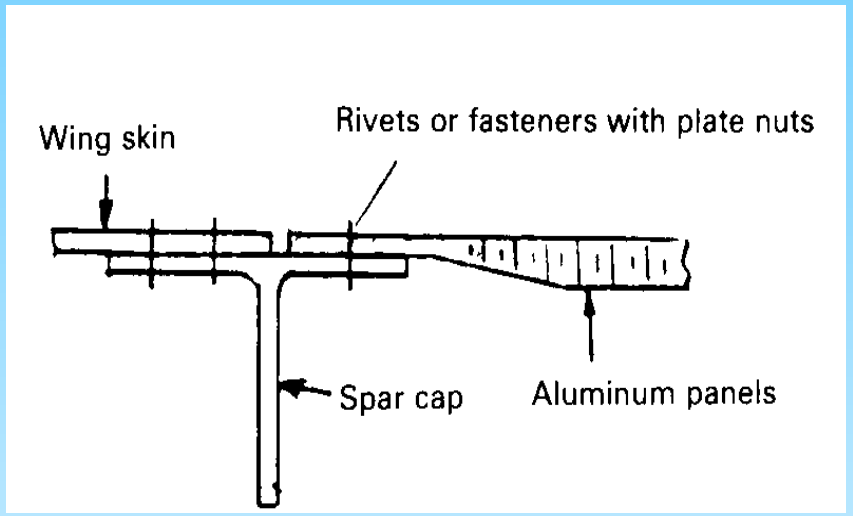


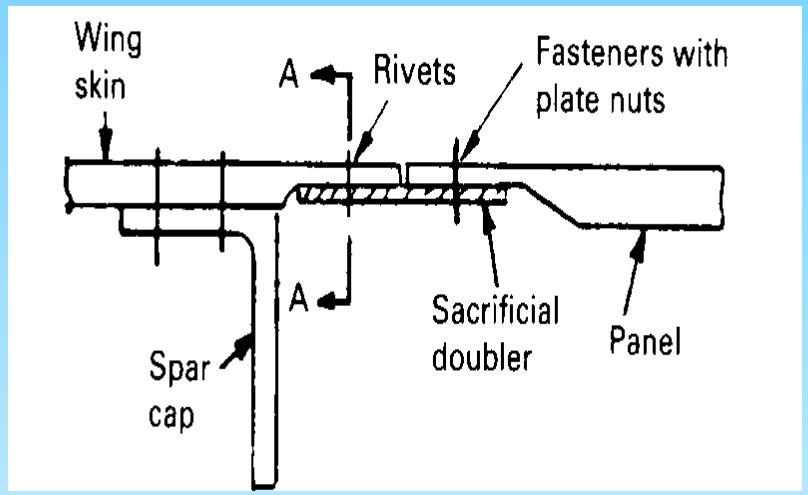
Y- Type

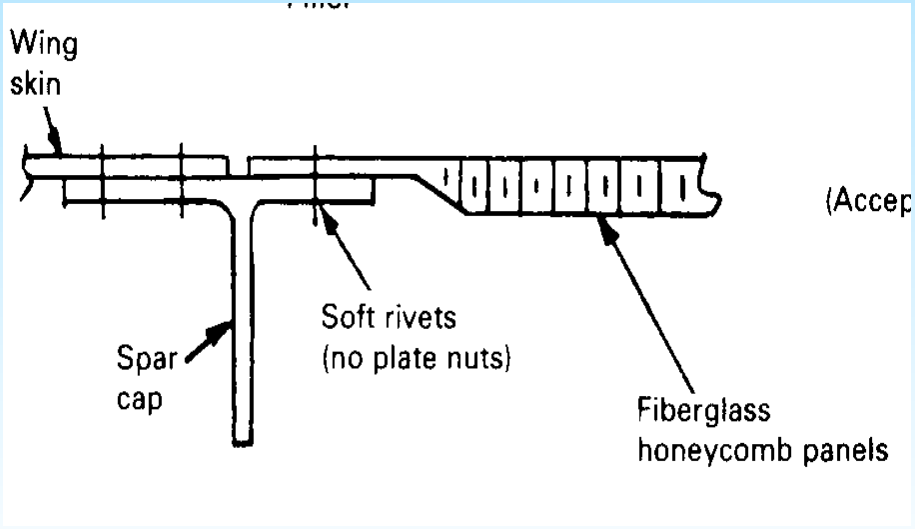


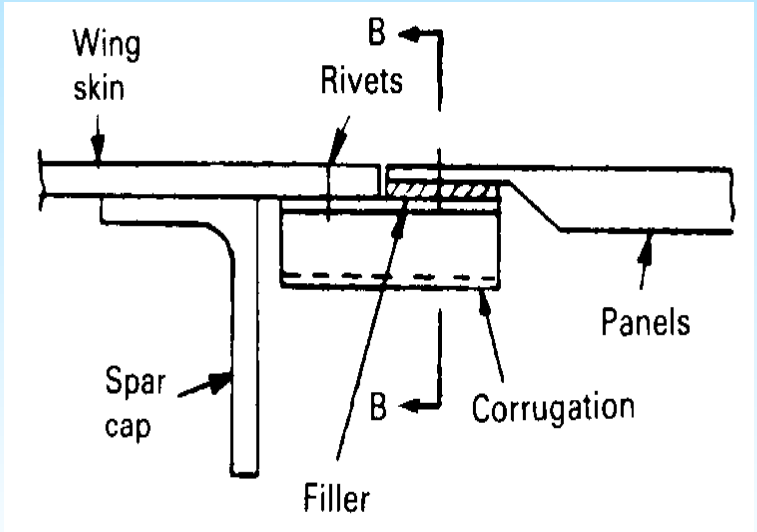
J- Splice

WING SKIN - EDGE SKIN ATTACHMENT



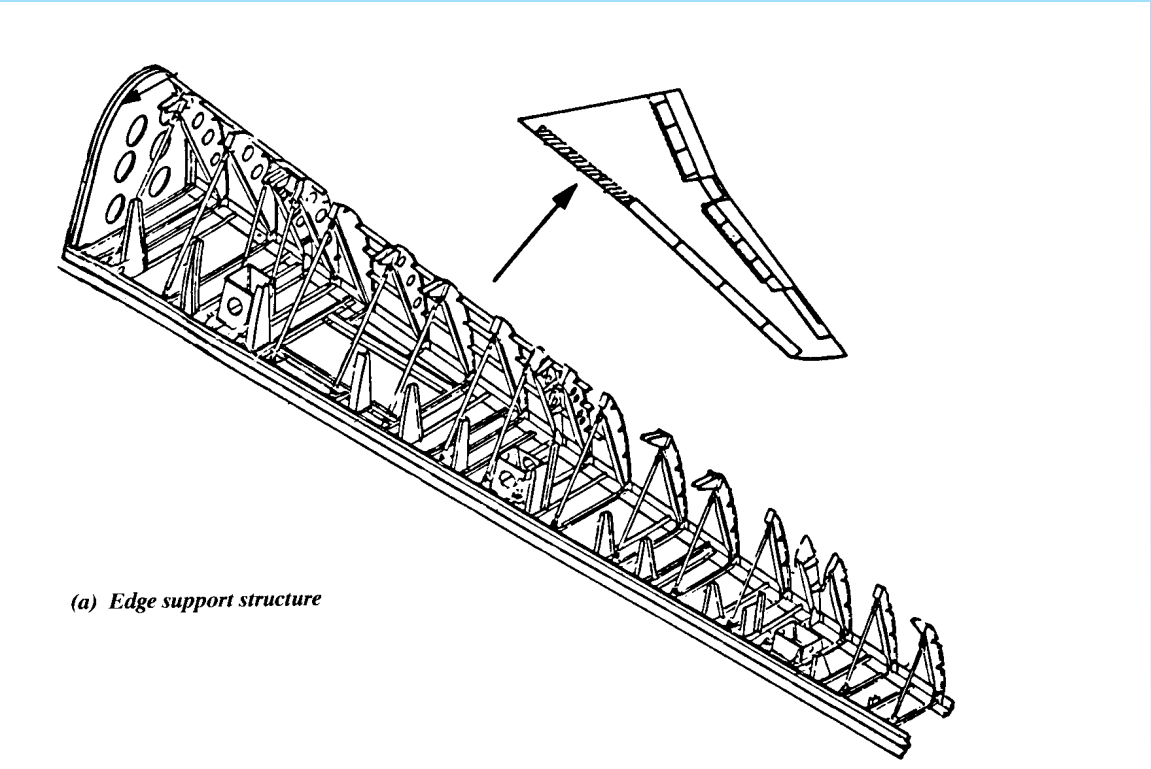






LEADING EDGE

- **Leading edge :**
