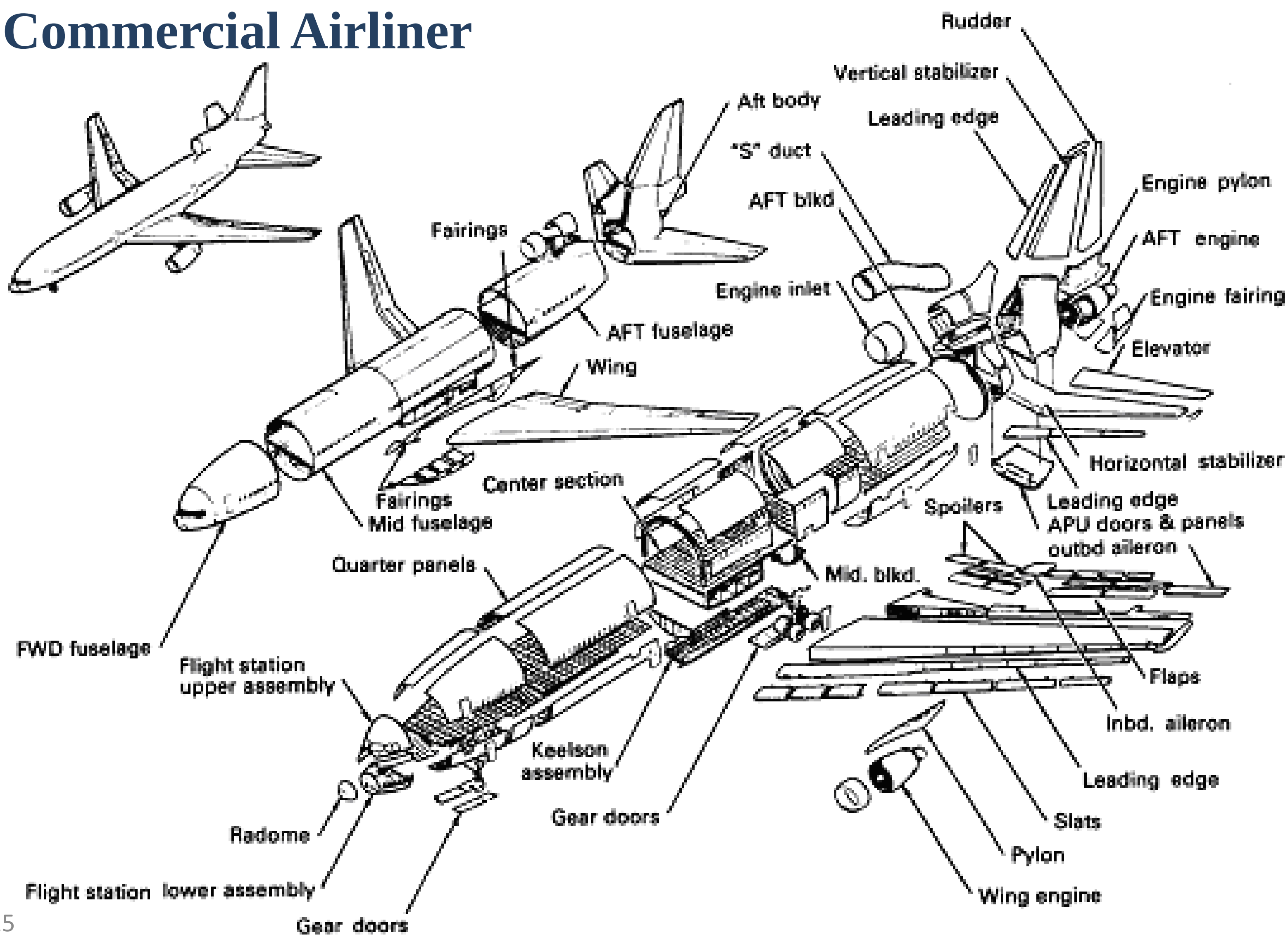
1. Aircraft Structural Breakdown

Commercial Airliner

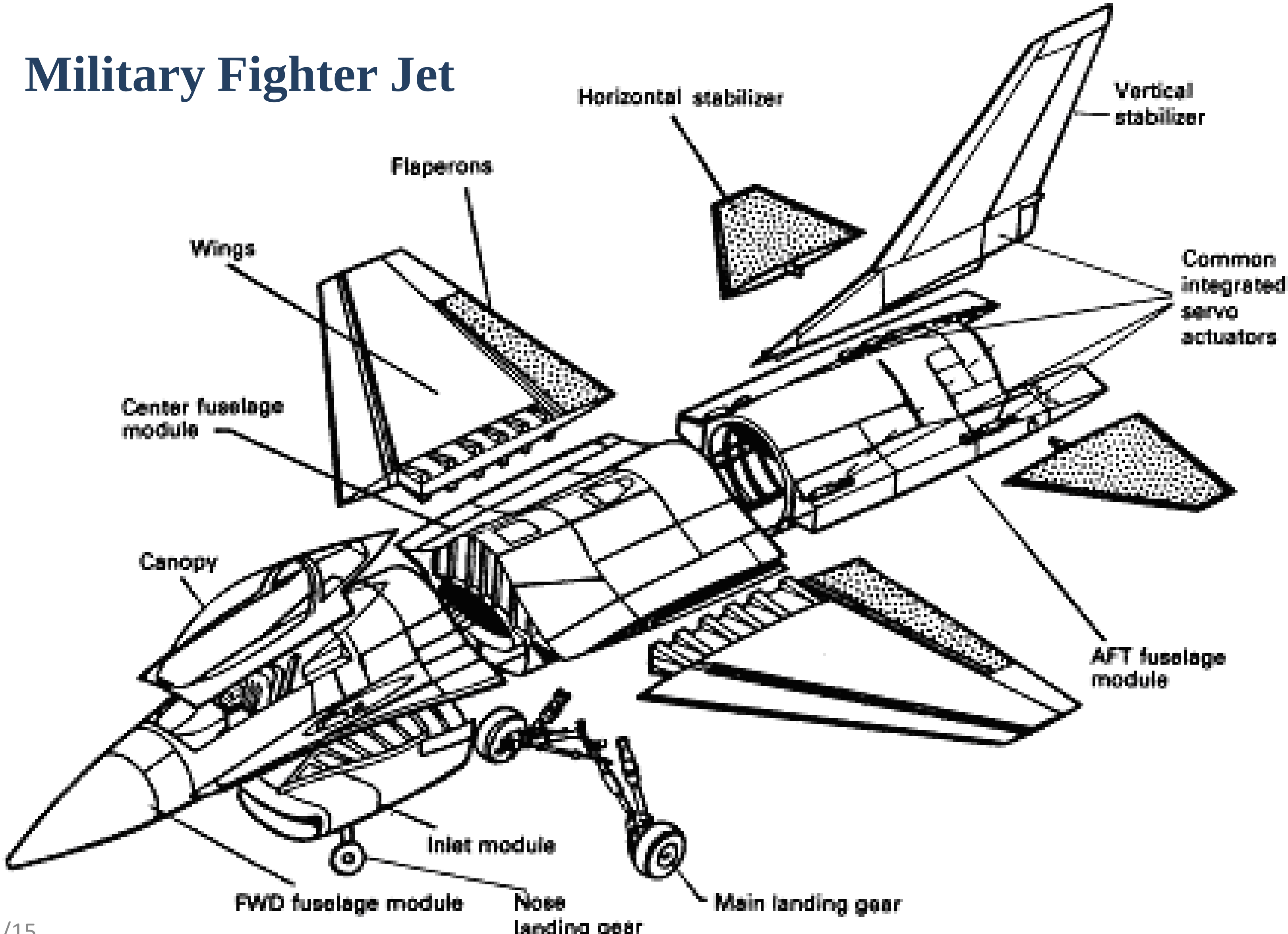


Boeing 787 Global Work Breakdown Structure

- **Manufacturing dispersed in many countries**
  - For Boeing's Dreamliner, 28 suppliers are located outside USA, e.g.
    - Wings produced in Japan
    - Ailerons produced in Australia
    - Fairings produced in Canada
    - Doors produced in France and Sweden
    - Final assembly in USA
- **Preassembled parts delivered allow for a vastly reduced final assembly crew.**
- **Faster assembly: 3 days**

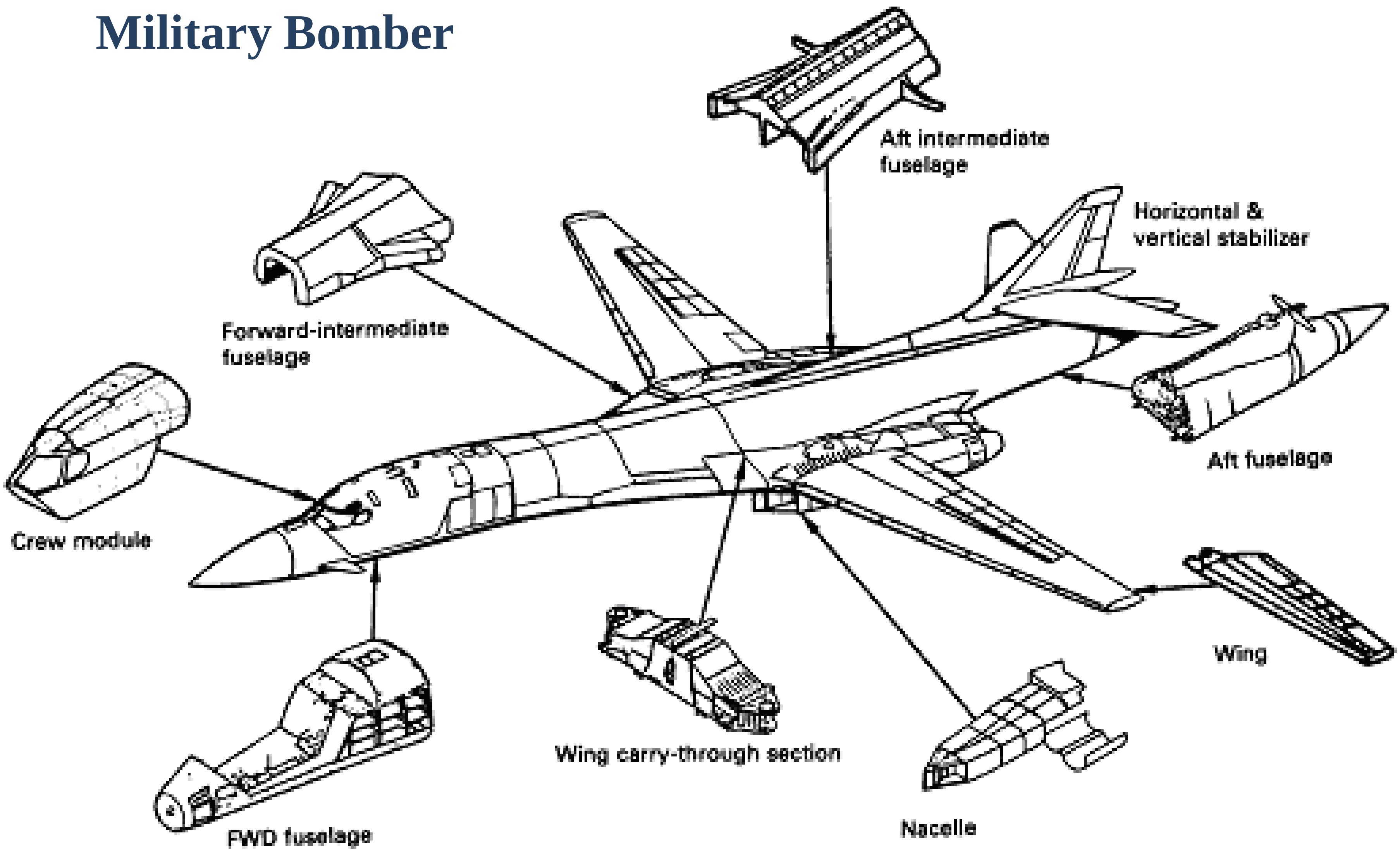
1. Aircraft Structural Breakdown

Military Fighter Jet

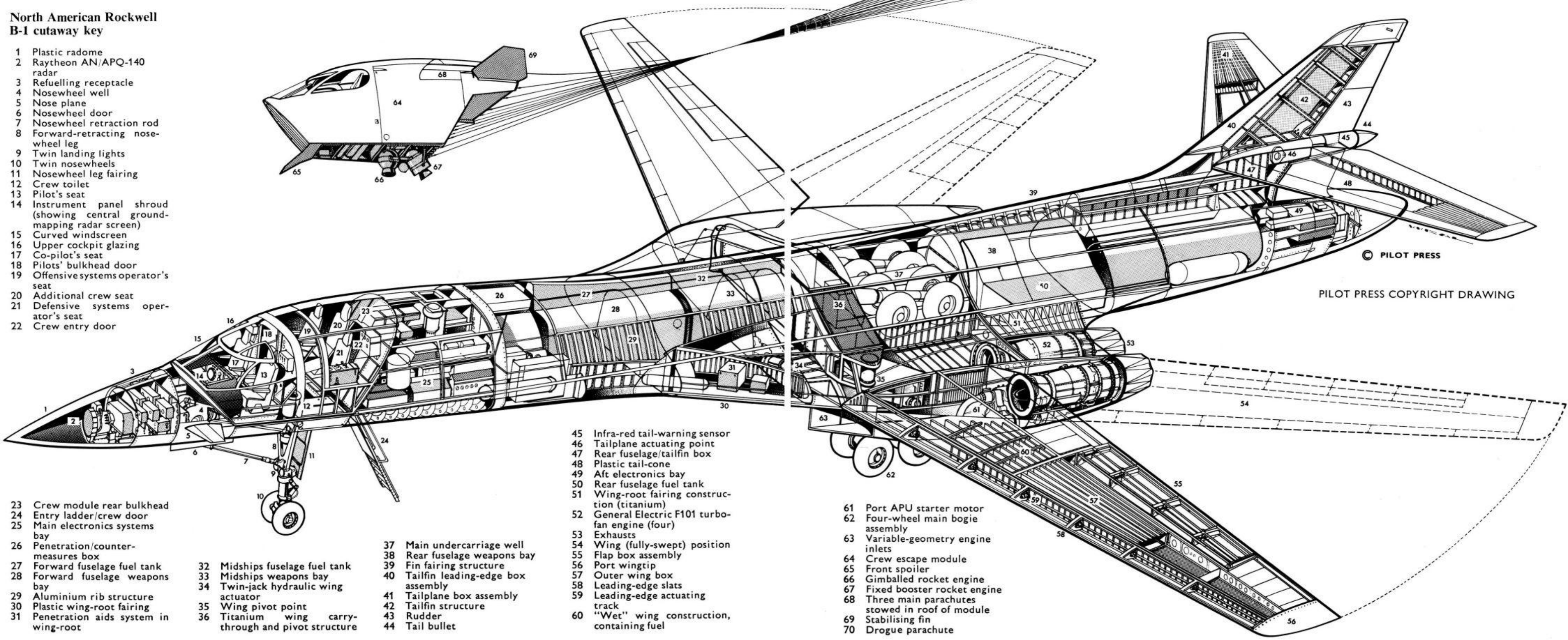


1. Aircraft Structural Breakdown

Military Bomber



Rockwell B1 Lancer



flight in the rough and turbulent air associated with low altitudes, have resulted in some high costs being incurred for structural modifications, capability improvements, and the maintenance of the B-52s over the years. Another decade

Contrary to the views of those in the late 'fifties who predicted the manned bomber's early demise in the face of advancing missile technology, the need for a B-52 replacement has persisted and even intensified. To the delight

conventional bombs internally in three weapon bays, and will have two external hard points, each carrying several SRAMS or up to 4,000 lb (1 815 kg) of fuel. "The B-1 is not optimised to meet a single threat", according to USAF

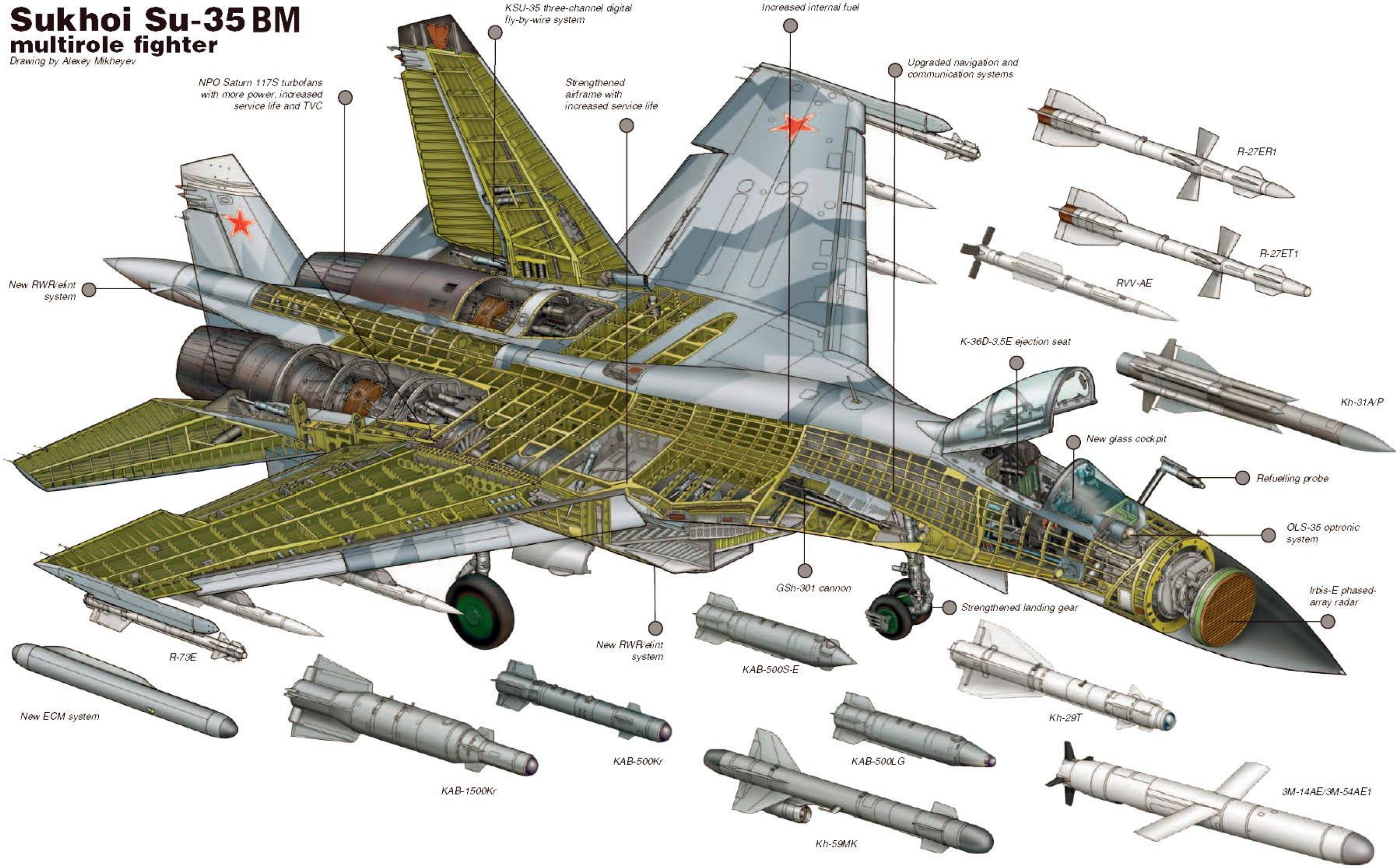
North American Rockwell B-1 cutaway key

1 Plastic radome
2 Raytheon AN/APQ-140 radar
3 Refuelling receptacle
4 Nosewheel well
5 Nose plane
6 Nosewheel door
7 Nosewheel retraction rod
8 Forward-retracting nosewheel leg
9 Twin landing lights
10 Twin nosewheels
11 Nosewheel leg fairing
12 Crew toilet
13 Pilot's seat
14 Instrument panel shroud (showing central ground-mapping radar screen)
15 Curved windscreen
16 Upper cockpit glazing
17 Co-pilot's seat
18 Pilots' bulkhead door
19 Offensive systems operator's seat
20 Additional crew seat
21 Defensive systems operator's seat
22 Crew entry door
23 Crew module rear bulkhead
24 Entry ladder/crew door
25 Main electronics systems bay
26 Penetration/counter-measures box
27 Forward fuselage fuel tank
28 Forward fuselage weapons bay
29 Aluminium rib structure
30 Plastic wing-root fairing
31 Penetration aids system in wing-root
32 Midships fuselage fuel tank
33 Midships weapons bay
34 Twin-jack hydraulic wing actuator
35 Wing pivot point
36 Titanium wing carry-through and pivot structure
37 Main undercarriage well
38 Rear fuselage weapons bay
39 Fin fairing structure
40 Tailfin leading-edge box assembly
41 Tailplane box assembly
42 Tailfin structure
43 Rudder
44 Tail bullet
45 Infra-red tail-warning sensor
46 Tailplane actuating point
47 Rear fuselage/tailfin box
48 Plastic tail-cone
49 Aft electronics bay
50 Rear fuselage fuel tank
51 Wing-root fairing construction (titanium)
52 General Electric F101 turbofan engine (four)
53 Exhausts
54 Wing (fully-swept) position
55 Flap box assembly
56 Port wingtip
57 Outer wing box
58 Leading-edge slats
59 Leading-edge actuating track
60 "Wet" wing construction, containing fuel
61 Port APU starter motor
62 Four-wheel main bogie assembly
63 Variable-geometry engine inlets
64 Crew escape module
65 Front spoiler
66 Gimballed rocket engine
67 Fixed booster rocket engine
68 Three main parachutes stowed in roof of module
69 Stabilising fin
70 Drogue parachute