  - **The portion of the wing front of the spar is called as leading edge**

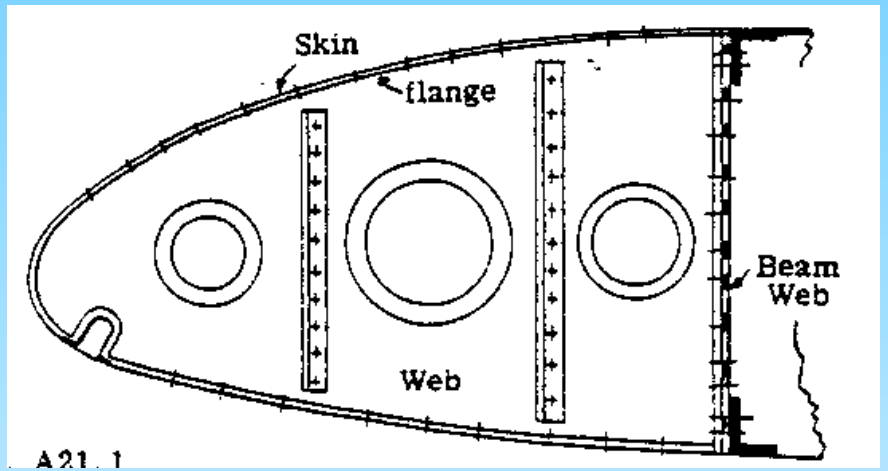


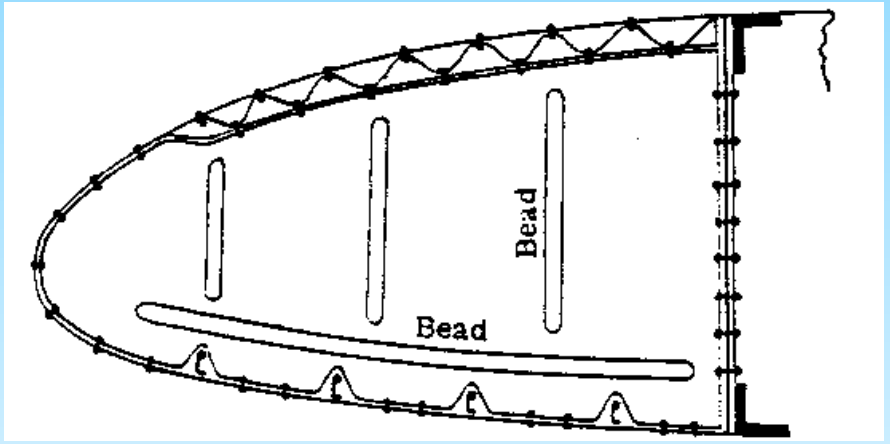
(a) Edge support structure

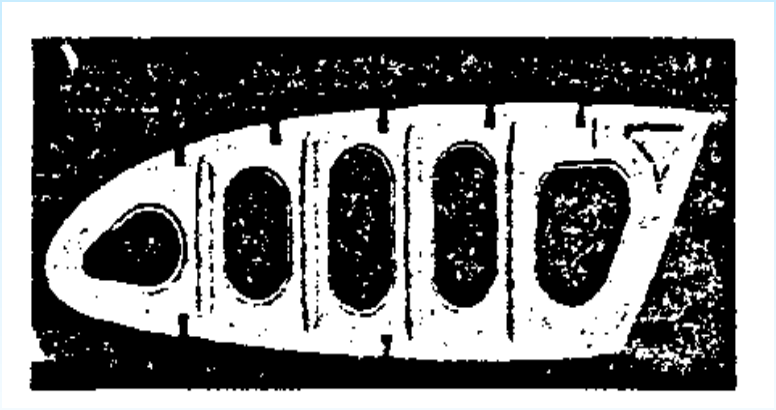
LEADING EDGE COMPONENTS

- **Leading edge consists of**
  - **Ribs**
  - **Slats**
  - **Skin**
  - **Plenum beam**
  - **Piccolo tube**
  - **Clips**