Rockwell B1 Lancer

1. Aircraft Structural Breakdown

Multirole Fighter



1. Aircraft Structural Breakdown

Supermaneuverable Sukhoi 35

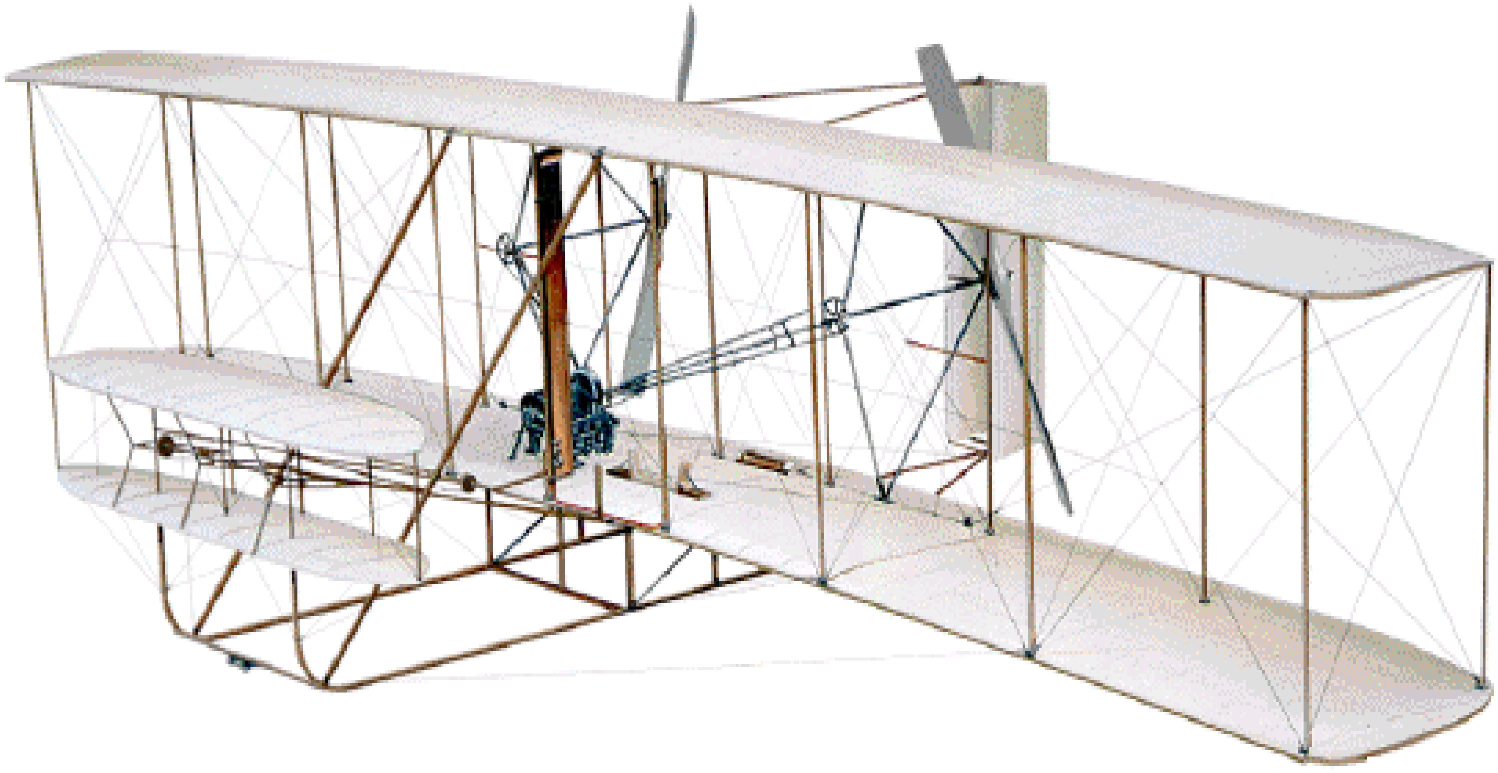
2. Wing Box Design

- Main loads for wing structure
- Types of wing structure
  - Thick box beam structure
  - Multi-spar box structure
  - Delta wing box
- Types of wing loads
  - Airloads
  - Internal fuel pressure
  - Land gear attachment loads
  - Wing leading and trailing loads

2. Wing Box Design

Wing Struts

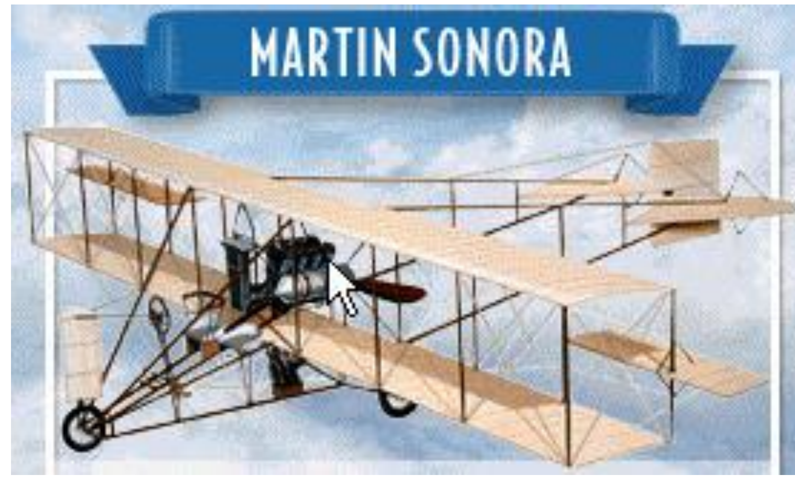
Light Aircrafts have external struts for wing bracing.




S.E.5A


FOKKER D.VII


NIEUPORT 28


MARTIN SONORA

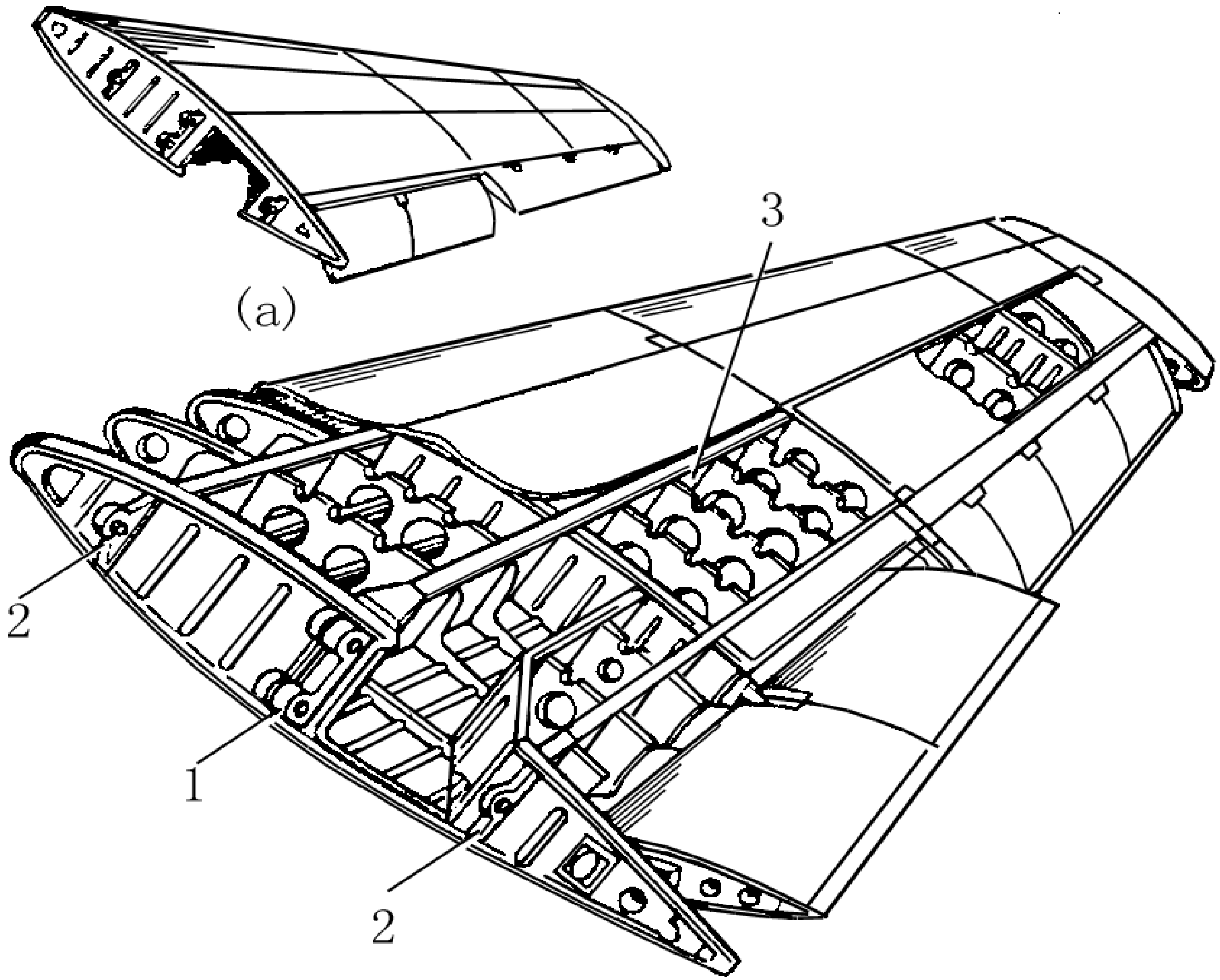

STANDARD JR-1B


MODEL 40A

2. Wing Box Design

Monoplane Wing

2. Wing Box Design

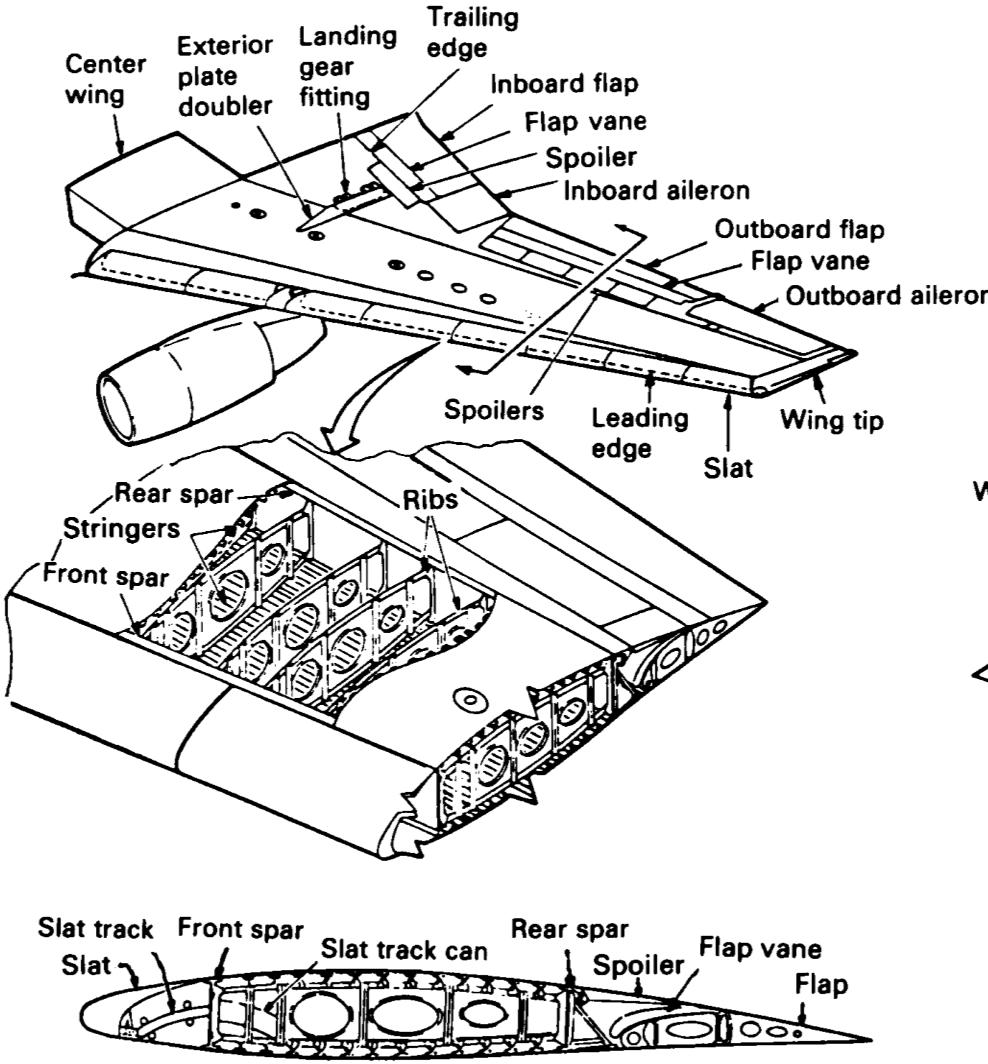


(b)

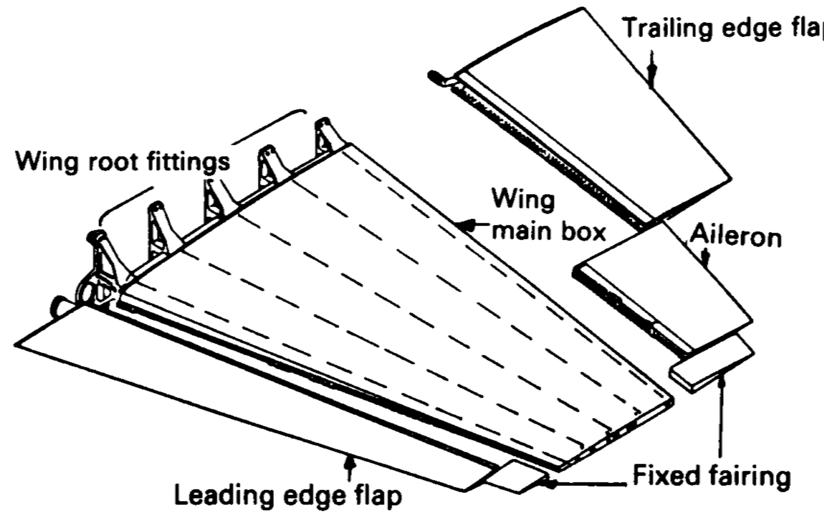
2. Wing Box Design

- **Wing structure for modern high speed airplanes**
  - Thick box beam structure
    - Usually built up with two or three spars for high aspect-ratio wings
  - Multi-spar box structure
    - For lower aspect-ratio wings with thin wing airfoil
  - Delta wing boxes

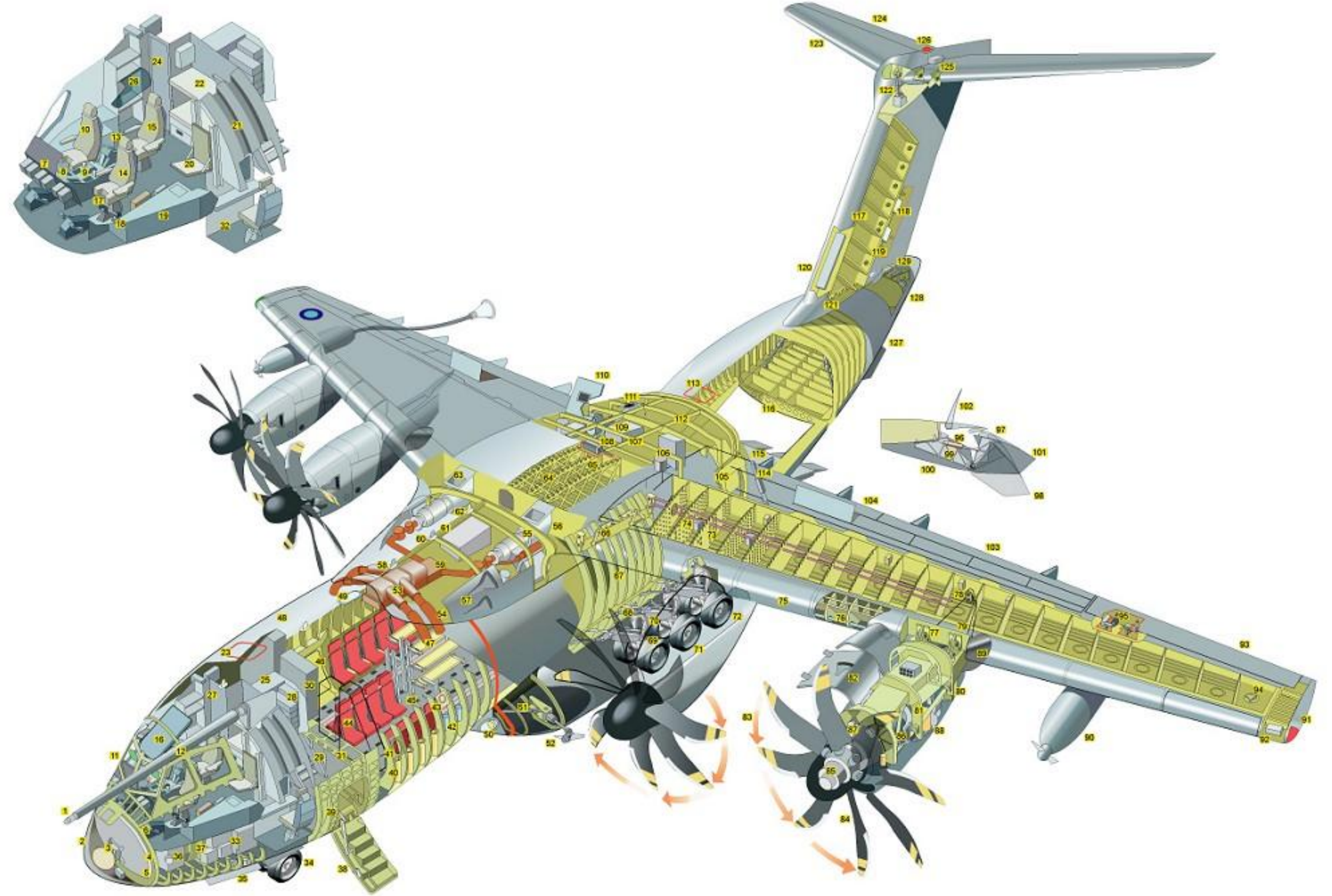
2. Wing Box Design



(a) Typical transport wing

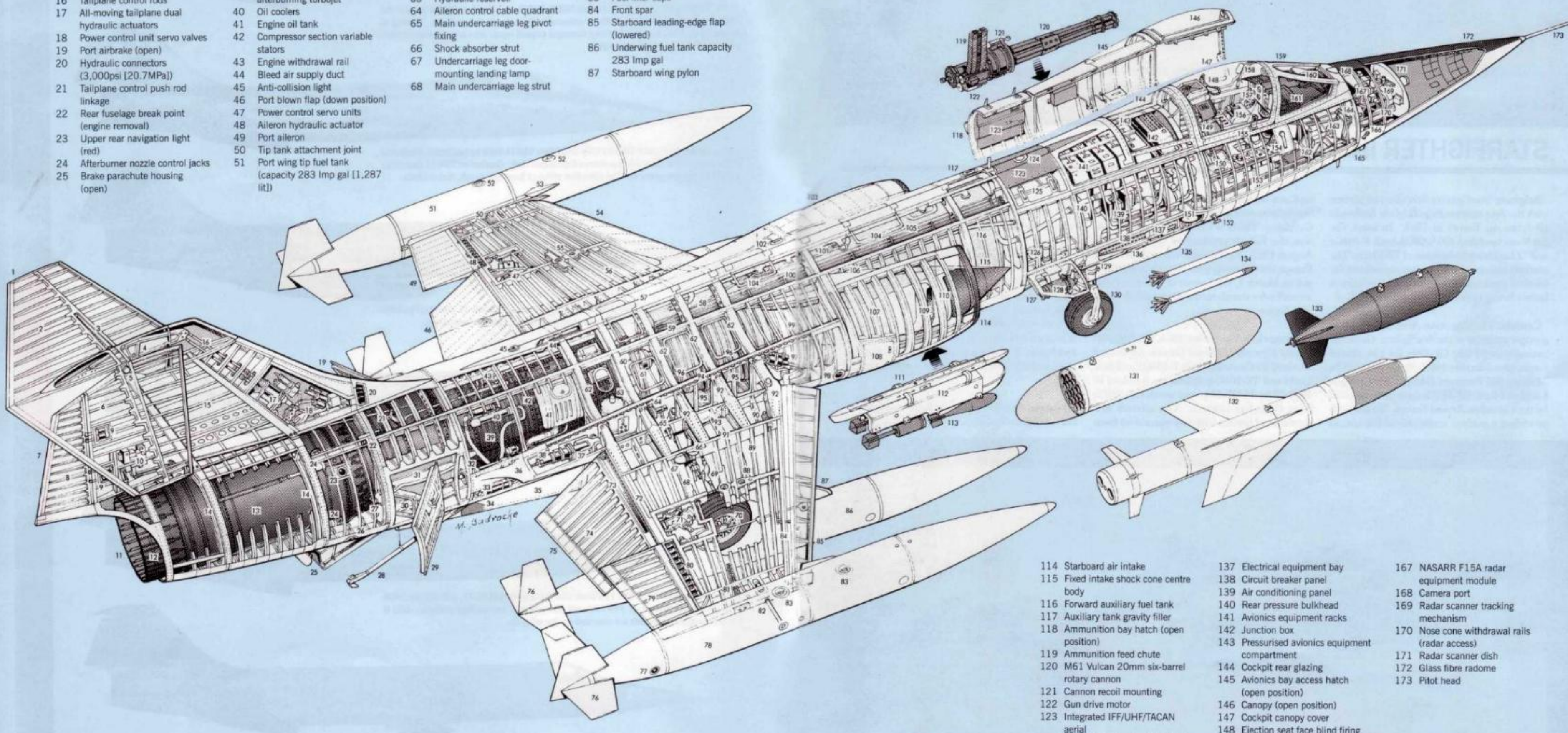


(b) Typical fighter wing



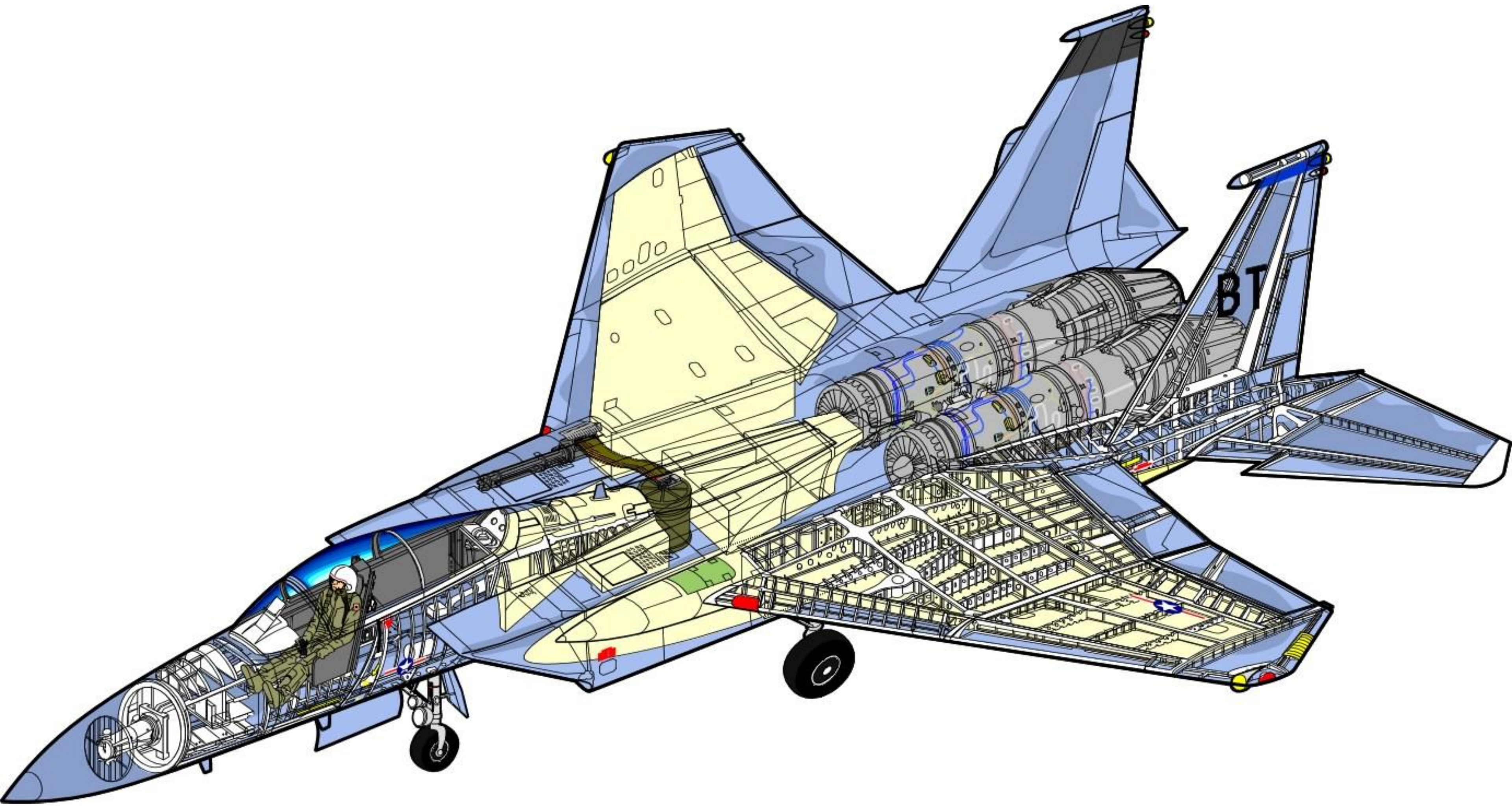
LOCKHEED F-104G STARFIGHTER • CUTAWAY DRAWING KEY