LEADING EDGE RIBS

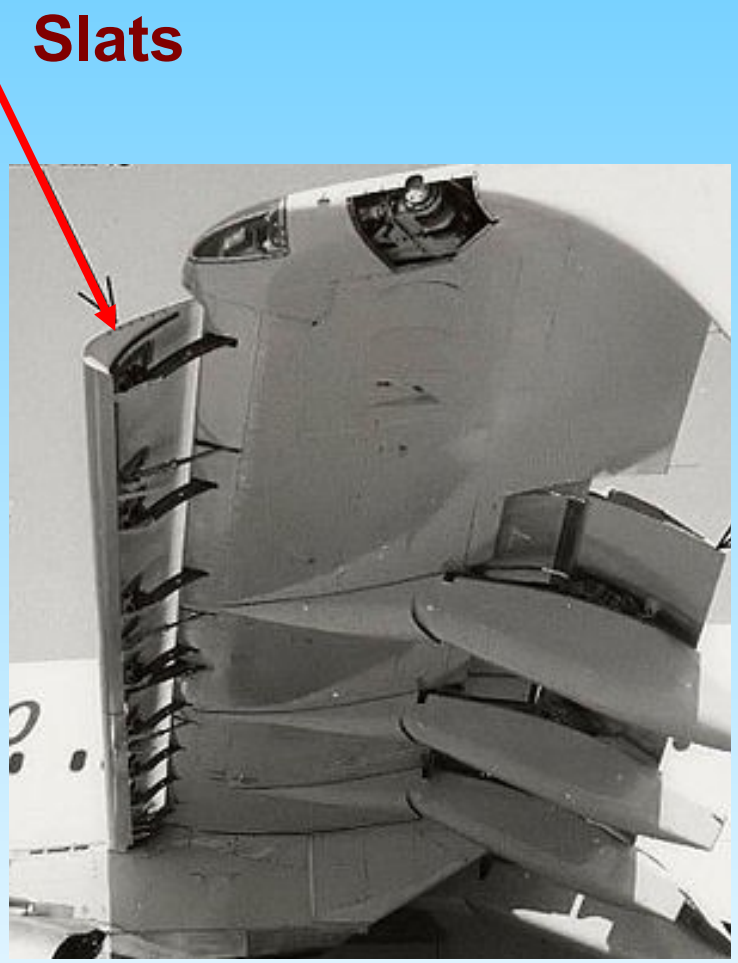






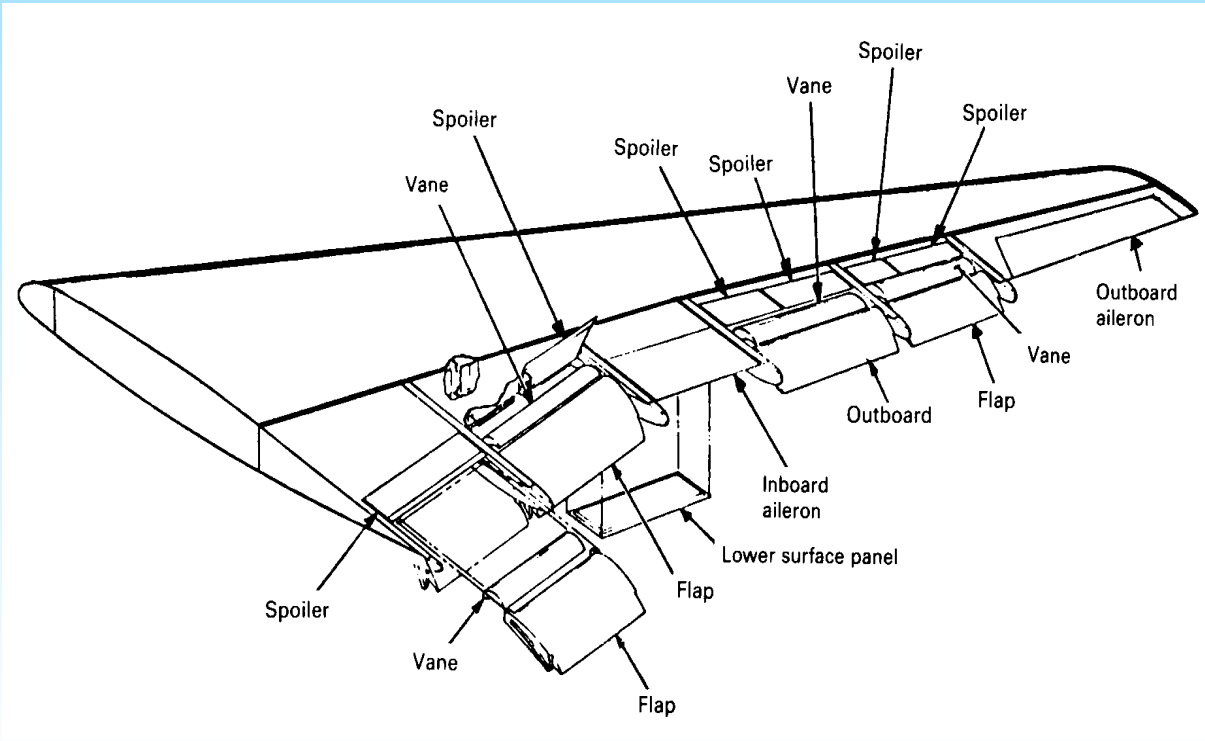
SLATS

- Slats are aerodynamic surfaces on the leading edge of the wings, which, when deployed, allow the wing to operate at a higher angle of attack
- A higher coefficient of lift is produced as a product of angle of attack and speed
- Used while landing or performing maneuvers which take the aircraft close to the stall
- Retracted in normal flight to minimize drag