1 One-piece all-moving tailplane
2 Tailplane rib construction
3 Tailplane spar
4 Rocking control arm
5 Tailplane pivot fixing
6 Fin trailing-edge ribs
7 Rudder
8 Rudder rib construction
9 Power control actuators
10 Power actuator servo valves
11 Variable-area afterburner nozzle
12 Nozzle control flaps
13 Afterburner duct
14 Fin attachment fuselage main frames
15 Tailfin construction
16 Tailplane control rods
17 All-moving tailplane dual hydraulic actuators
18 Power control unit servo valves
19 Port airbrake (open)
20 Hydraulic connectors (3,000psi [20.7MPa])
21 Tailplane control push rod linkage
22 Rear fuselage break point (engine removal)
23 Upper rear navigation light (red)
24 Afterburner nozzle control jacks
25 Brake parachute housing (open)
26 Lower rear navigation light (white)
27 Jet pipe thrusting mounting
28 Runway emergency arrester hook (lowered)
29 Starboard airbrake (open)
30 Airbrake hinge linkage
31 Airbrake housing
32 Airbrake hydraulic jack
33 Vertical hydraulic equipment servicing bay
34 IFF/TACAN antenna
35 Ventral fin
36 Wing root trailing-edge fillet
37 Flap actuator
38 Electric drive motor
39 General Electric J79-GF 11 afterburning turbojet
40 Oil coolers
41 Engine oil tank
42 Compressor section variable stators
43 Engine withdrawal rail
44 Bleed air supply duct
45 Anti-collision light
46 Port blown flap (down position)
47 Power control servo units
48 Aileron hydraulic actuator
49 Port aileron
50 Tip tank attachment joint
51 Port wing tip fuel tank (capacity 283 Imp gal [1,287 lit])
52 Fuel filler caps
53 Tip tank vane
54 Port leading-edge flap (lowered)
55 Wing pylon hardpoint
56 Port wing panel multi-spar construction
57 Dorsal spine air duct fairing
58 Fuselage rear main fuel tank total internal fuel capacity 746 Imp gal (3,391 lit)
59 Upper main longeron
60 Intake duct spill flaps (engine bay ventilation)
61 Engine starter
62 Wing attachment fuselage main frames
63 Hydraulic reservoir
64 Aileron control cable quadrant
65 Main undercarriage leg pivot fixing
66 Shock absorber strut
67 Undercarriage leg door-mounting landing lamp
68 Main undercarriage leg strut
69 Swivelling axle control rods
70 Starboard mainwheel
71 Aileron servo control valves
72 Rear spar
73 Flap blowing air duct
74 Flap rib construction
75 Starboard blown flap (down position)
76 Auxiliary fuel tank tail fins
77 Starboard navigation light
78 Wing tip fuel tank
79 Starboard aileron
80 Aileron ten-cylinder hydraulic actuator
81 Tip tank fuel connectors
82 Jettisonable tip tank attachment joint
83 Fuel filler caps
84 Front spar
85 Starboard leading-edge flap (lowered)
86 Underwing fuel tank capacity 283 Imp gal
87 Starboard wing pylon
88 Pylon attachment hard point
89 Starboard wing panel multi-spar construction
90 Leading edge flap lock actuator and linkage
91 Wing root rib
92 Forged wing root attachment fittings
93 Main undercarriage hydraulic retraction jack
94 Wing root attachment longeron
95 Intake flank fuel tanks
96 Access panels
97 Leading-edge flap electric actuator
98 Starboard position light
99 Intake ducting
100 Control cable runs
101 Fuel system piping
102 Gravity fuel filler cap
103 Port air intake duct
104 Fuselage access panels
105 Forward main fuel tank
106 Boundary layer spill duct
107 Starboard air intake duct framing
108 Intake duct access door
109 Shock cone boundary layer air ventral spill duct
110 Boundary layer air bleed slot
111 Fuselage centreline pylon
112 Practice bomb carrier
113 20lb (9.8kg) practice bombs (four)
114 Starboard air intake
115 Fixed intake shock cone centre body
116 Forward auxiliary fuel tank
117 Auxiliary tank gravity filler
118 Ammunition bay hatch (open position)
119 Ammunition feed chute
120 M61 Vulcan 20mm six-barrel rotary cannon
121 Cannon recoil mounting
122 Gun drive motor
123 Integrated IFF/UHF/TACAN aerial
124 Upper formation light (white)
125 Ammunition magazine (725 rounds)
126 Ram air turbine spring actuator
127 Ram air turbine door (open)
128 Emergency ram air turbine (hydraulic and electrical power)
129 Nose undercarriage shock absorber leg strut
130 Nosewheel (forward retracting)
131 LAU-3A rocket pack 19 x 2¾in (70mm) folding-fin aircraft rocket (FFAR)
132 Kormoran air-to-surface anti-shipping missile
133 1,000lb (454kg) HE bomb
134 2¾in (70mm) FFAR
135 Nosewheel doors
136 Refrigeration unit ram air intake
137 Electrical equipment bay
138 Circuit breaker panel
139 Air conditioning panel
140 Rear pressure bulkhead
141 Avionics equipment racks
142 Junction box
143 Pressurised avionics equipment compartment
144 Cockpit rear glazing
145 Avionics bay access hatch (open position)
146 Canopy (open position)
147 Cockpit canopy cover
148 Ejection seat face blind firing handle
149 Martin-Baker Mk GQ-7A ejection seat
150 Side console panel
151 Liquid oxygen converter
152 Total temperature probe
153 Cockpit floor level
154 Canopy external latch
155 Control column
156 Engine throttle lever
157 Rear view mirrors
158 Instrument panel
159 Armoured windscreen panels
160 Optical sighting unit
161 Instrument panel shroud
162 Rudder pedals
163 Control cable quadrants
164 Front pressure bulkhead
165 TACAN aerial
166 Angle of attack transmitter
167 NASARR F15A radar equipment module
168 Camera port
169 Radar scanner tracking mechanism
170 Nose cone withdrawal rails (radar access)
171 Radar scanner dish
172 Glass fibre radome
173 Pitot head



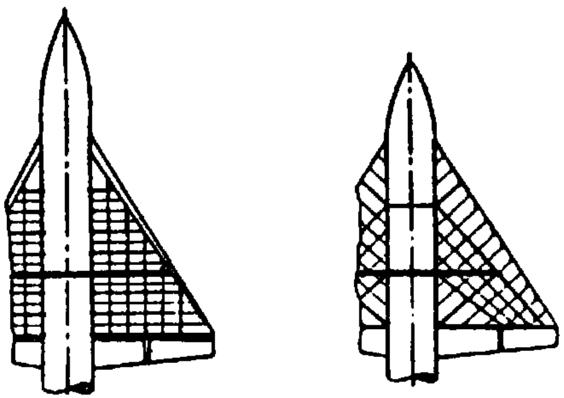
AIR International

2. Wing Box Design

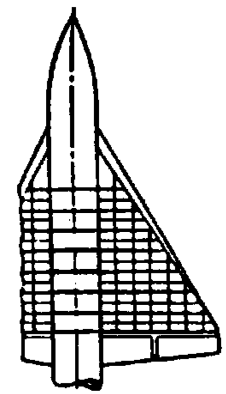


2. Wing Box Design

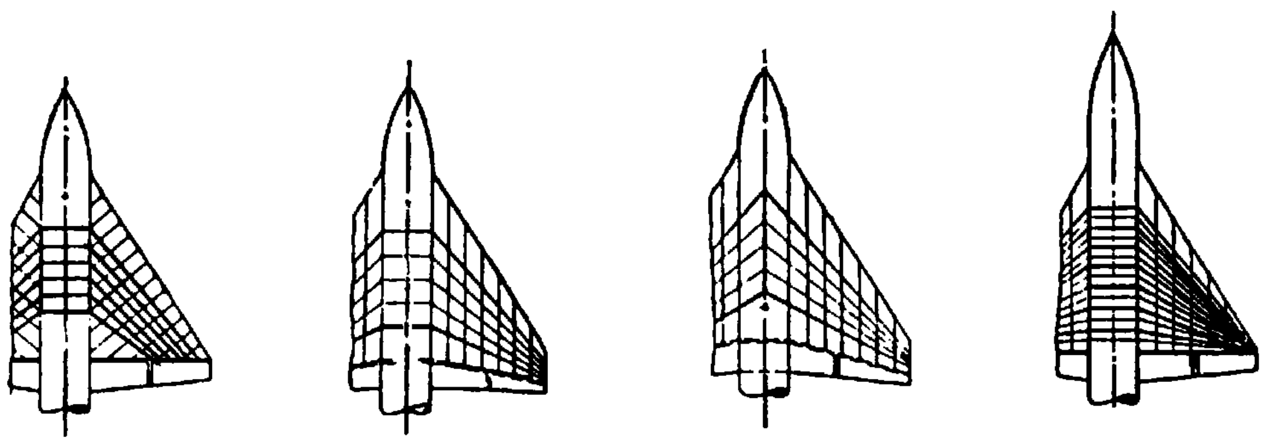
Several Structural arrangement for Delta wing box



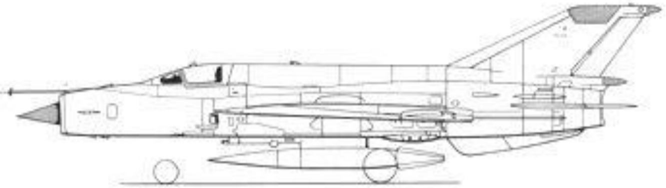
(a) Single main spar



(b) Multi-spars

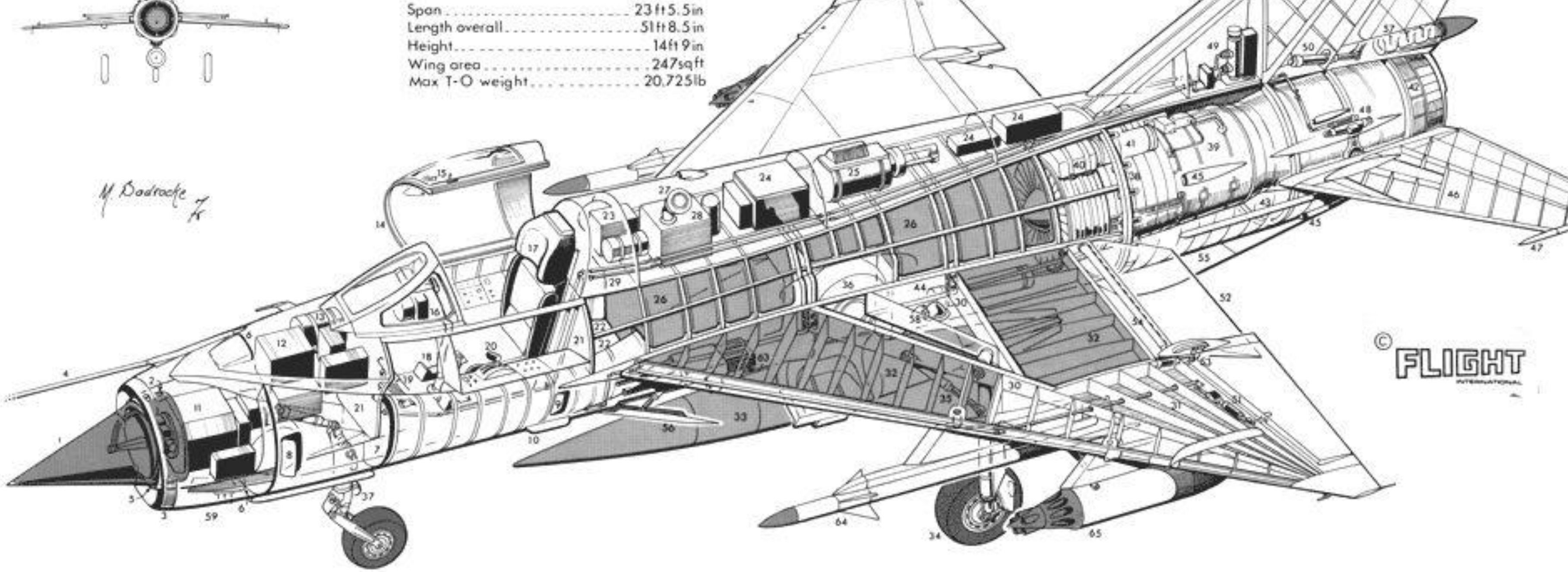


(c) Covering spars



FLIGHT INTERNATIONAL

Span	23ft 5.5in
Length overall	51ft 8.5in
Height	14ft 9in
Wing area	247sqft
Max T-O weight	20,725lb



2. Wing Box Design

- **The model of wing mechanics**
  - Beam theory:
    - The wing is essentially a beam which transmits and gathers all of the applied air-load to the central attachment to the fuselage.
  - Load Simplicity:
    - Load consideration
    - Simplicity in load transmission

2. Wing Box Design

- **Load Consideration**

- Primary loads: Airloads
  - For preliminary structural sizing and load purposes it is generally assumed that the total wing load equals the weight of the aircraft times the limit load factor times a safety factor of 1.5.
- Secondary loads:
  - Internal fuel pressure
  - Landing gear attachment loads
  - Wing leading and trailing loads

2. Wing Box Design

- **Simplicity in load transmission**

  - The local concentration of loads require a rib to distribute the load
  - Shear is carried by the wing spars
  - Bending moment is carried by the wing covers
  - Bending moment is regarded as the cover loads

2. Wing Box Design

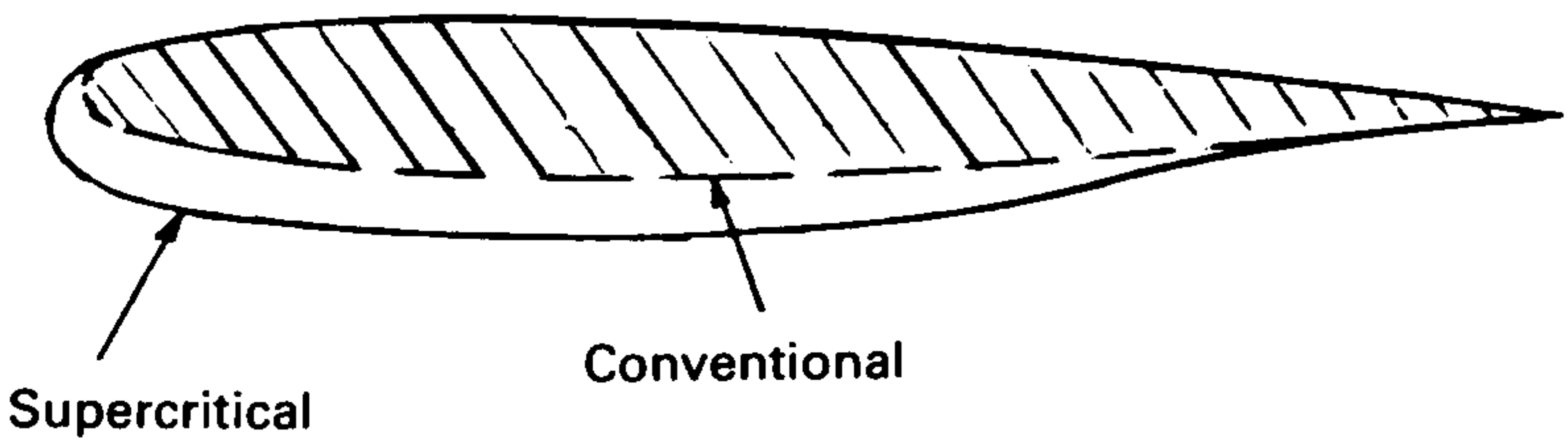
- **Wing covers design principle**
  - The covers represent fifty to seventy percent of the structural weight of the wing.
  - Lower cover is loaded in tension, it needs assure fairly high tensile strength to density ratio combined with good fracture toughness and fatigue life.
  - The upper cover is loaded primarily in compression, it need prevent from buckling.

2. Wing Box Design

- **Supercritical airfoil**
  - Supercritical airfoils can provide greater gains by increasing airfoils thickness and/or decreasing wing sweep at the same cruise Mach number.
  - Increase depth
  - Reduce sweep
  - Increase aspect ratio

2. Wing Box Design

- **Supercritical airfoil**



2. Wing Box Design

- **Disadvantages of Supercritical airfoil**

  - The incompatibility of the sharply "undercut" trailing edge with extensive flaps
  - The extremely close tolerances needed to maintain laminar flow

2. Wing Box Design

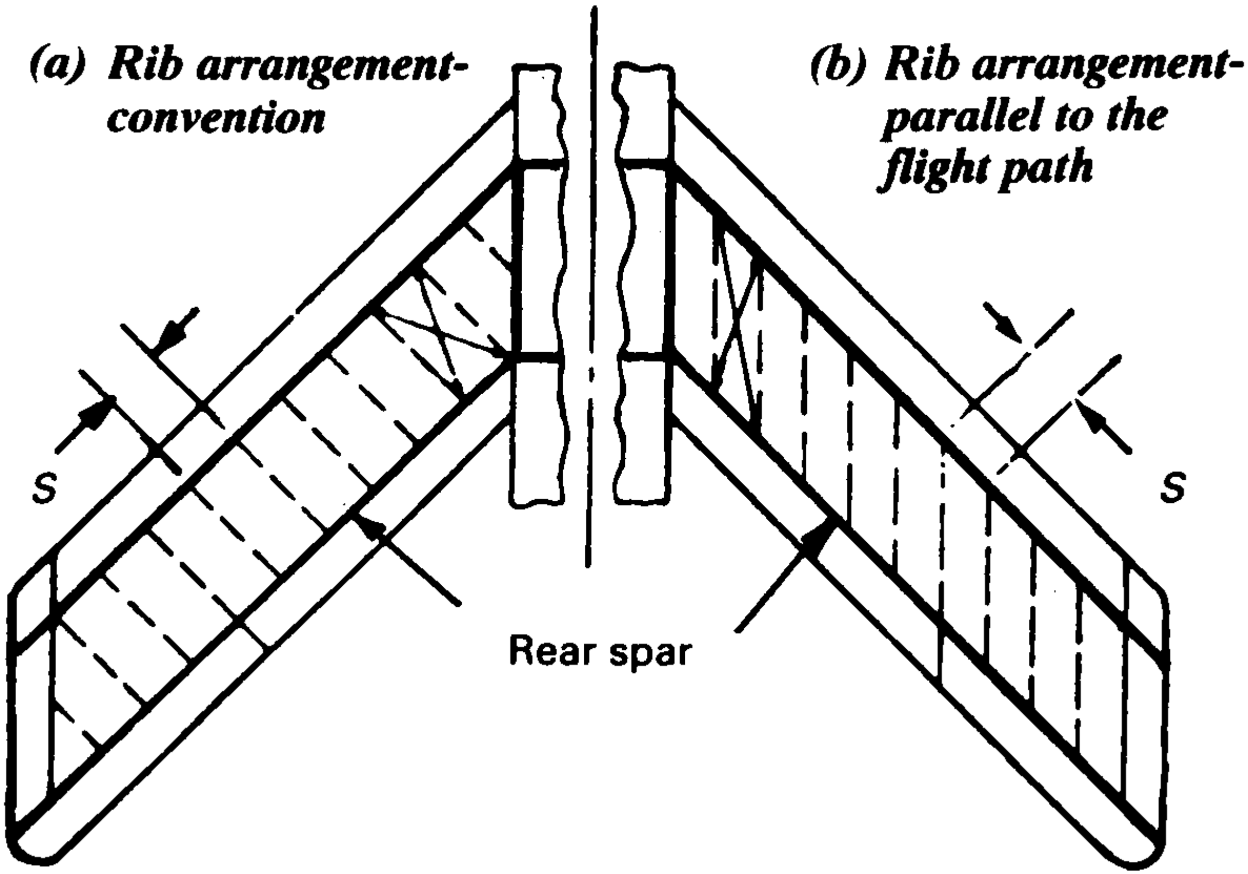
- There are two primary problems to be discussed in a wing structure layout:
  - Whether wing bending should be carried by the spars, or whether by the cover.
  - In which direction should be primary ribs run along the flight path, or normal to the rear spar.

2. Wing Box Design

- **Skin is used for transmission of bending load**
  - Skin should be utilized for a large percentage of the bending material.
  - The skin can be used for both primary bending and torsion material.
  - Spanwise stiffeners space fairly close together to keep the buckling of the bending material down to minimum.

3. Swept-Back Wing

➢ **Comparison of rib direction**



3. Swept-Back Wing

- **Comparison of rib direction**

  - Some opinions hold it necessary to have the wing ribs parallel to the flight path in order to insure a smooth aerodynamic shape between the spars.
  - This arrangement seems to have too many disadvantages to be structurally sound.
  - The total rib length is 28% longer for the wing with the ribs parallel to the flight path, with corresponding weight loss for the alternative option of ribs arrangement perpendicular to the leading edge.

3. Swept-Back Wing

- **Problems with sweptback wing**

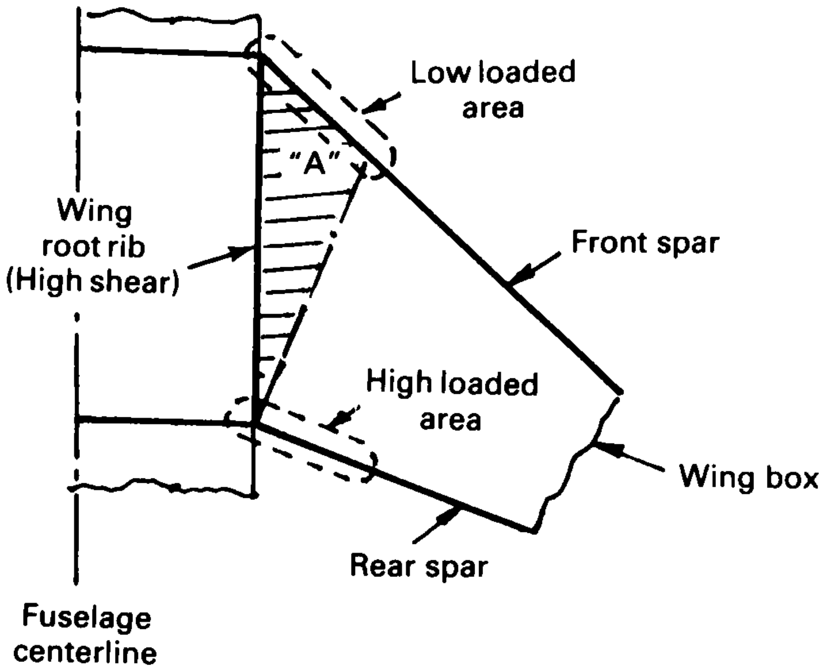


Fig. 8.2.2 Wing root load distribution problem of swept wing (a high indeterminate structure).

3. Swept-Back Wing

➤ Problems with sweptback wing

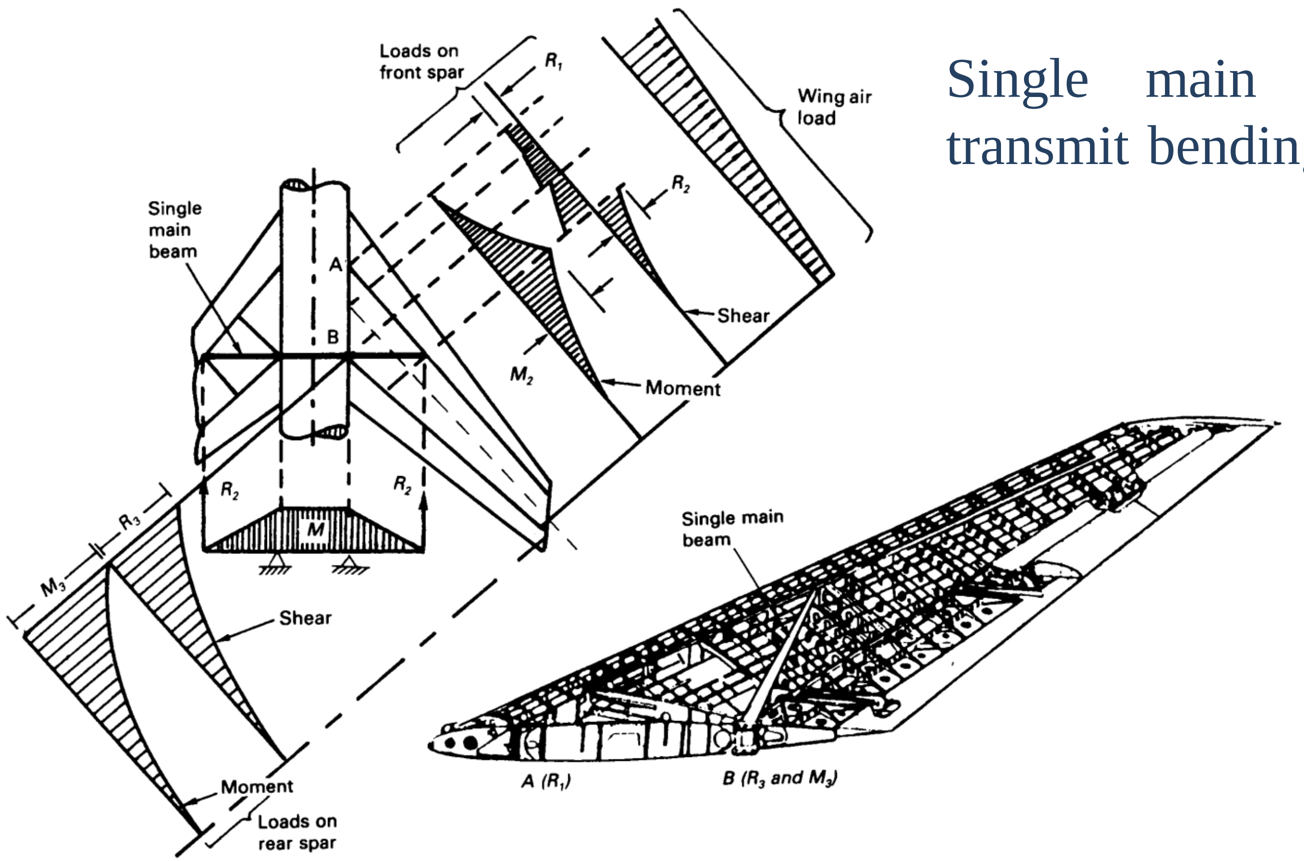


Fig. 8.2.3 Single beam design for very high swept wing.

Single main beam used to transmit bending for swept-wing.

4. Spar Location

- **Wing-body joint**

  - The design of the wing body joint, and development and sizing of the hydraulic components, control components, and electrical systems may require changing spar locations as design progresses.
  - However, firm spar locations must be established very early in the design and preferably by the time the final mathematically defined loft are available.
  - In any case, both are required before final layouts and drawings can be started.

4. Spar Location

- The rear spar must be located at a suitable chord-wise station, leaving sufficient space for the flaps and for housing the controls to operate the flaps, ailerons and spoilers.
- A rearward shift of this spar increases the cross-sectional area of the torsion box (and incidentally the fuel storage space) but the reduction in the sectional height will make it less efficient in bending.
- Similar criteria apply to the front spar when it is moved forward.

4. Spar Location

- It is noted that the best flap chord for simple plain and split flaps is about 25% of the wing chord, but highly efficient slotted flap systems are more effective with flap chords of up to 35% or even 40% of the wing chord.
- In general, the front spar is located at about 15% chord, the rear spar at 55 to 60%. About 5 to 10% chord should be available between the nested flap and the rear spar for control system elements.

4. Spar Location

- The central part of the wing, bounded by the front and rear spars, takes the loads from the nose and rear sections and carries them to the fuselage, together with its own loads.
- Primary wing structure of transport aircraft is in effect a leak-proof, integral fuel tank, the arrangement of which in the spanwise direction is dictated by considerations of balancing the aircraft for various fuel loads.
- Center tanks should be avoided from the outset, (why?) although for long-range aircraft they are more or less essential.

4. Spar Location

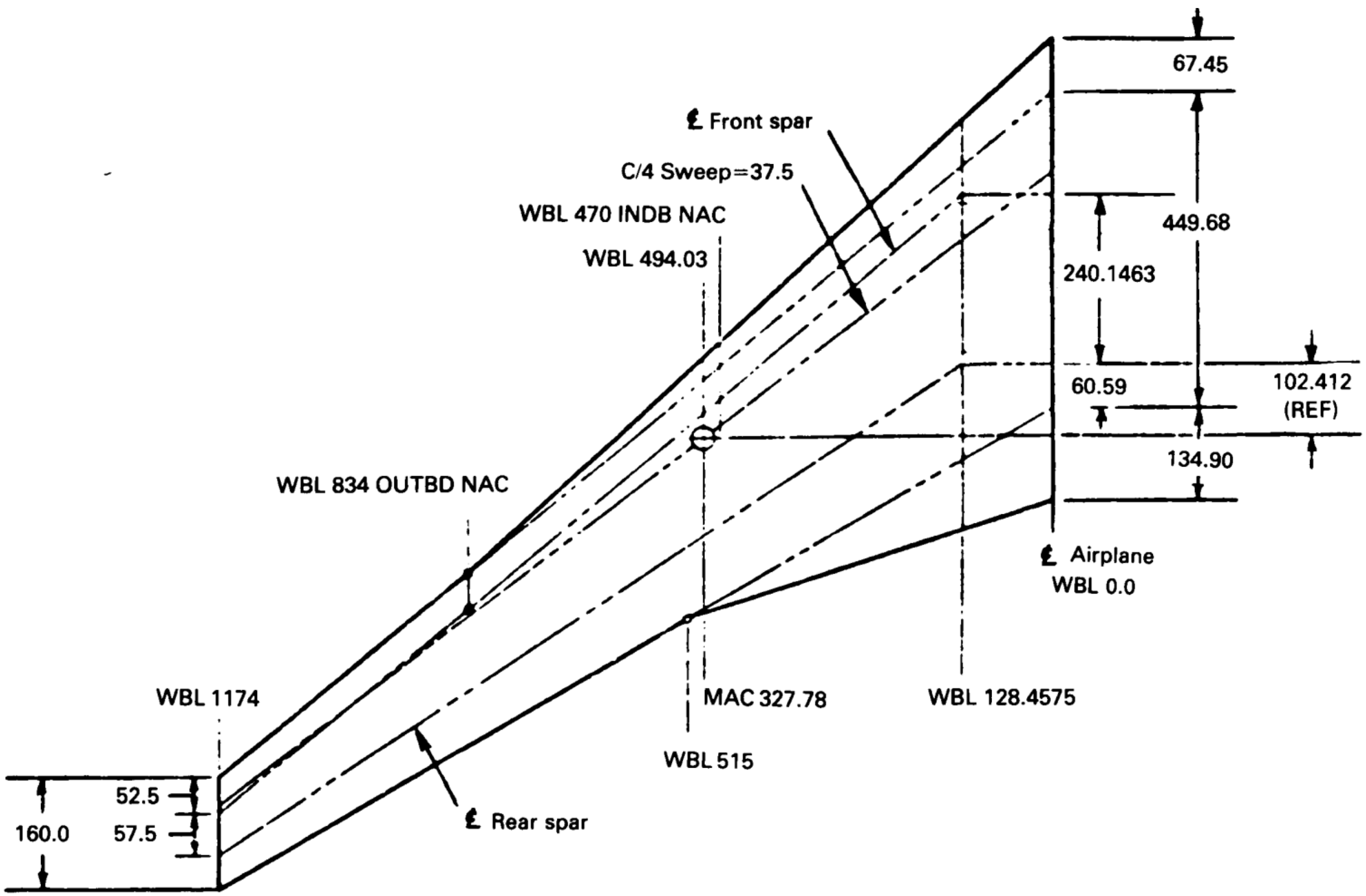
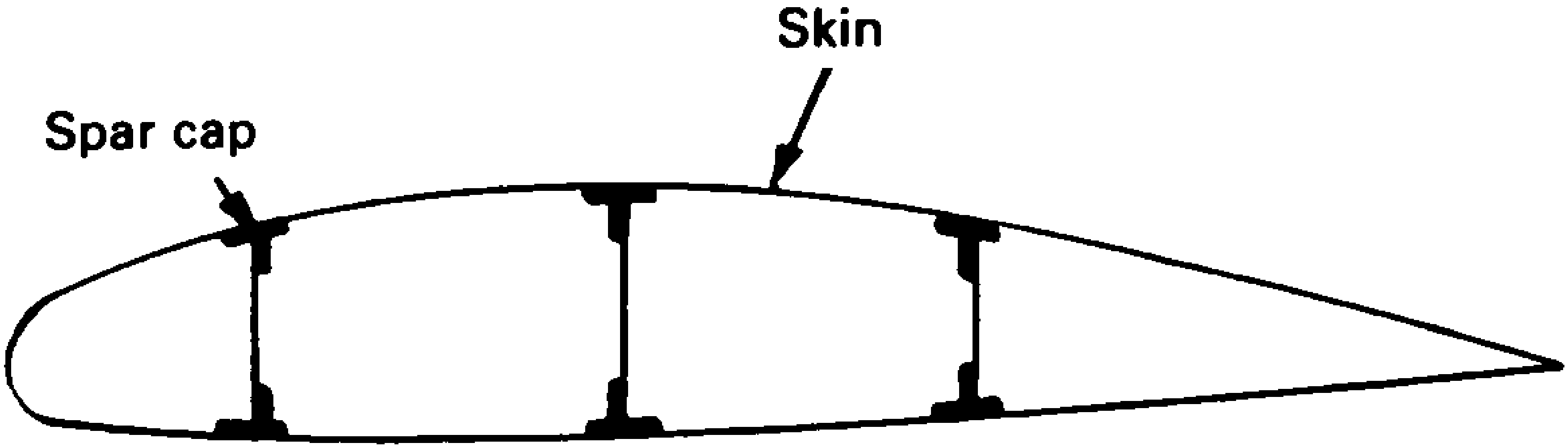


Fig. 8.2.4 Wing plan view layout of a transport.

5. Wing Skin

- **Spar cap-type cover- three spar wing**



All bending material is concentrated in the spar caps.

5. Wing Skin

- **Spar cap-type cover- three spar wing**

  - In the consideration of bending material it is convenient to classify wing structure 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.

5. Wing Skin

- **Advantages of the concentrated spar cap type cover**

  - Simplicity of construction (mostly used on general aviation aircraft).
  - Because of the concentration of material, the spar caps can be so designed that buckling occurs near the ultimate stress of the material; this allows the use of higher allowable stresses.

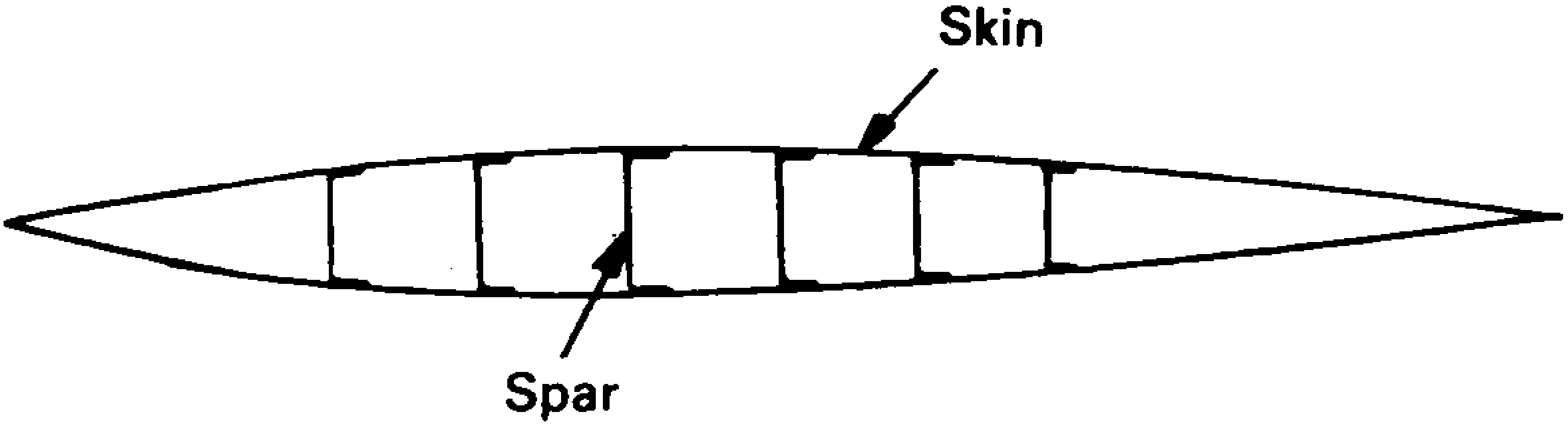
5. Wing Skin

- **Disadvantages of the concentrated spar cap type cover**

  - Skin will buckle at a very low load. The load-carrying ability of the skin, in so far as bending is concerned, is therefore negligible, which means that it has a certain amount of material which is not being utilized.
  - Skin can be in a wave state having relatively large amplitudes which disturbs the airflow over the wing profile and causes an increase in drag.
  - Fatigue failures due to the local bending stress in the buckled sheet.

5. Wing Skin

- **Multi-spar skin bending material**



The bending material is distributed around the periphery of the profile

5. Wing Skin

- **Multi-spar skin bending material**

  - The distributed bending material consists of stiffening elements running in a spanwise direction. In high speed airplanes, the wing structure is usually made of multiple spars which are primarily shear material and carry vertical shear.
  - Very little bending material is contributed by the spars. They may be built-up shear webs or channel sections.

5. Wing Skin

- The wing bending loads which cause compression at the upper surface of the wing are generally somewhat higher than those causing compression at the lower surface. This requires that the stiffening elements along the upper surface be more efficient and also more closely spaced than those on the lower surface.

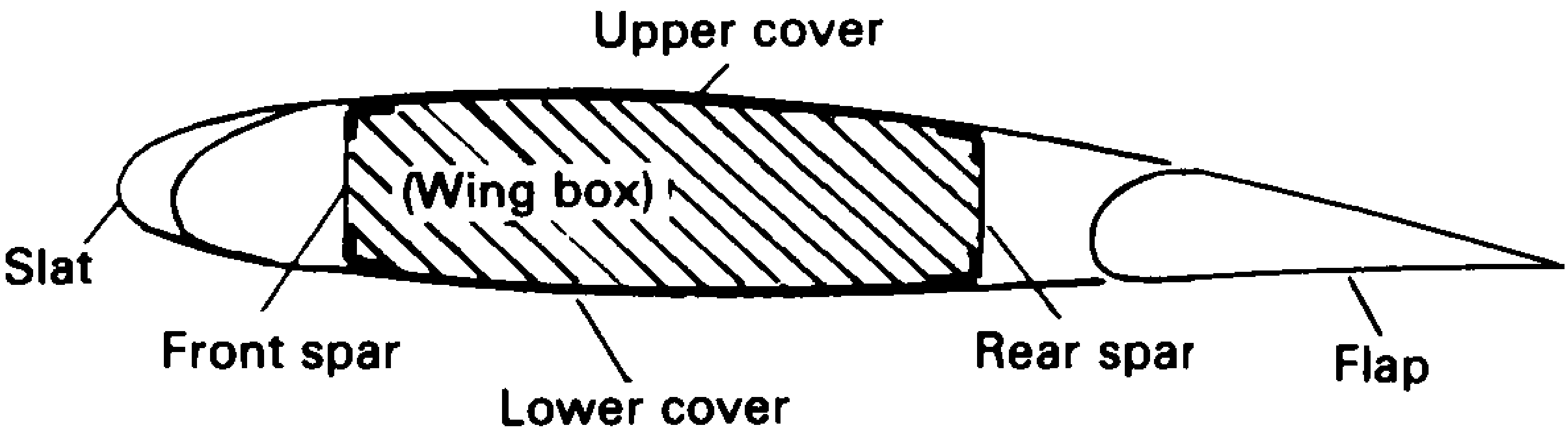
5. Wing Skin

- **Wing Tortional moment**

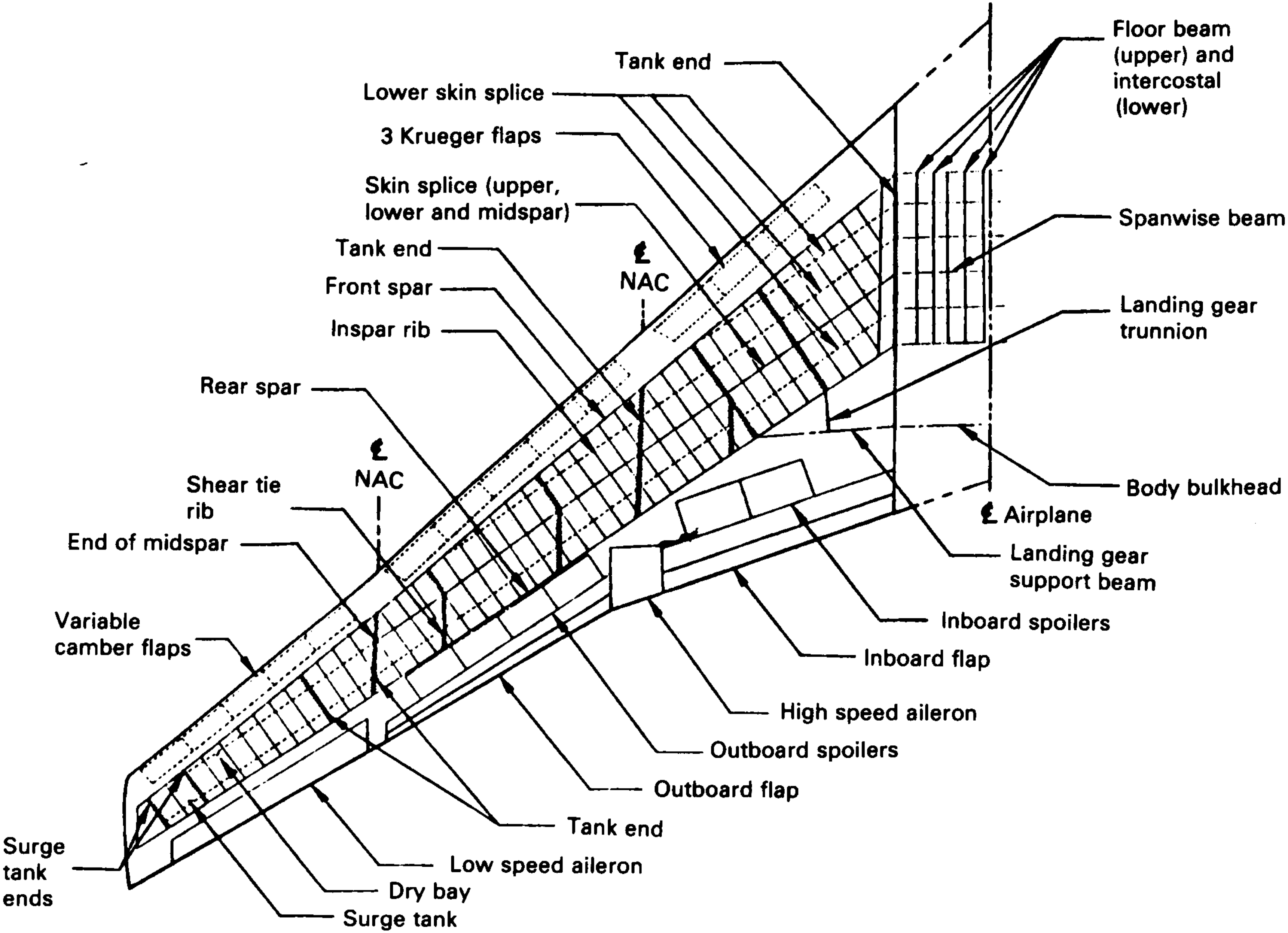
  - The torsional moments are primarily resisted by the skin and the front and rear spars. The portion of the wing aft of the rear spar is usually over the greater portion of the chord for control surfaces which does not resist any of the torsional loads.

5. Wing Skin

- **Wing tortional moment**



Typical wing torque box enclosed area.



Airliner wing lower surface skin panels.

5. Wing Skin

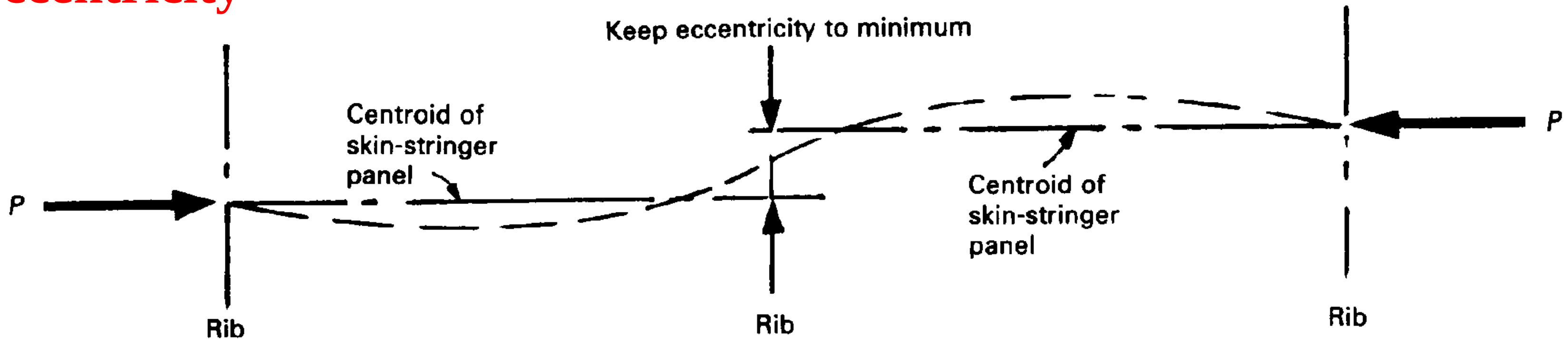
➢ **Design considerations for compression surface**

- ➢ Direct compression induced by bending of the entire section.
- ➢ Shear flows — Maximum panel shear flows induced by wing box torsion loads.
- ➢ Combination of maximum compression panel load with corresponding local shear flow, or maximum shear flow with corresponding local compression load to optimize the least weight structure.
- ➢ Local bending effects caused by surface aerodynamic pressure load
- ➢ Local bending effects caused by wing tank fuel loads which includes fuel vapor pressure, refueling pressure, inertia, etc.
- ➢ Local bending effects caused by wing bending crushing loads

5. Wing Skin

➢ Design considerations for compression surface

Eccentricity

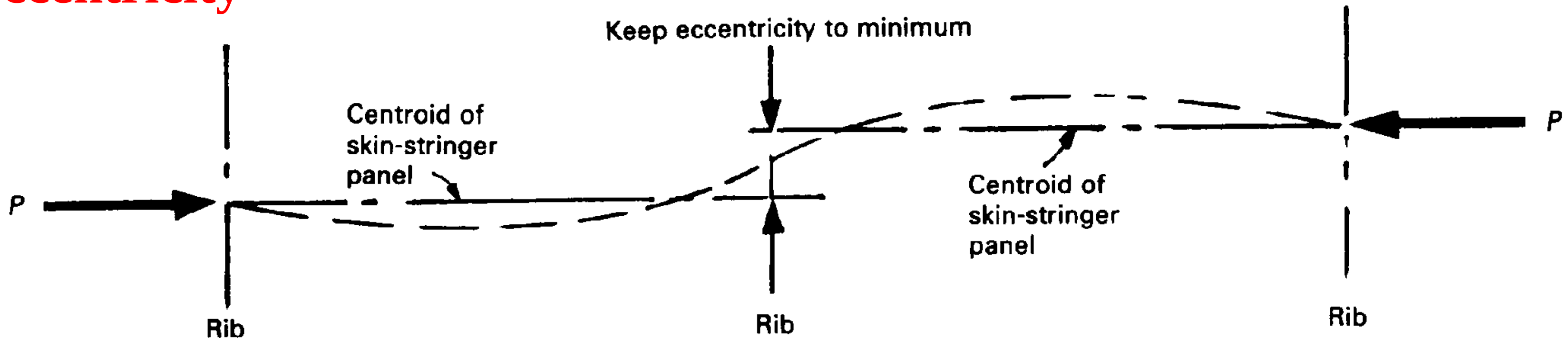


- If a stringer is spliced from two different sections, the centroidal axes of the section may differ in location.
- This will weaken the strength of the member locally and must be considered at the splice point and in the adjacent bays; therefore, this splice should be made at a rib location.