TRAILING EDGE

- The portion of the wing behind the rear spar
- It consists of
  - Fixed trailing edge
  - Ailerons
  - Flaps
  - Spoilers

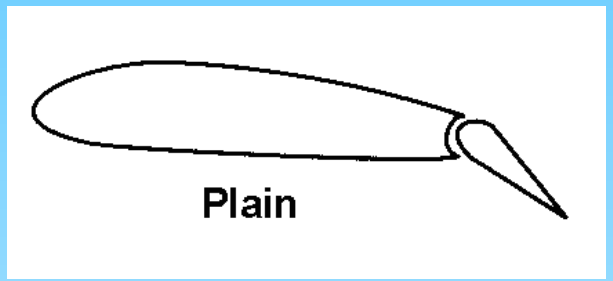


FLAPS

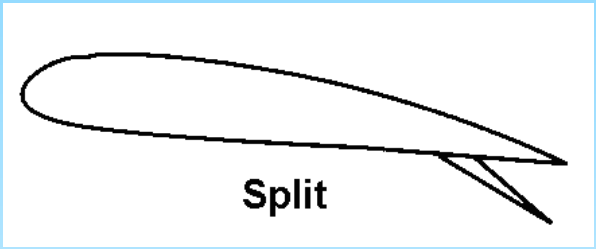
- **Flaps** are hinged surfaces on the trailing edge of the wings of a fixed wing aircraft
- As flaps are extended so the stalling speed of the aircraft is reduced
- A **stall** is a sudden reduction in the lift forces generated by an airfoil
- Flaps are also used on the leading edge of the wings of some high-speed jet aircraft, where they may be called slats
- Flaps reduce the stalling speed by increasing the camber of the wing and thereby increasing the maximum lift coefficient
- Some trailing edge flaps also increase the area of the wing and, for any given aircraft weight, this reduces the stalling speed
- The Fowler flap is an example of one which increases the area of the wing

TYPES OF FLAPS

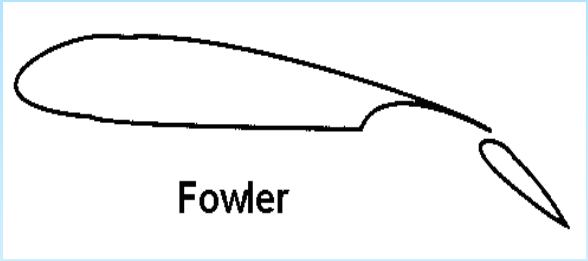
- **Plain Flap**
  - rotates on a simple hinge



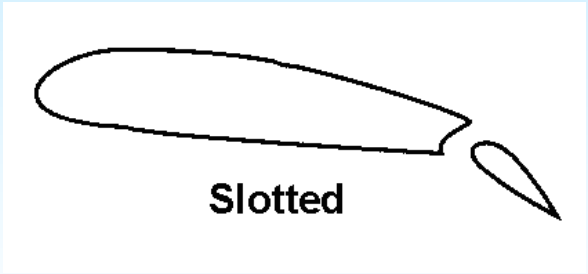
- **Split flap**
  - upper and lower surfaces are separate, the lower surface operates like a plain flap, but the upper surface stays immobile or moves only slightly



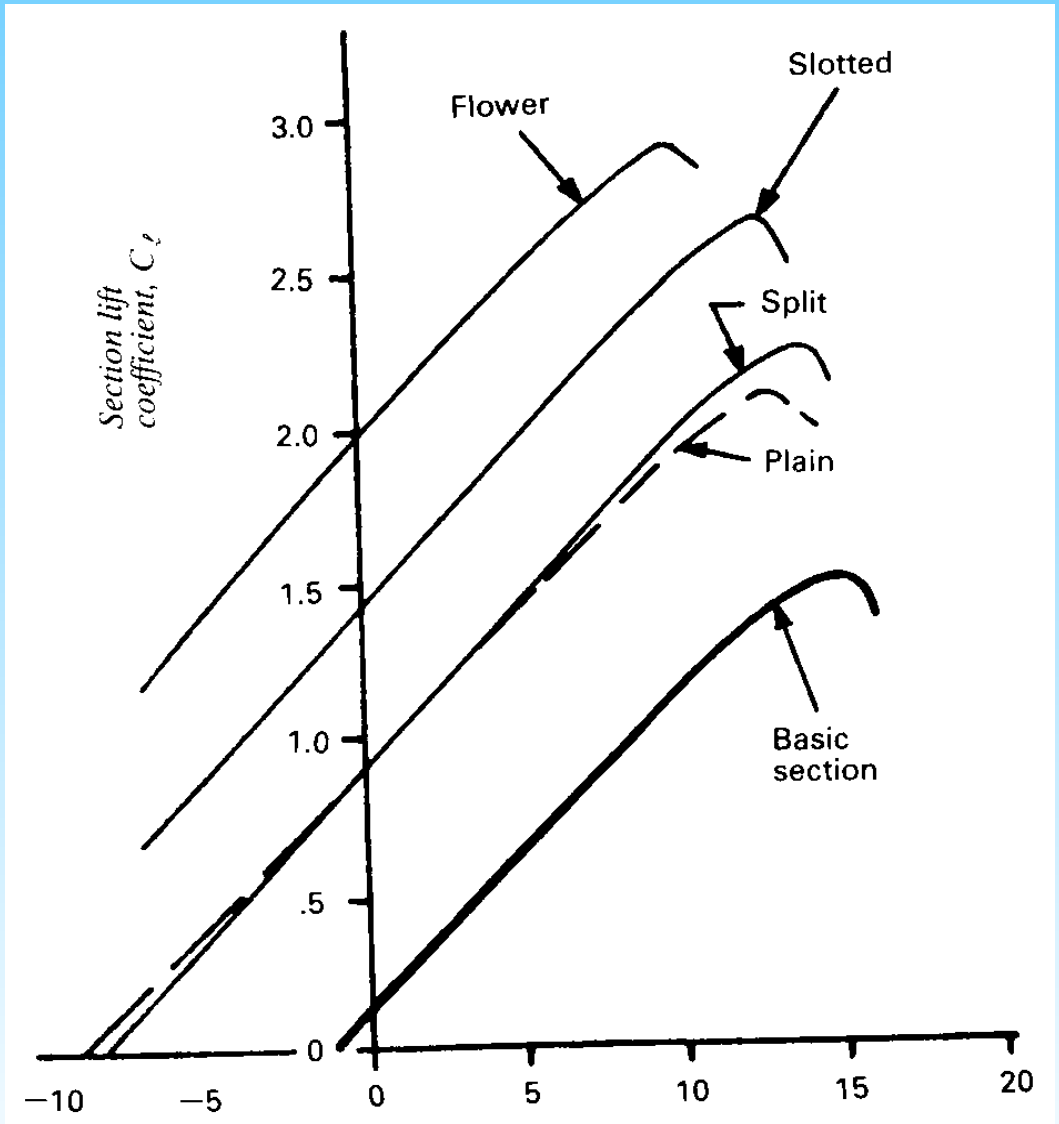
- **Fowler flap**
  - slides backwards before hinging downwards, thereby increasing both camber and chord, creating a larger wing surface better tuned for lower speeds