5. Wing Skin

➢ Design considerations for compression surface

Eccentricity

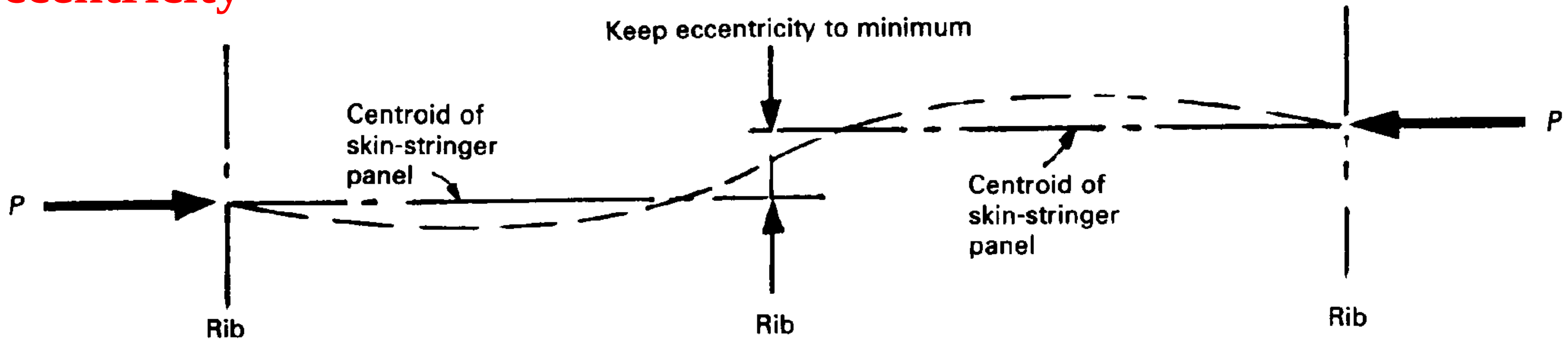


- The principal source of eccentricity occurs where stringers end.
- To properly provide for this eccentricity stringers should be ended only at ribs where the shear load due to surface pressures and eccentricity or loading can be resisted without over-straining the skin.

5. Wing Skin

➢ Design considerations for compression surface

Eccentricity

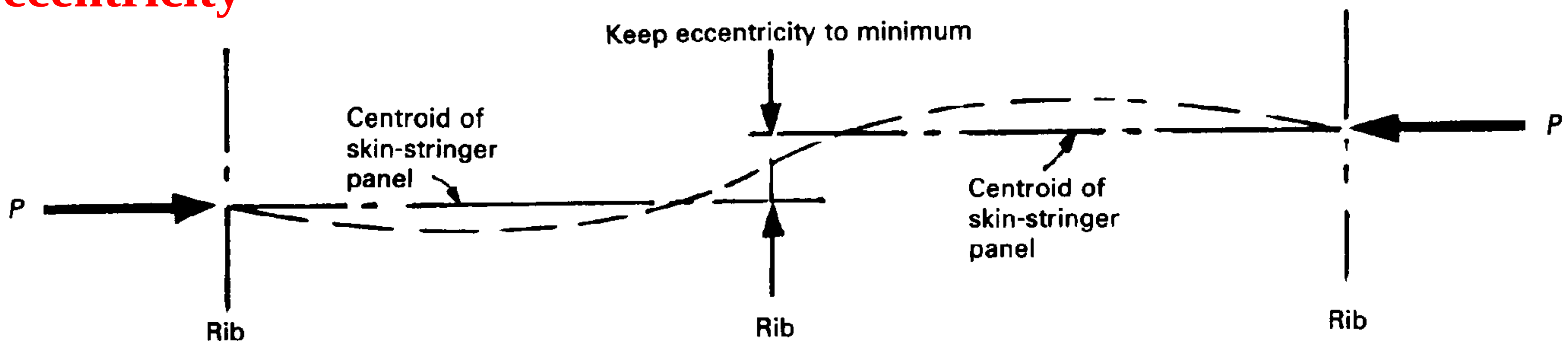


- The stringer should be tapered at the end to prevent a sharp change in section.
- The stringer will tend to carry the same stress as the skin since they are both tied together.
- A sharp change of section can overload the rivets near the end and may cause failure.

5. Wing Skin

➢ Design considerations for compression surface

Eccentricity



- ➢ It is good practice to space the rivets near the end reasonably close together and also taper the stringer thickness near the end to reduce relative deflection between the stringer and skin.

5. Wing Skin

➢ Skin-Stringer Panels

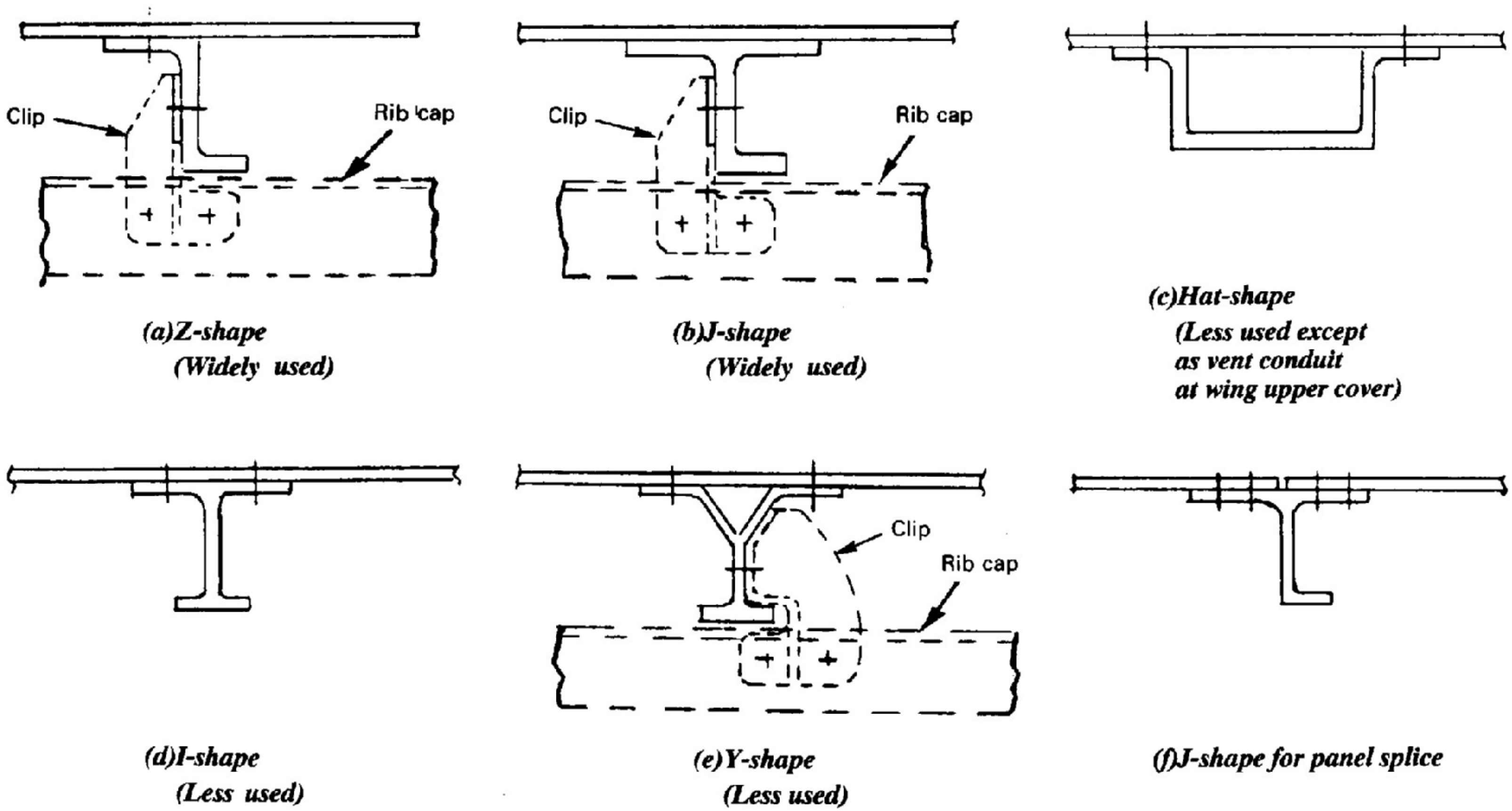


Fig. 8.3.7 Typical wing skin-stringer panels.

5. Wing Skin

- Wing skins are mostly machined from a thick plate to obtain the required thickness at different locations and then required pads can be integral; otherwise the pads or doublers have to be riveted or bonded on the basic skin around cutouts.
- The machined skins combining with machined stringers are the most efficient structures to save weight.
- This machined skin process has been adopted by modern aircraft structures.

5. Wing Skin

➢ Advantages of integral machined skins

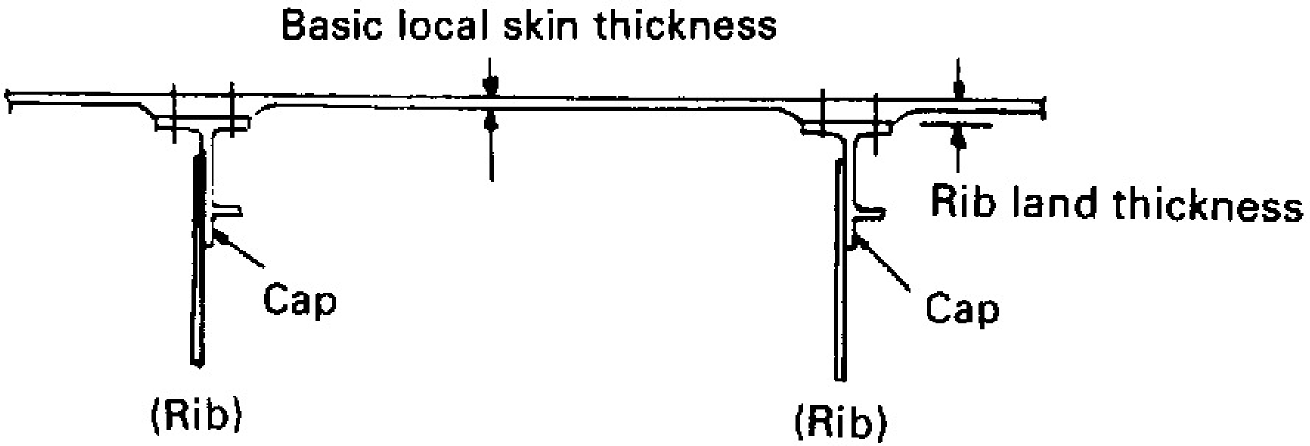


Fig. 8.3.8 Rib lands in integral wing skin-panel.

- ➢ The skins can be tapered spanwise and chordwise, thickened around holes and to produce rib lands.
- ➢ With integral skins, when designing a sweep wing, with its associated problems at the root, the ability to place end load-carrying material where it is required is a great advantage.

5. Wing Skin

➢ Skin-Stringer Panels

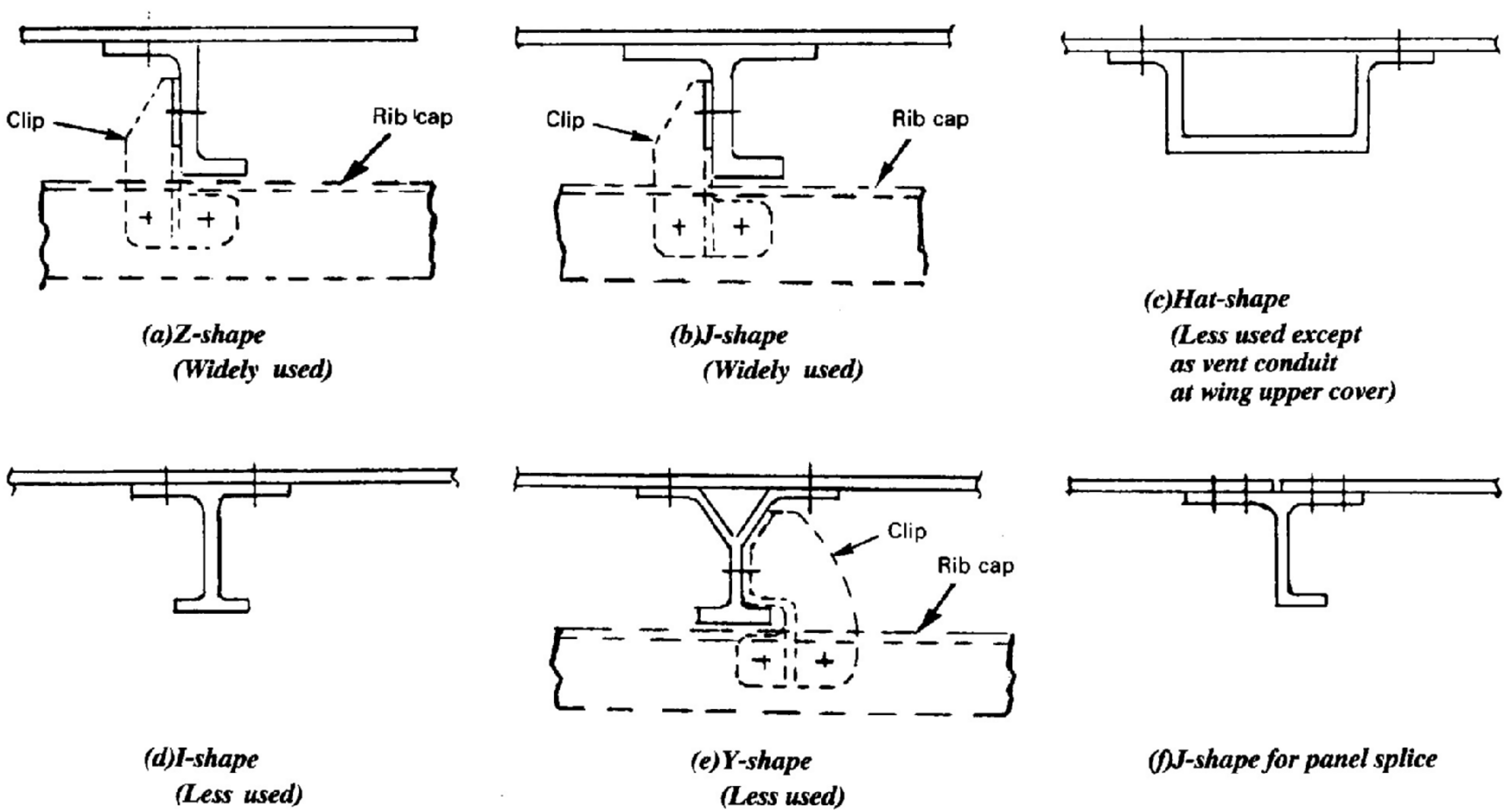
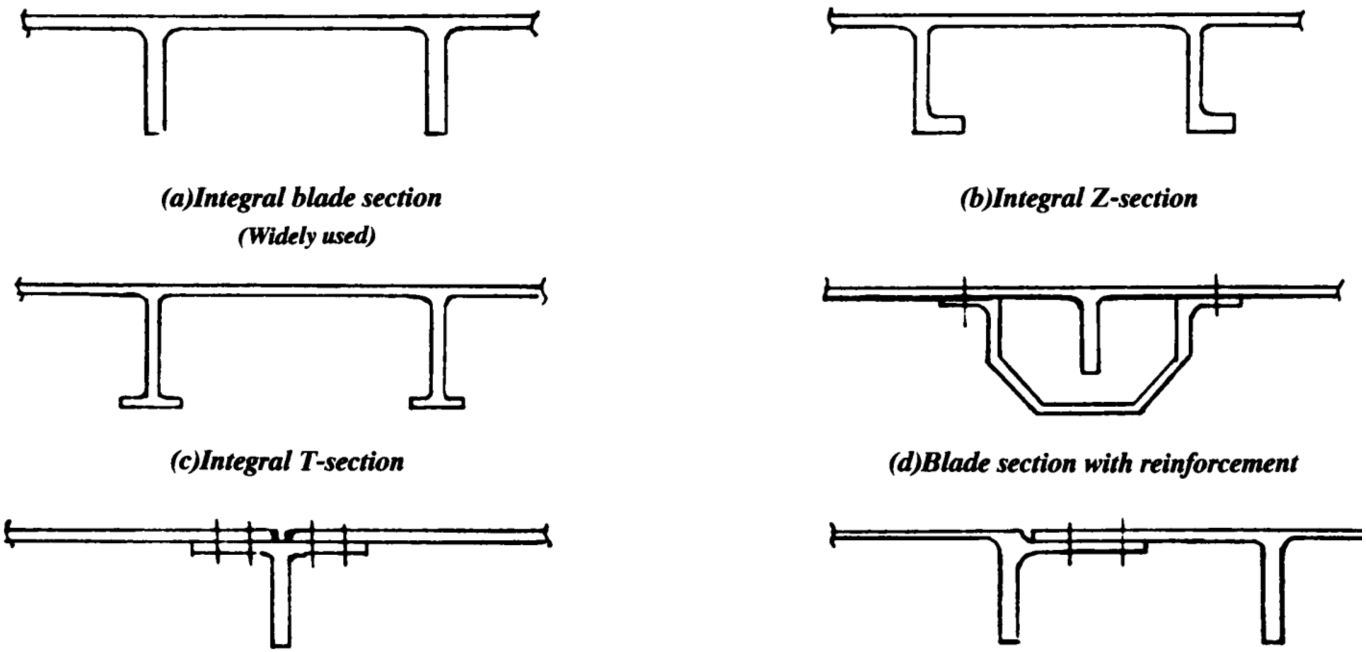


Fig. 8.3.7 Typical wing skin-stringer panels.

5. Wing Skin

➢ Integrally Stiffened Panels



(a)Integral blade section (Widely used)

(b)Integral Z-section

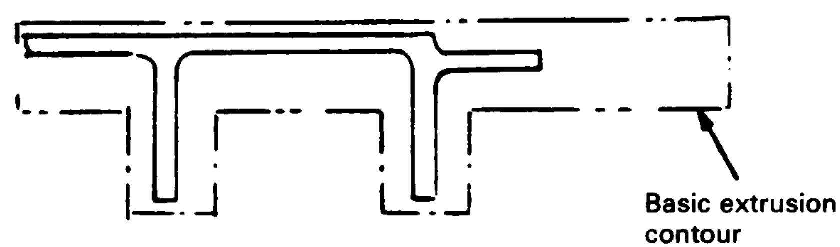
(c)Integral T-section

(d)Blade section with reinforcement

(e)Splice configuration

(f)Splice configuration (avoid)

Fig. 8.3.10 Typical integral stiffened panels (planks).



5. Wing Skin

Integrally Stiffened Panels

- Integrally stiffened structural sections have proved particularly effective as a light weight, high-strength construction.
- Composed of skin and stiffeners formed from the same unit of raw stock, these one-piece panel sections can be produced by several different techniques.
- Size and load requirements are usually the important considerations in selecting the most feasible process.

5. Wing Skin

- **Integrally Stiffened Panels**
  - For highly loaded long panels, extrusions or machined plates are most commonly employed.
  - Section discontinuities such as encountered in the region of cutouts can often be produced more easily from machined plate.
  - From a cost standpoint it is usually better to machine a section from the extruded integrally stiffened structures than to machine a section of the same size from a billet or plate.

5. Wing Skin

- **Advantages of integrally stiffened structures over comparable riveted panels**
  - Reduction of amount of sealing material for pressurized fuel tank structures
  - Increase in allowable stiffener compression loads by elimination of attachment flanges
  - Increased joint efficiencies under tension loads through the use of integral doublers, etc.
  - Improved performance through smoother exterior surfaces by reduction in number of attachments and nonbuckling characteristics of skin
  - Light weight structures

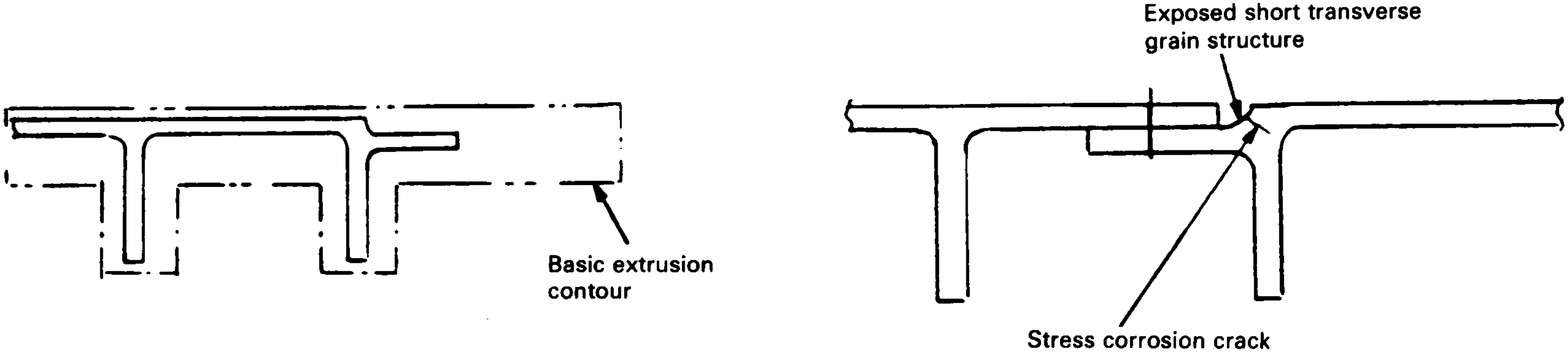
5. Wing Skin

➢ Advantages of integrally stiffened structures over comparable riveted panels

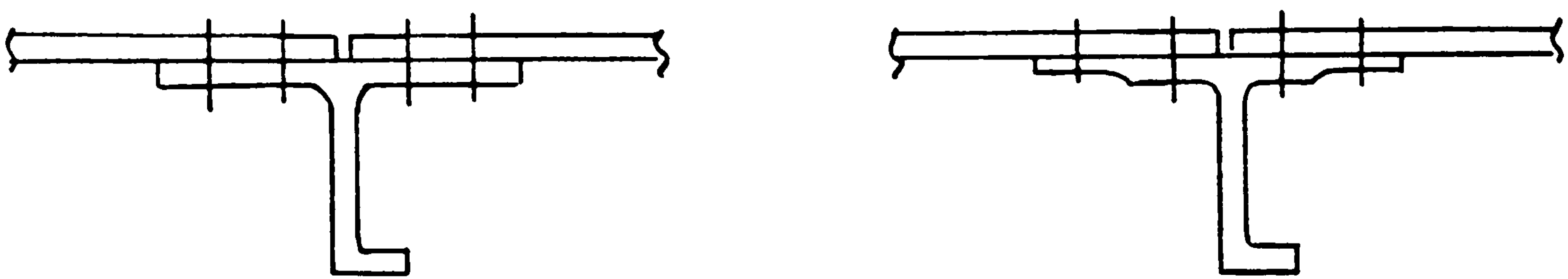
- ➢ Integrally stiffened structures have their greatest advantage in highly loaded applications because of their minimum section size.
- ➢ Investigations have indicated that an integrally stiffened section can attain an exceptionally high degree of structural efficiency.
- ➢ A weight reduction of approximately 10—15% was realized by the use of an integrally stiffened structure.
- ➢ Lightest cover panel design can be obtained with an integrally stiffened cover structure supported by sheet metal ribs with a preference for a large spacing

5. Wing Skin

➢ Cover panel splice design



(a)Avoid

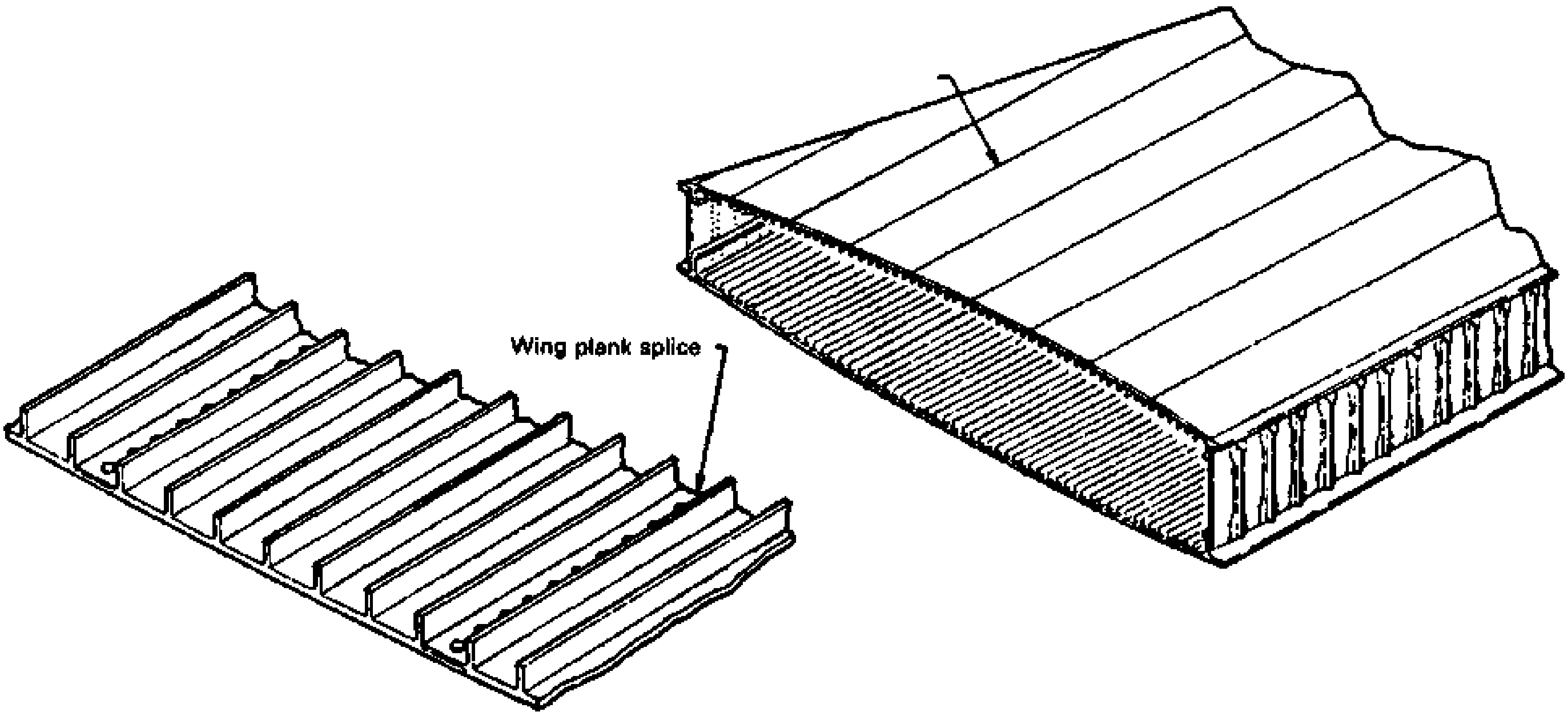


(b)Preferred

Fig. 8.3.12 Wing cover panel splice configurations.

6. Wing Box

- **Integral Wing Box**



6. Wing Box

➢ Access Holes

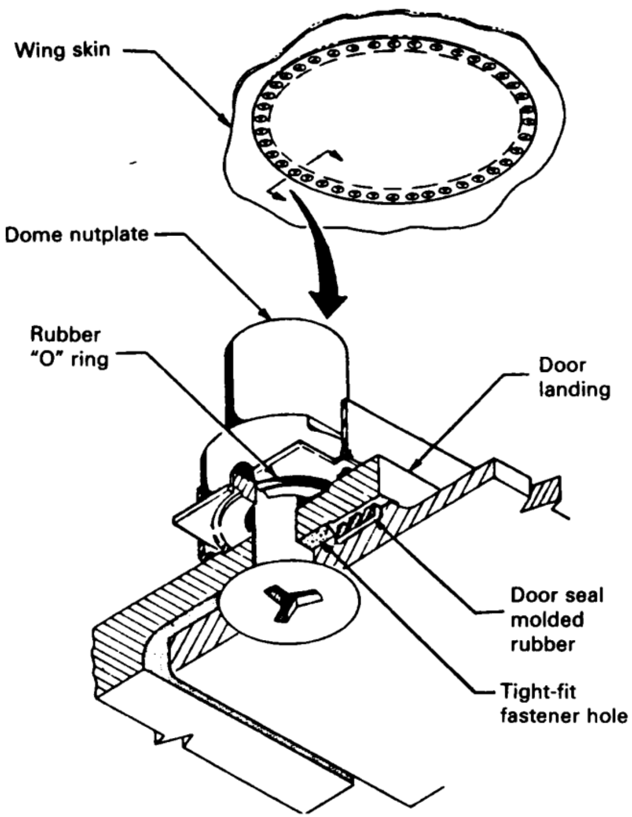


Fig. 8.3.15 Wing access hole with stressed door.

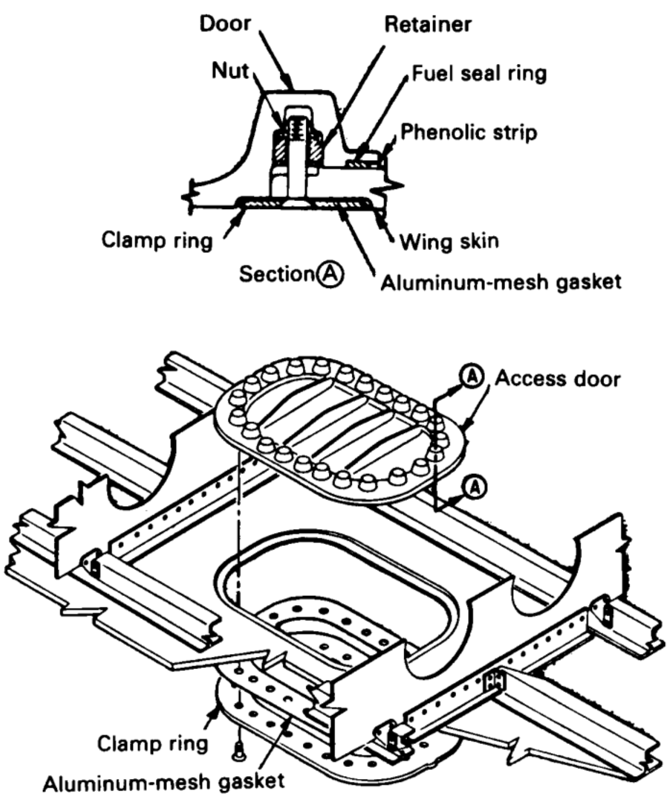


Fig. 8.3.16 Wing access hole with non-stressed door.

6. Wing Box

➢ **Integral Wing Box**

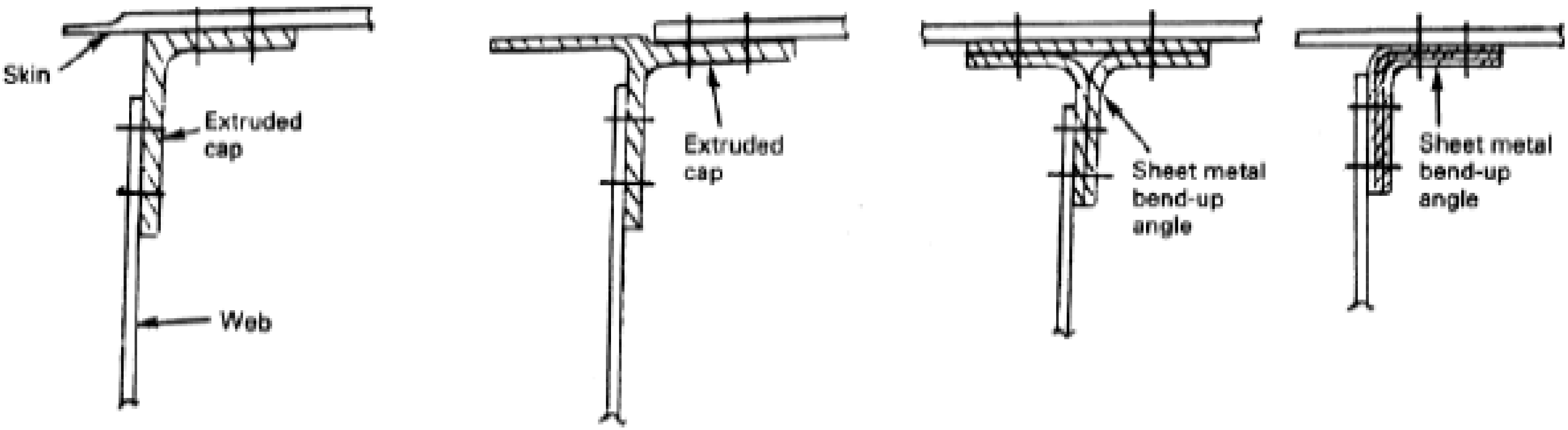
- Stress concentrations in wing box structures will result at end fasteners where trailing edge and leading edge skins, such as fixed leading and trailing edge panels, rivet to the wing spar caps or wing skins.
- Several approaches are introduced as follows:
  - Corrugated splice strap
  - Sacrificial doubler design
  - Fiber glass panel attached to wing box design
  - Access panel attached to wing box by gooseneck hinges

7. Spars

- The air loads act directly on the wing cover which transmits the loads to the ribs.The ribs transmit the loads in shear to the spar webs and distribute the load between them in proportion to the web stiffnesses.
- In the past it has been customary to design wings with three or more spars.
- The use of several spars permit a reduction in rib stresses and also provides a better support for the spanwise bending material.
- Another important purpose is to designed for structural fail -safe feature.

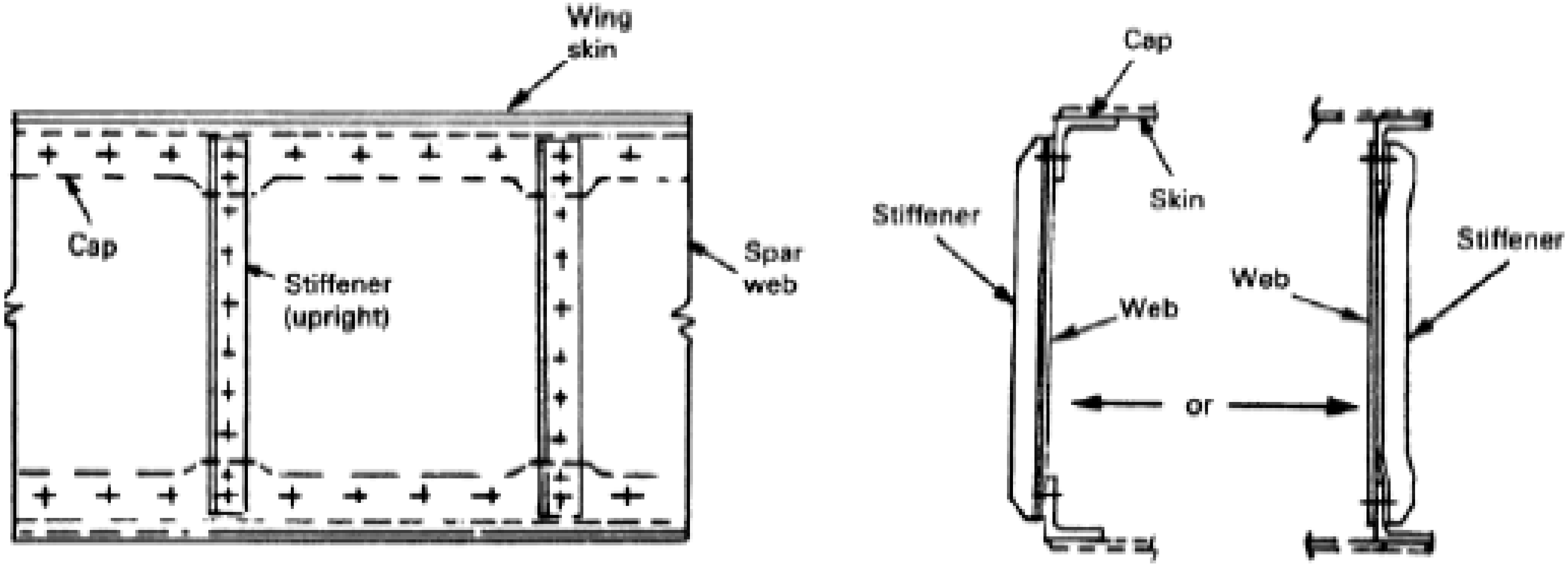
7. Spars

- **Spar cap**



7. Spars

- **Spar web**



7. Spars

Two-spar wing

- A two-spar wing construction usually consists of a front and rear spar.
- The front spar located that the wing leading edge slats can be attached to it.
- The rear spar located that the control surface such as these hinge brackets of flaps, aileron, spoiler, etc, can be attached to it.
- Furthermore, the front and rear spars combined with wing skin panels form as the closing member of the torsion-resistant box and also serves as integral fuel tank.

7. Spars

- **Fail-safe design**

  - A truly fail-safe structure must not fail when a shear beam is damaged for any reason.
  - Multiple beam construction has the advantage of supplying alternate load paths for tension in case any single beam web should fail.
  - Assuming that a fatigue crack would start as usual at the lower wing cover, it would probably run upward through the web unless stopped in some manner.

7. Spars

➢ Crack stoppers

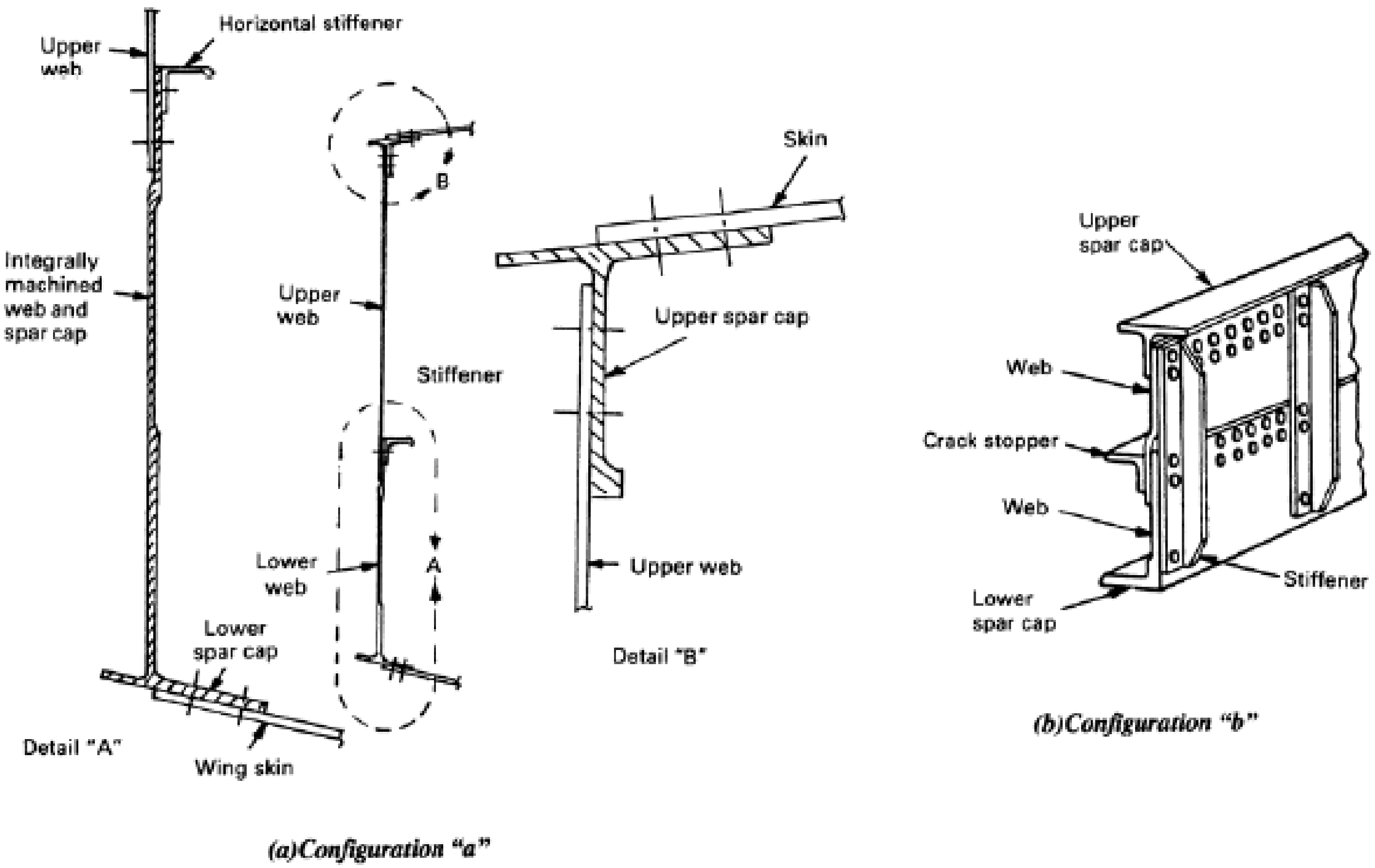


Fig. 8.4.15 Spar shear web crack stopper for fail-safe feature.

7. Spars

- **Crack stoppers**

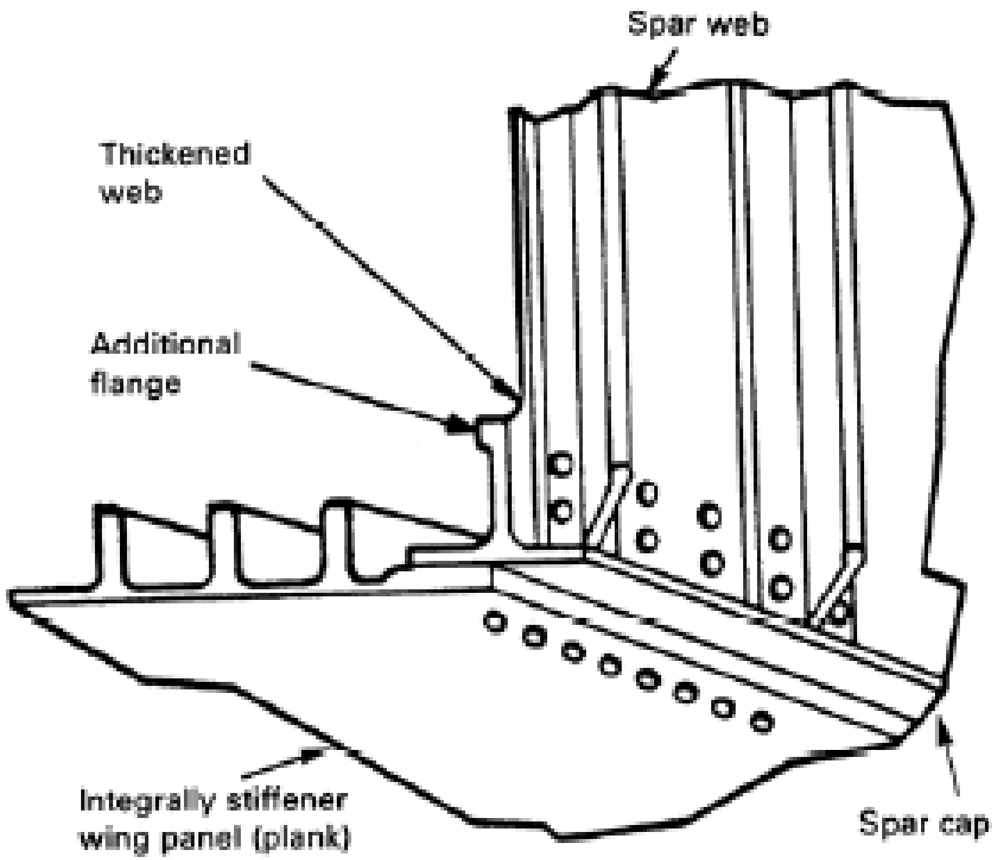


Fig. 8.4.16 Fail-safe spar shear web design.

7. Spars

➢ **Crack stoppers**

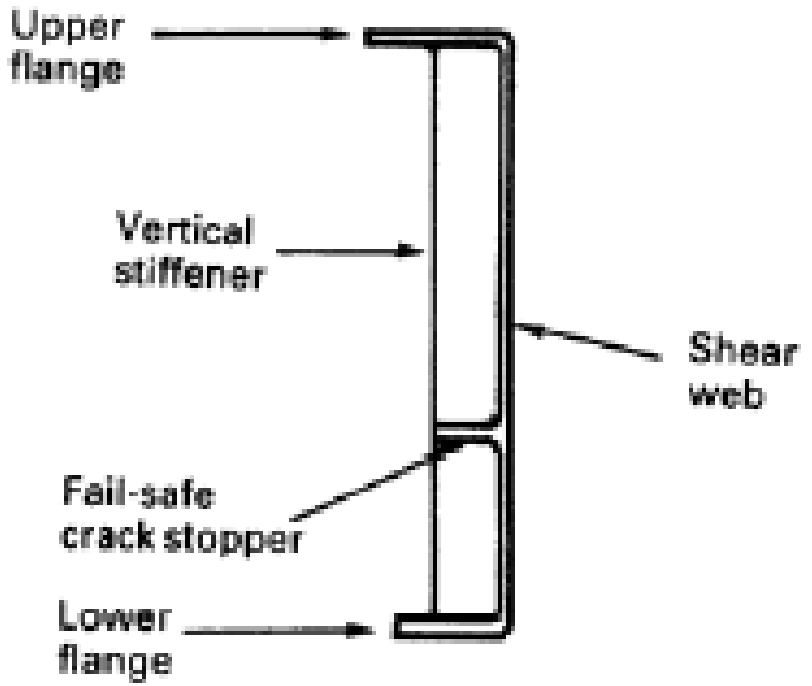


Fig. 8.4.17 Integrally machined A310 front and rear spars.