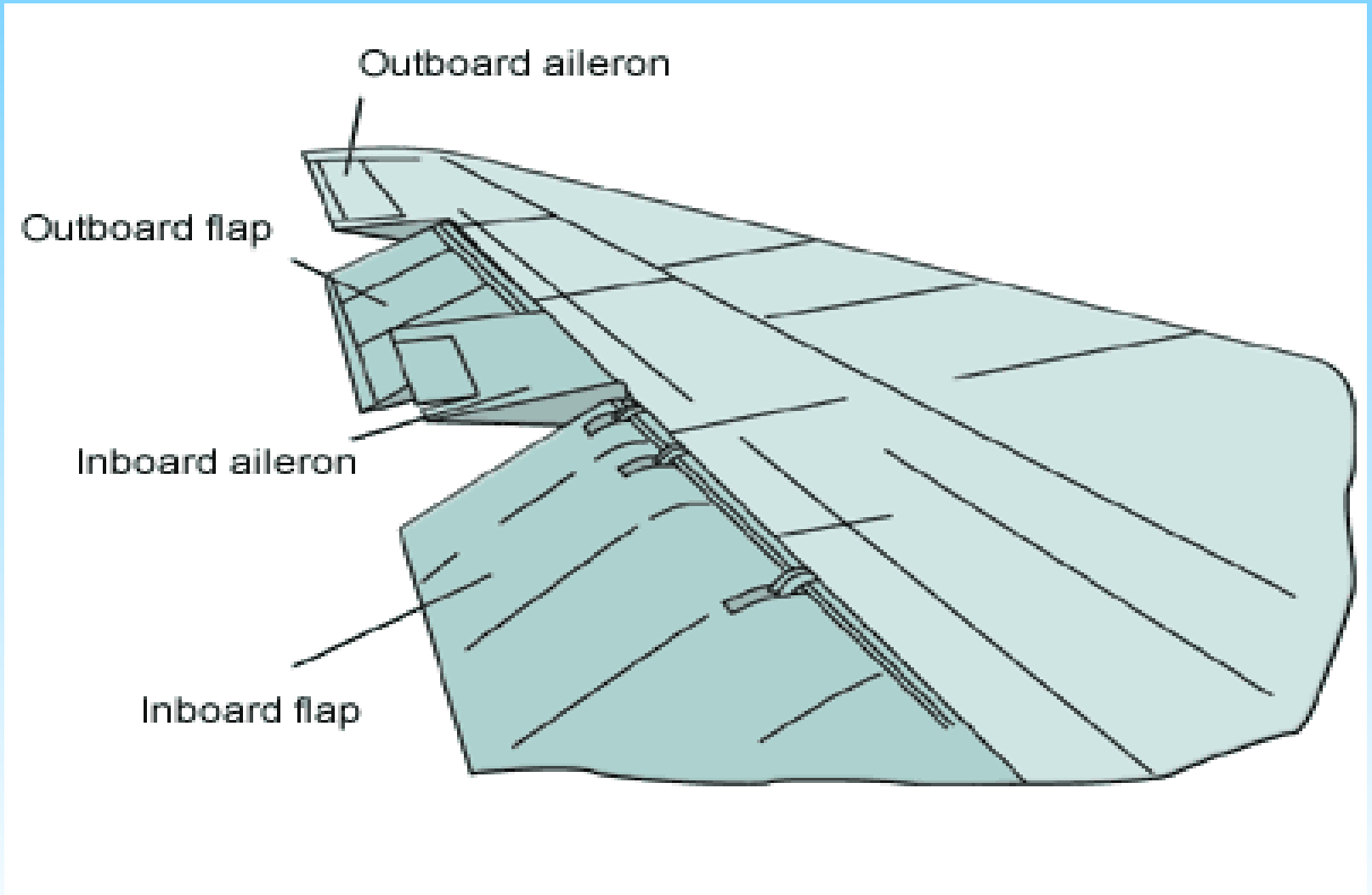
- **Slotted flap**
  - A slot (or gap) between the flap and the wing enables high pressure air from below the wing to re-energize the boundary layer over the flap



COMPARISON OF FLAPS

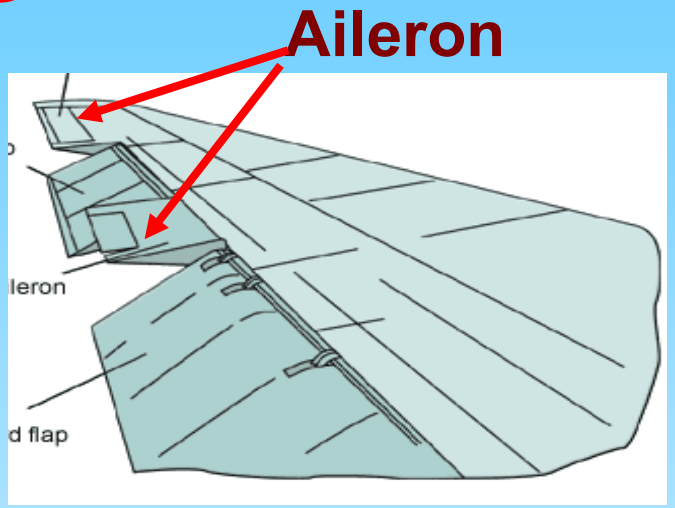


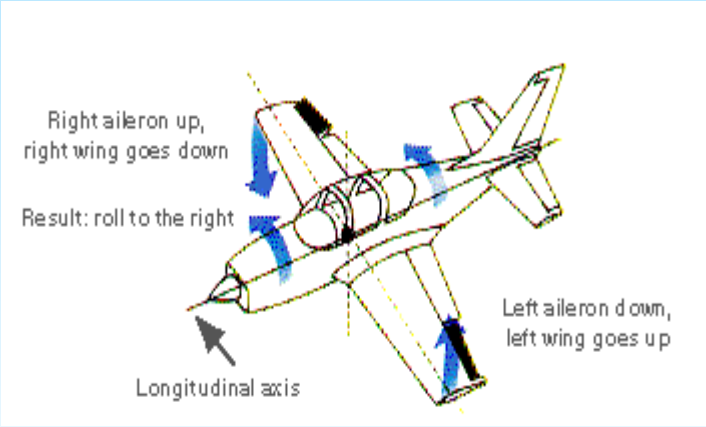
FLAP ARRANGEMENT



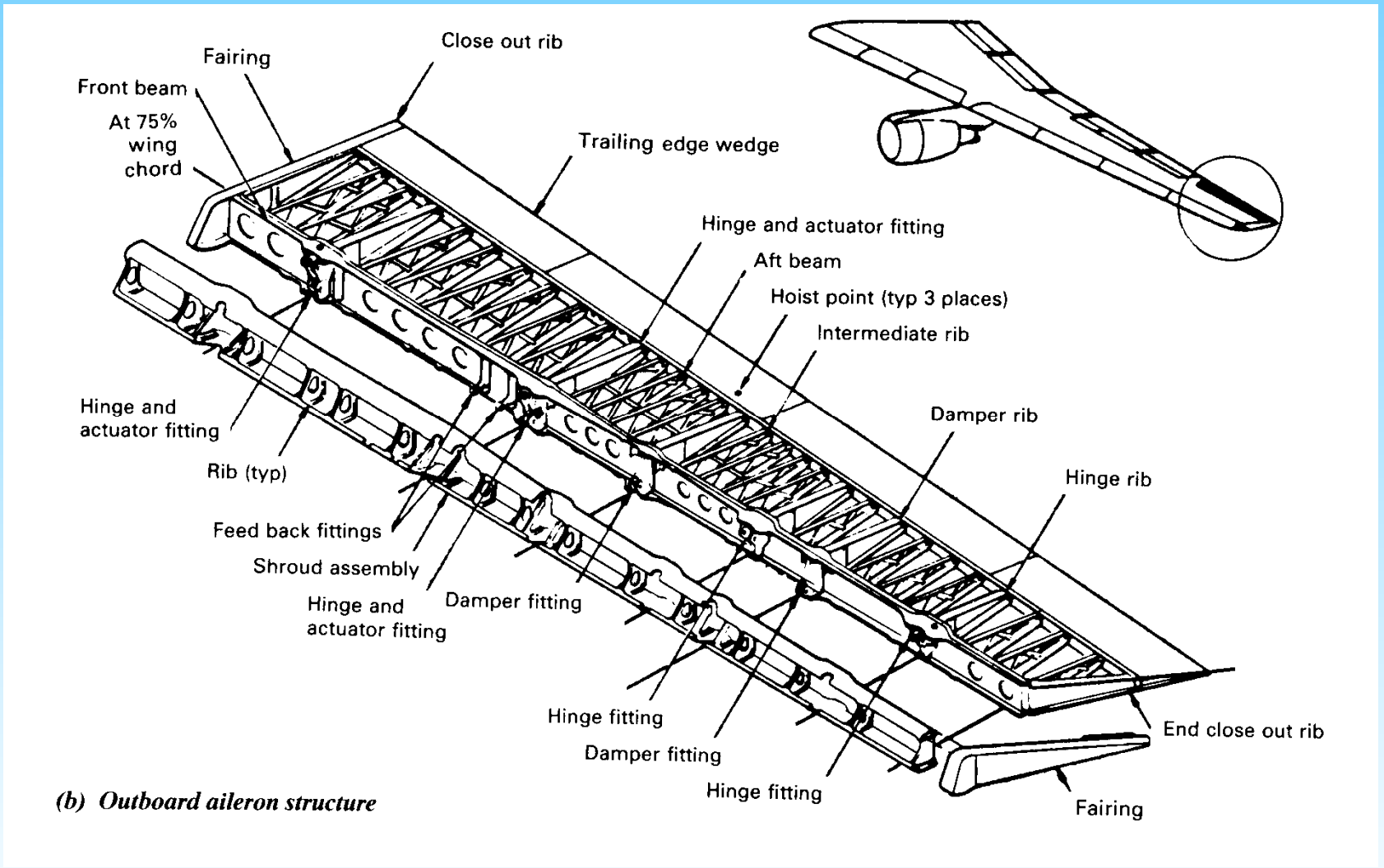
AILERONS

- **Ailerons are hinged control surfaces attached to the trailing edge of the wing of a fixed wing aircraft**
- Aileron is a French word meaning “little wing”
- There are two ailerons
- Ailerons are used to control the aircraft in roll
- Down going aileron increases the lift and up going aileron reduces the lift in the respective wings causing rolling movement about the longitudinal axis of the aircraft
- Aileron operation causes an additional yawing moment