8. Ribs and Bulkheads

- **Ribs**

  - Ribs are used to hold the cover panel to contour shape and also to limit the length of skin-stringer or integrally stiffened panels to an efficient column compressive strength.
  - The rib also acts as a transfer or distribution of loads. The applied loads may be only distributed surface air and/or fuel loads which require relatively light internal ribs to carry through or transfer these loads to main spar structures.

8. Ribs and Bulkheads

➢ **Ribs**

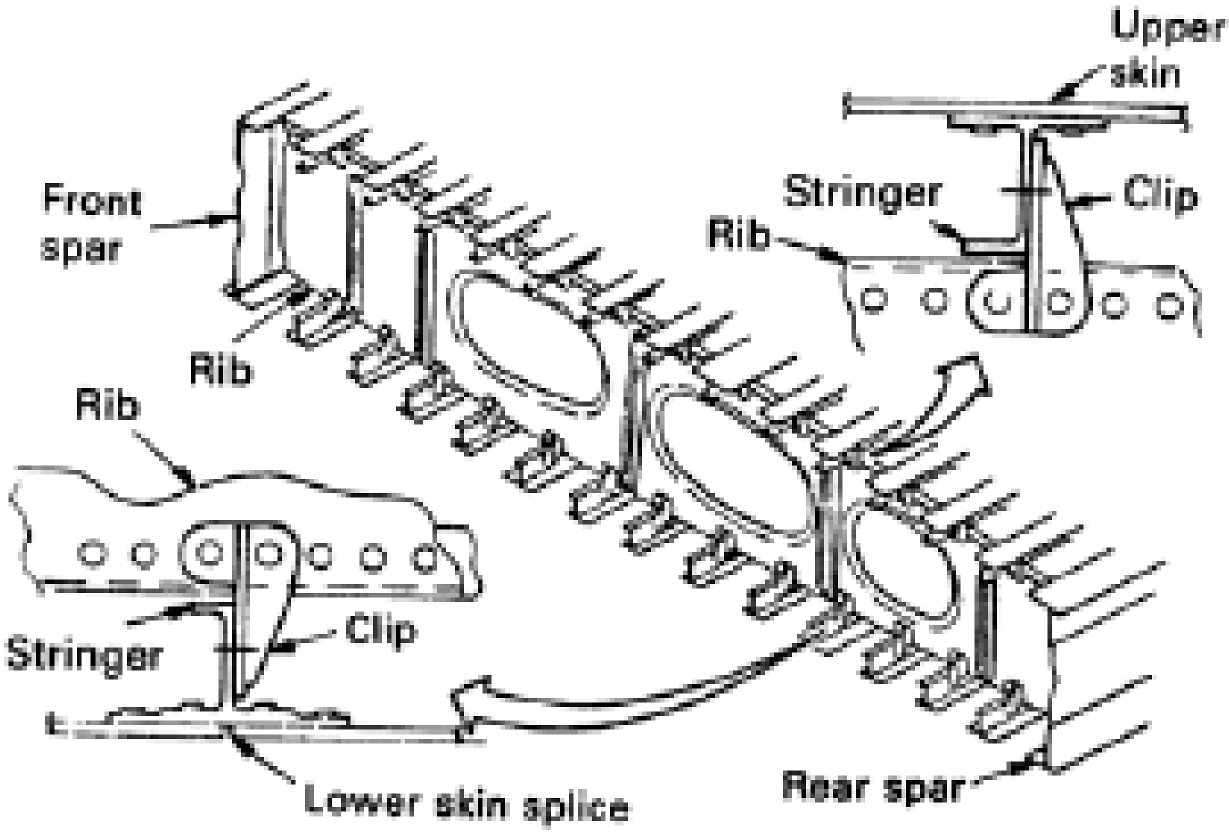


Fig. 8.5.2 Typical rib construction.

8. Ribs and Bulkheads

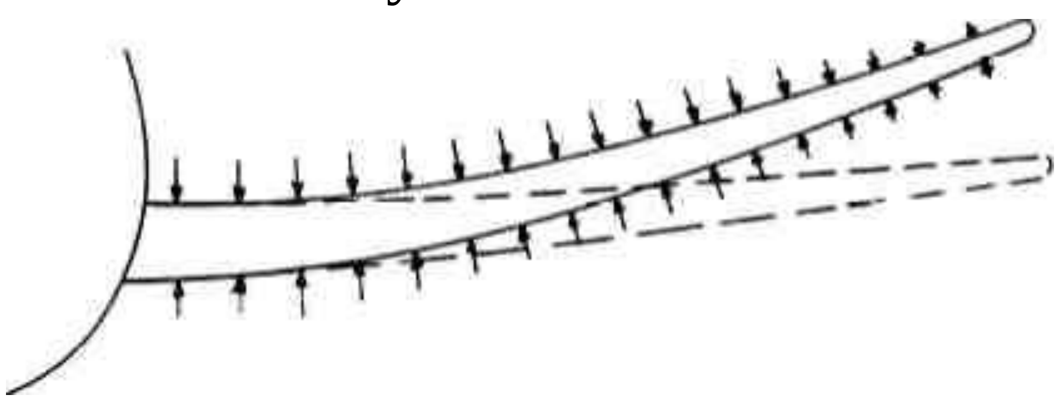
- **Ribs**

  - A typical wing rib is composed of caps, stiffeners and webs.
  - Lightening holes in the web are large enough for a man to crawl through and provide access from bay to bay.
  - Forged clips are used for attachment of stringers to ribs in lieu of bolting to stringer and rib cap flanges.
  - Rib bulkheads are also provided for such purposes as flap, aileron, pylon and landing gear support, tank ends and redistribution of loads at the sweep and dihedral break.

8. Ribs and Bulkheads

➢ Function of wing rib

- Wing ribs is used to carry internal loads and crushing loads.
- Ribs must effect a redistribution of shear flows in a wing where concentrated loads are applied or where there is a change in cross section such as cutouts, dihedral change or taper change, etc.
- The analysis of rib is usually similar to that of a simple beam.



8. Ribs and Bulkheads

➢ Function of wing rib

- **The carry the following loads:**
- The primary loads - acting on a rib are the external air loads and the transfer of them to the spars.
- Inertia loads - fuel, structure, equipment, external stores (missiles, rockets, etc.).
- Crushing loads due to flexure bending - when a wing box is subjected to bending loads, the bending of the box as a whole tends to produce inward acting loads on the wing ribs. Since the inward acting loads are oppositely directed on the tension and compression side they tend to compress the ribs.

8. Ribs and Bulkheads

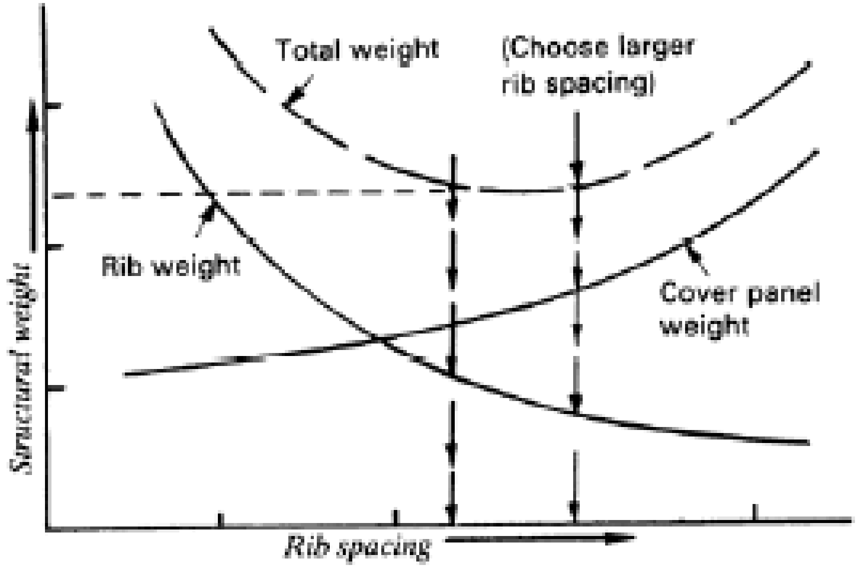
➢ Function of wing rib

- Redistributes concentrated loads - such as nacelle and landing gear loads to wing spars and cover panels.
- Supports members - such as skin-stringer panels in compression and shear.
- Diagonal tension loads from skin - when the wing skin wrinkles in a diagonal tension field the ribs act as compression members.

8. Ribs and Bulkheads

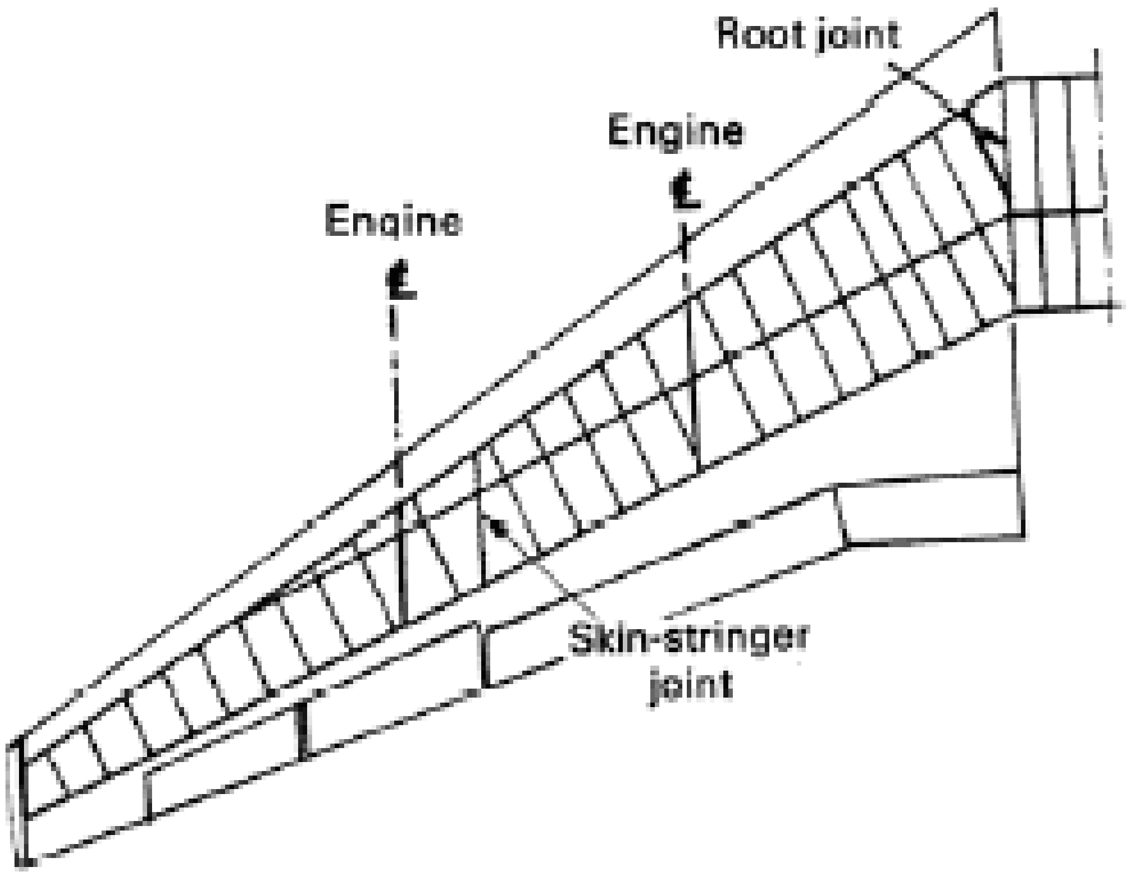
➢ Rib spacing

- ➢ Since the weight of the ribs is a significant amount of the total box structure, it is important to include the ribs in the overall optimization consideration of the structure.
- ➢ It is advantageous to select a larger rib spacing; for equal structural weight it leads to cost savings and less fatigue hazards.