AILERONS



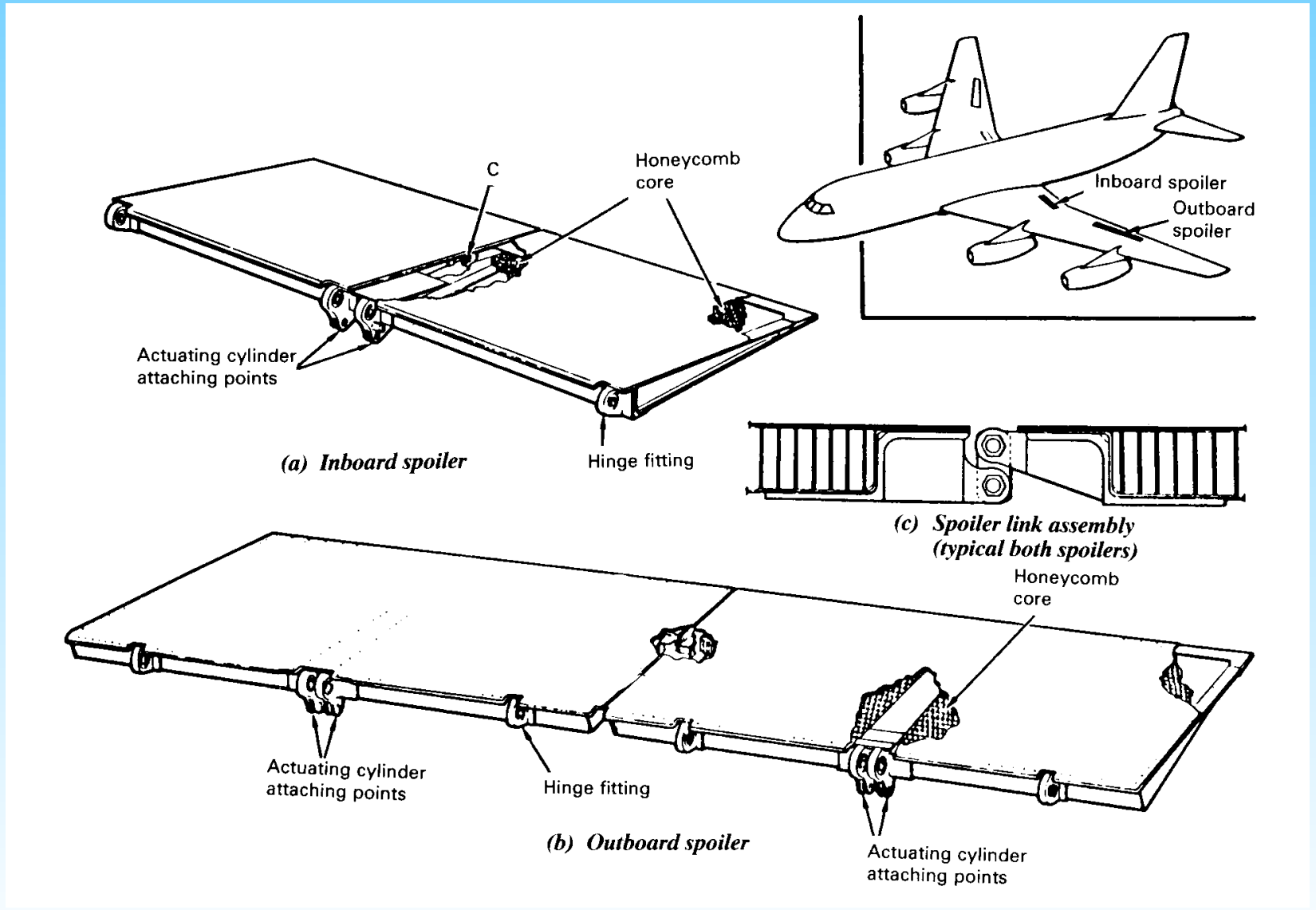
(b) Outboard aileron structure

SPOILERS

- SPOILERS are small, hinged plates on the top portion of wings

- Spoilers can be used
  - To slow an aircraft
  - To make an aircraft descend
  - To generate rolling motion

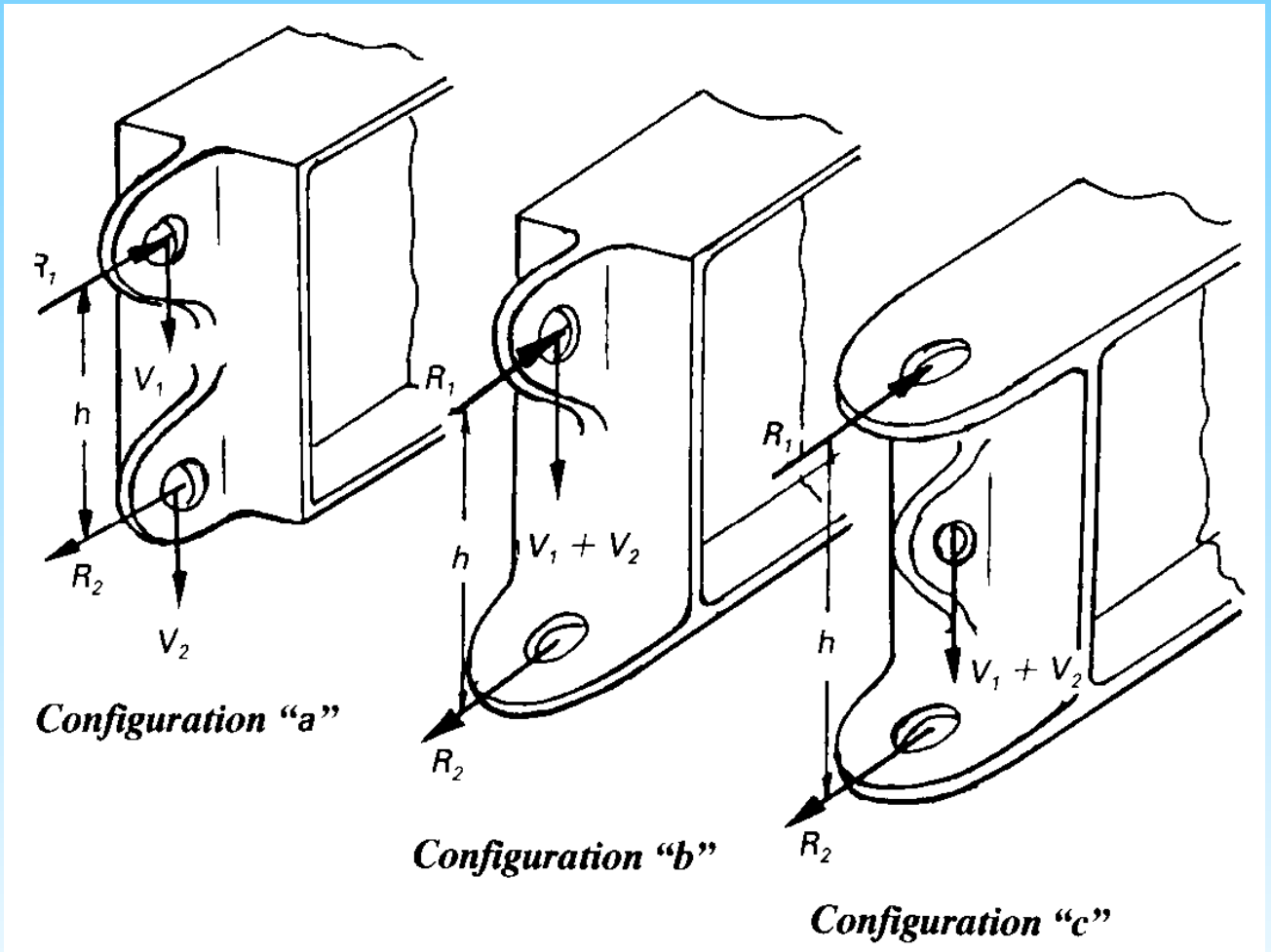
SPOILERS


C
Honeycomb core
Actuating cylinder attaching points
Hinge fitting
(a) Inboard spoiler
Inboard spoiler
Outboard spoiler
(c) Spoiler link assembly (typical both spoilers)
Honeycomb core
Actuating cylinder attaching points
Hinge fitting
(b) Outboard spoiler
Actuating cylinder attaching points

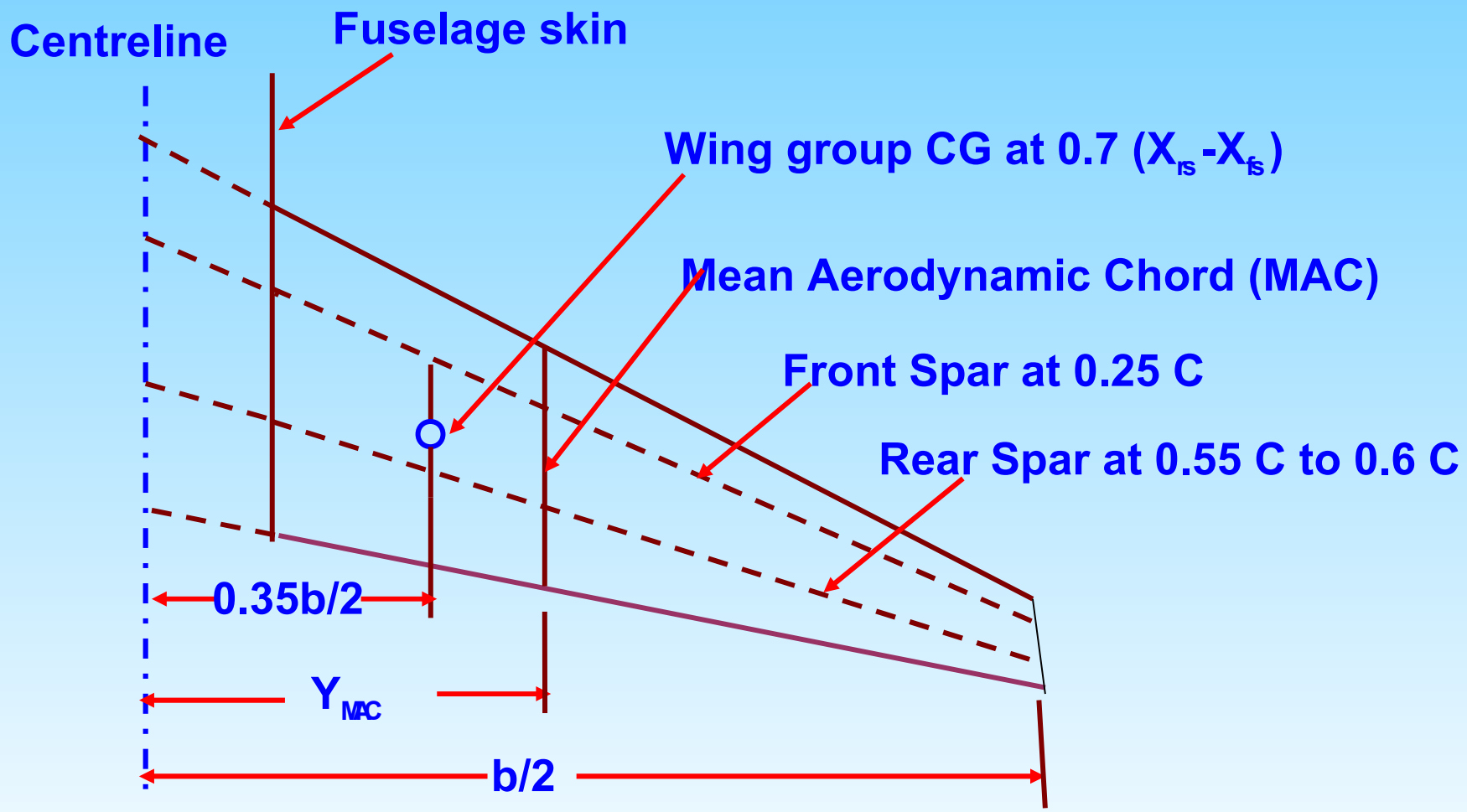
WING ROOT JOINT

- Spliced plate
- Tension bolts
- Lug
- Splice plate & tension bolt

TYPES OF LUG ARRANGEMENTS



WING GROUP CENTRE OF GRAVITY



WING LOADS

- Air pressure (Lift loads)
- Drag
- Bending moment
- Pitching moment

THANK YOU