8. Ribs and Bulkheads

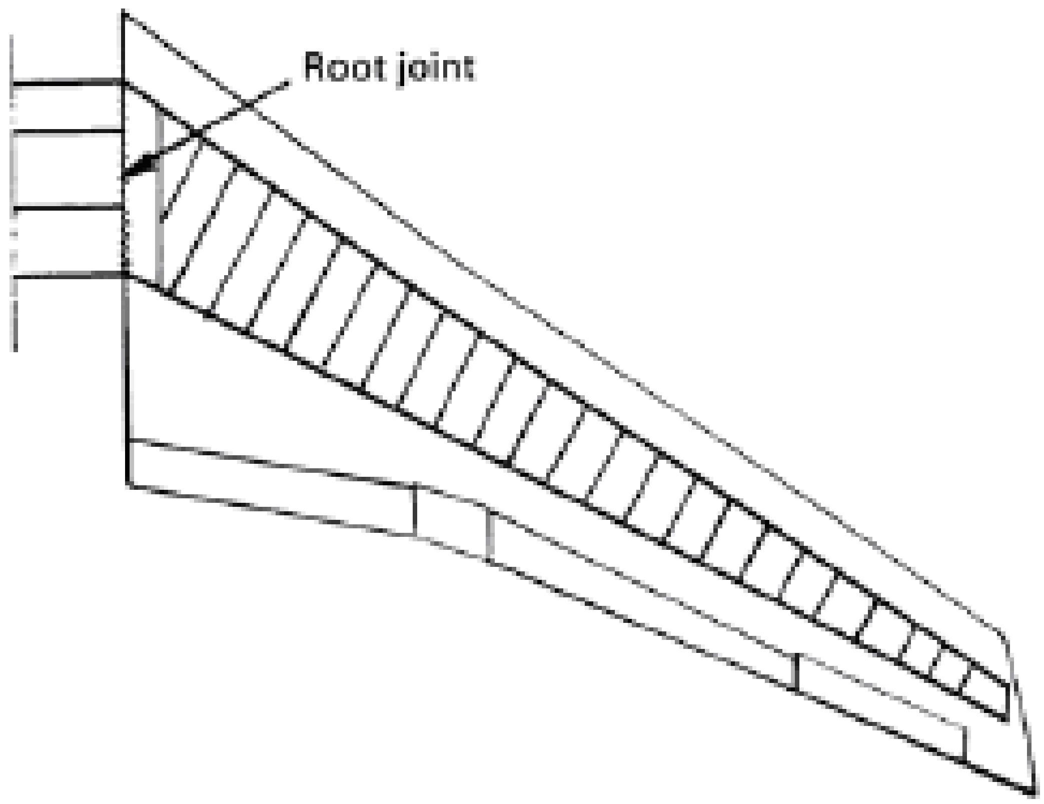
- **Rib alignment**



(a)DC-8

8. Ribs and Bulkheads

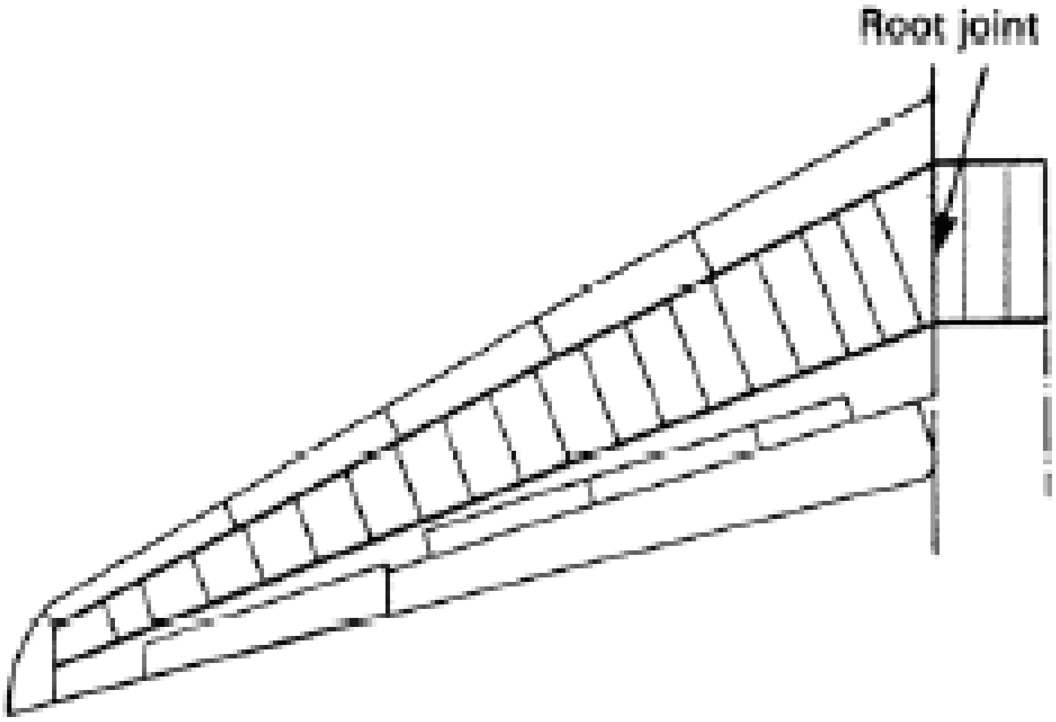
- **Rib alignment**



(c)B727

8. Ribs and Bulkheads

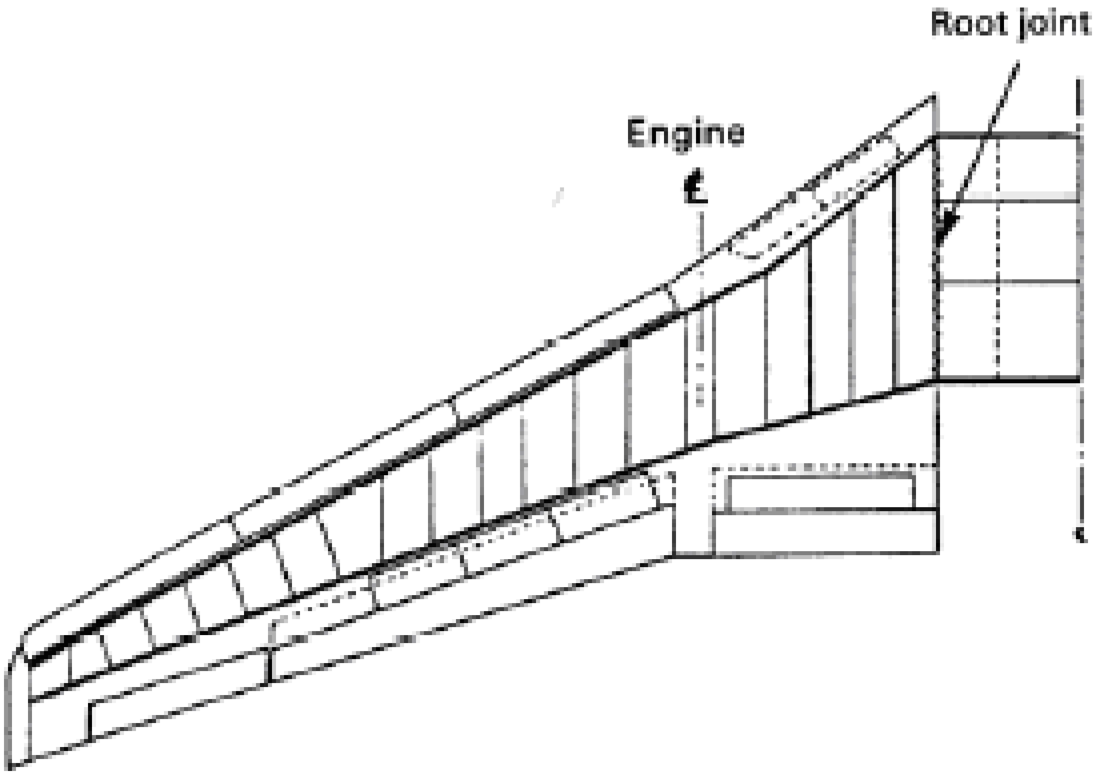
➢ **Rib alignment**



(d)DC-9

8. Ribs and Bulkheads

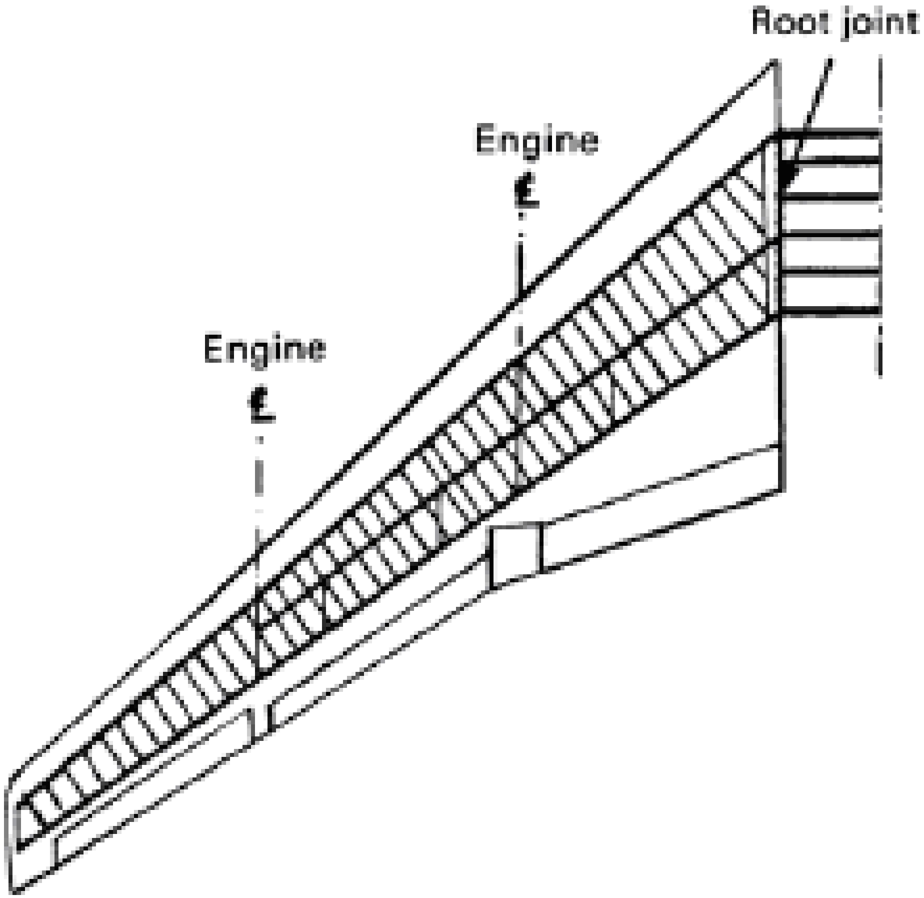
- **Rib alignment**



(e)B737

8. Ribs and Bulkheads

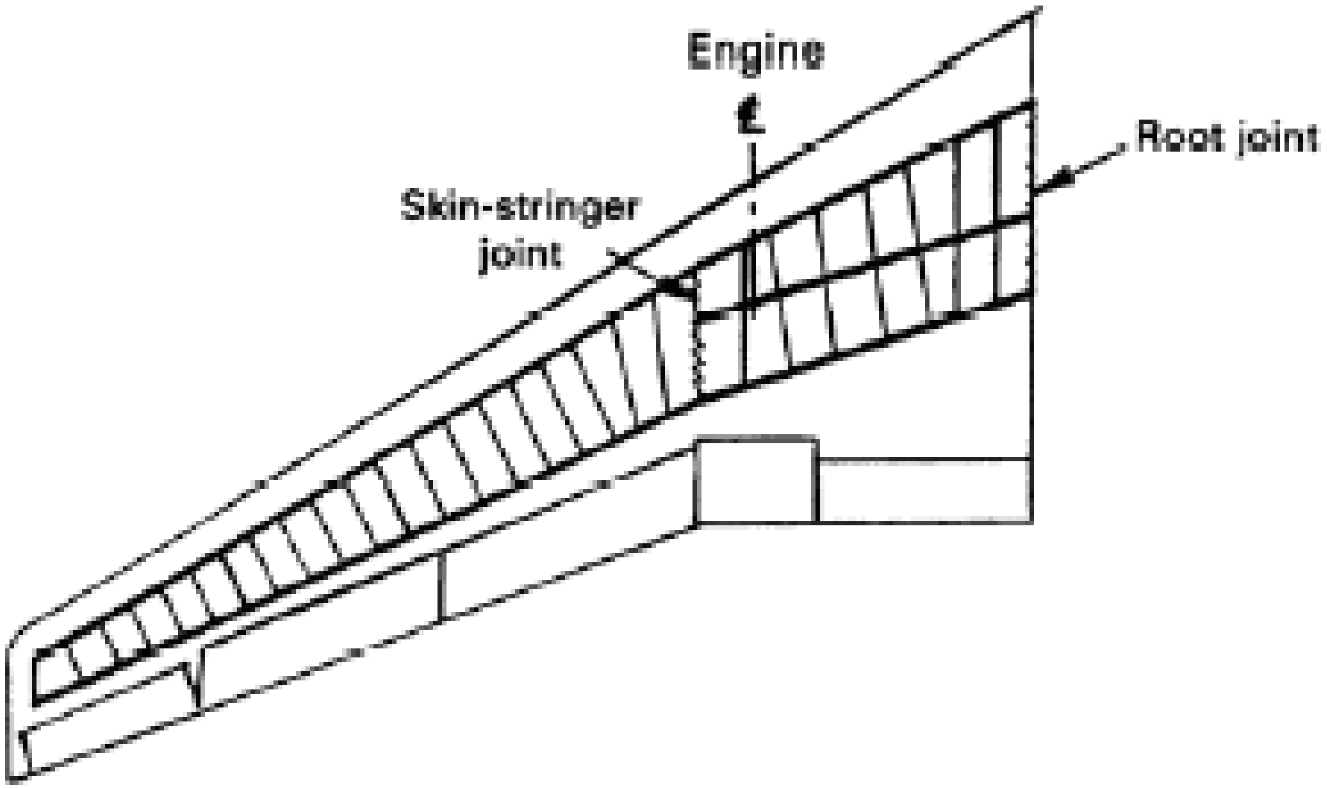
- **Rib alignment**



(f)B747

8. Ribs and Bulkheads

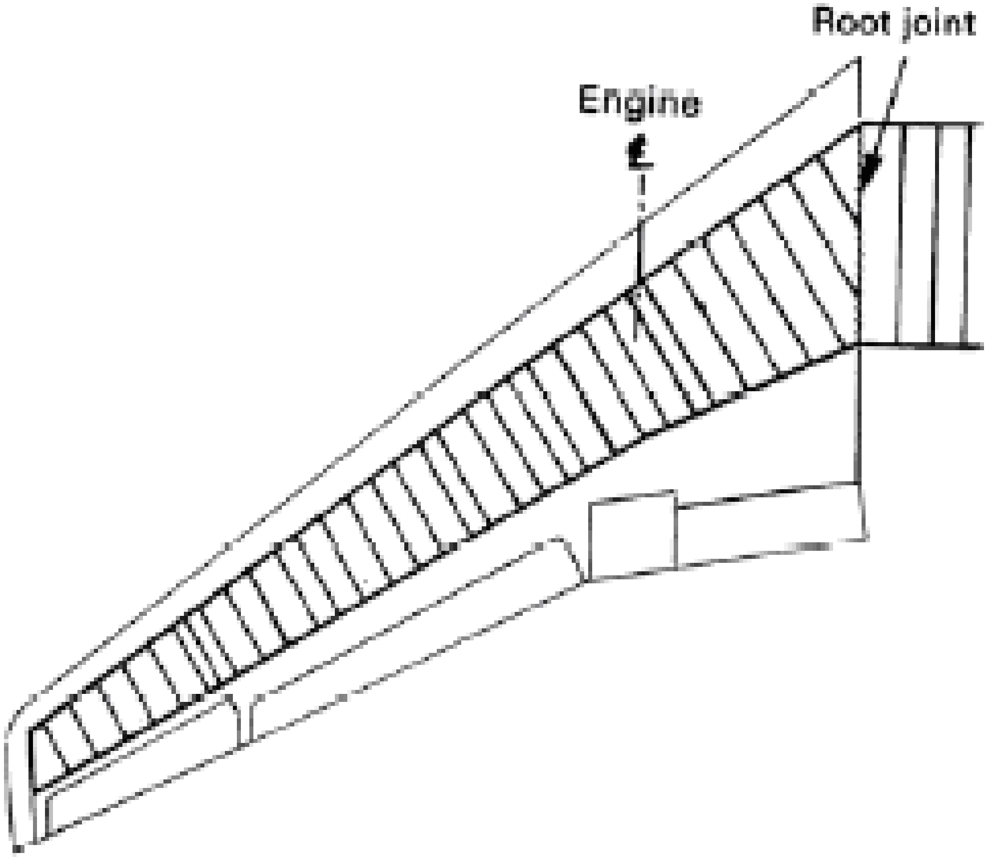
- **Rib alignment**



(g)A300

8. Ribs and Bulkheads

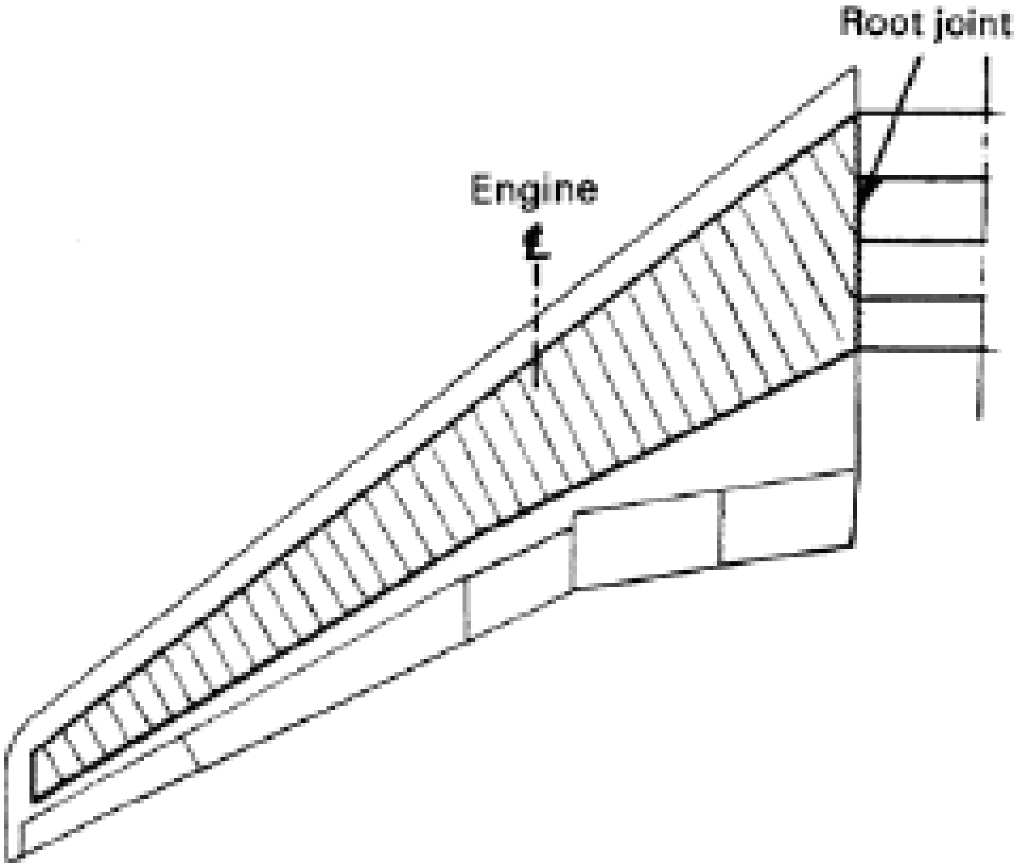
- **Rib alignment**



(h)DC-10

8. Ribs and Bulkheads

- **Rib alignment**



(i)L-1011

8. Ribs and Bulkheads

➢Wing Root Joints

- Wing joint design is one of the most critical areas in aircraft structures, especially for fatigue consideration of long life structure.
- The best fatigue design, of course, is one with no joints or splices. This is accomplished on the modern transports, which have no joints across the load path except at the side of the fuselage.
- Wing sweep plus dihedral and manufacturing joint requirements make the joint at the side of fuselage necessary.

8. Ribs and Bulkheads

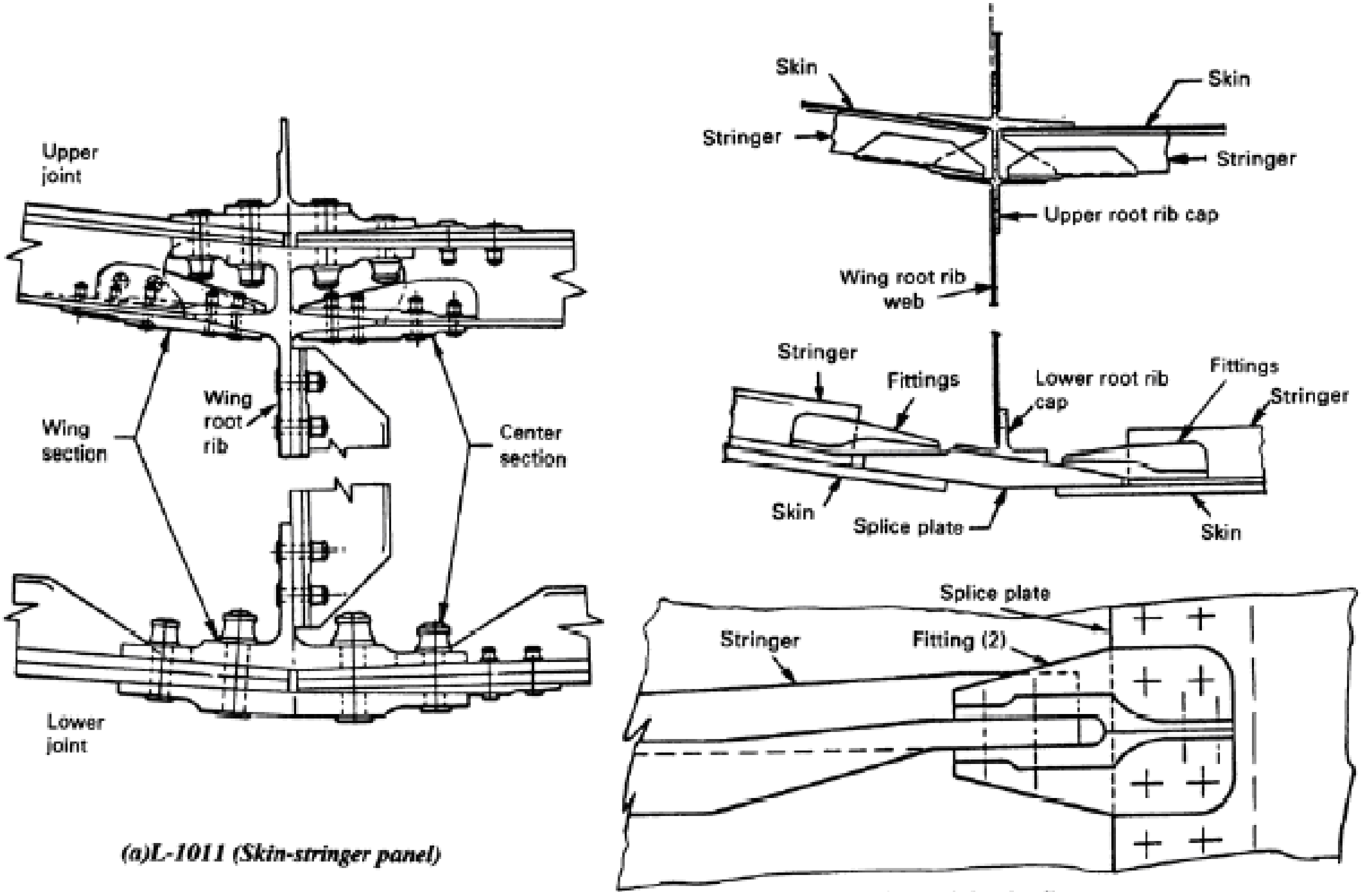
➢Wing Root Joints

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

Fig. 8.6.1 Wing root fixed joints.

8. Ribs and Bulkheads

➢Wing Root Joints

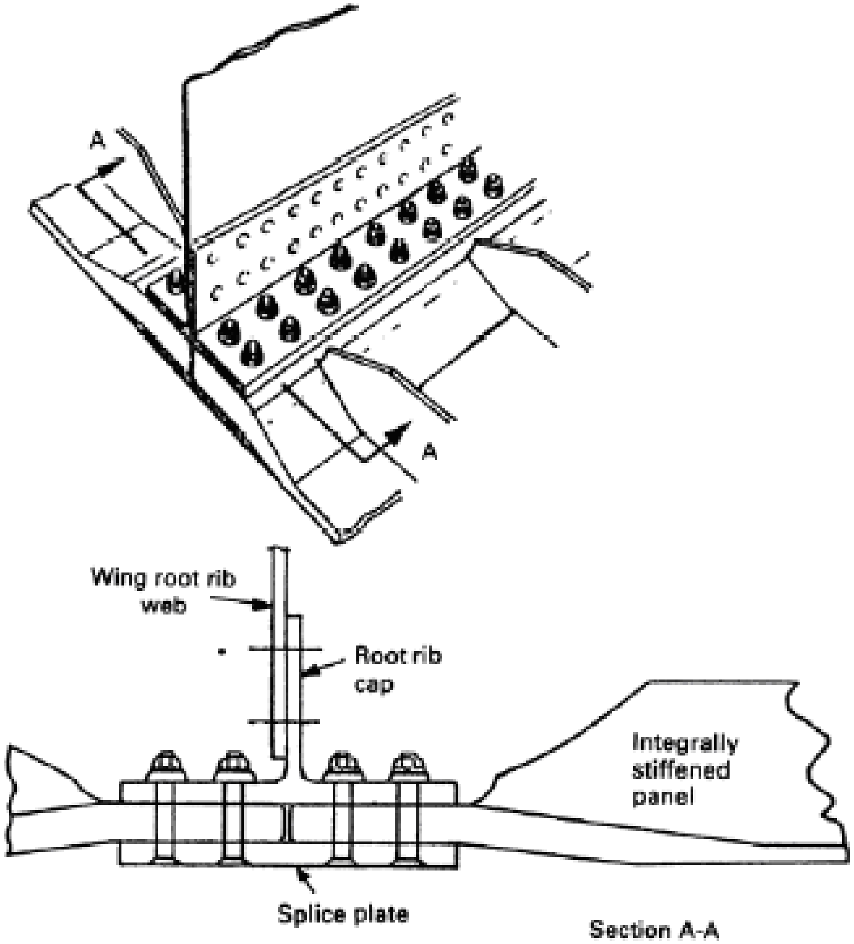


(a)L-1011 (Skin-stringer panel)

(b)B727 (Skin-stringer panel)

8. Ribs and Bulkheads

➢Wing Root Joints



(c)C-141 (Integrally stiffened panel)

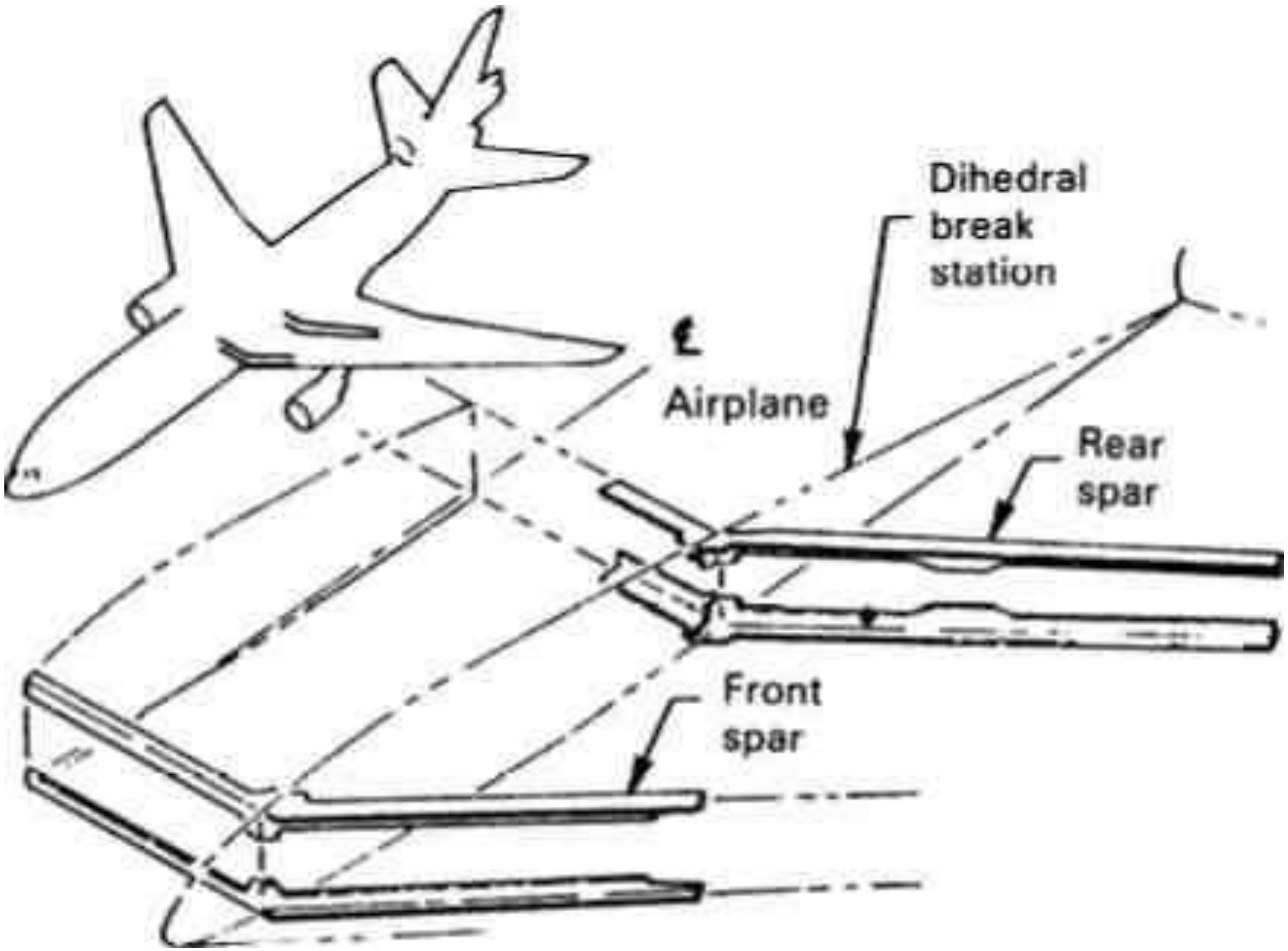
8. Ribs and Bulkheads

➢ Wing Root Joints

- One of the peculiar designs is in the area of the sweepback and dihedral break of the transport wing box.
- The front spar forged cap extends from the airplane centerline to outboard of the fuselage; the rear spar forged cap extends from the airplane centerline to the aerodynamic break where there is a slight change in sweep angle of the rear spar.
- Continuous spar caps and webs across the dihedral and sweep break are a major factor in achieving good fatigue life.

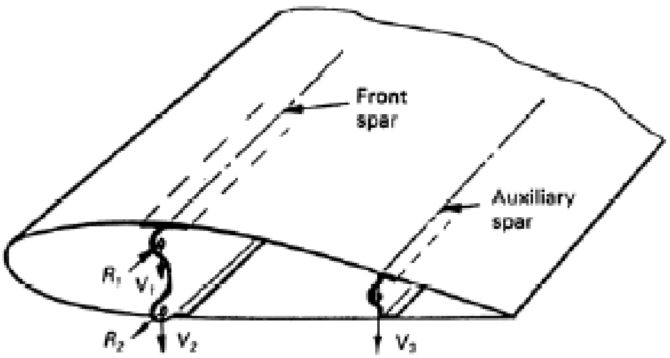
8. Ribs and Bulkheads

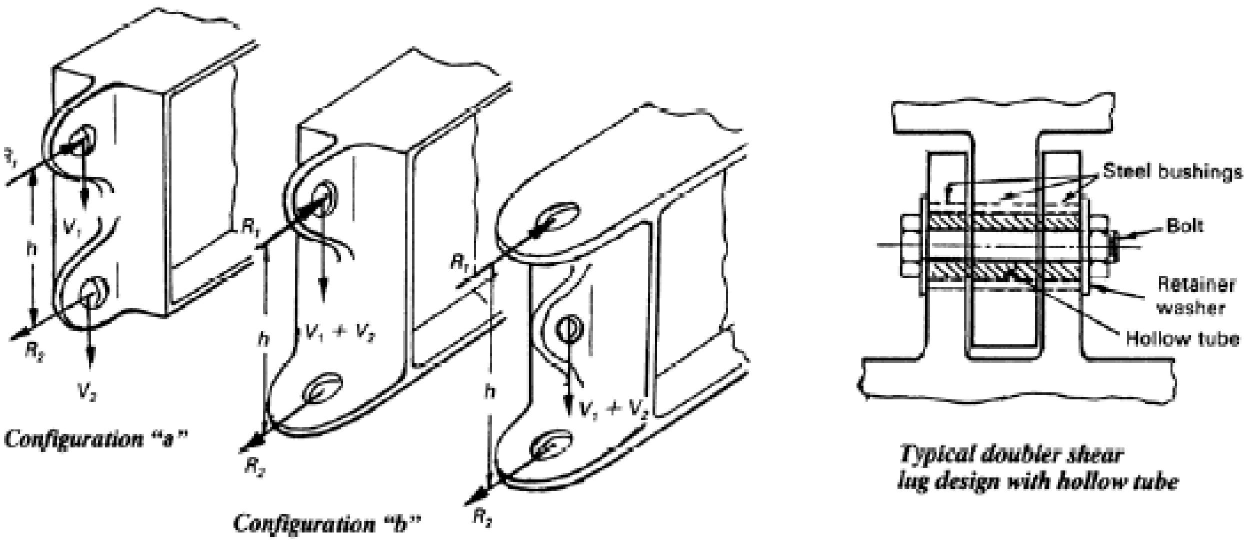
➢ **Wing Root Joints**



8. Ribs and Bulkheads

➢Wing Root Joints





Configuration "a"

Configuration "b"

Configuration "c"

Typical doubler shear lug design with hollow tube

8. Ribs and Bulkheads

➢Wing Root Joints

Configuration		Advantages	Disadvantages
"a"	Upper and lower lugs take axial load and vertical load shared by these two lugs	Stronger fittings Less machining cost	Smallest moment arm (h) and produce the highest lug axial loads Difficult to install due to its close tolerance holes requirement Vertical load distribution is difficult to predict
"b"	Upper and lower lugs take axial load and vertical load taken by upper lug only	Easy to install Load distribution is clear Longer moment arm (h) and then produce moderate lug load	Not enough space to install lower lug, if beam depth is too shallow
"c"	Upper and lower lugs take axial load and vertical load taken by center lug only	Easy to install Load distribution is clear Longest moment arm (h) and then produce small lug load	Heavy weight because of the third lug Highest machining cost Not enough space for the center lug, if beam depth is too shallow
Note: Always use double shear design with steel bushings to ensure fatigue life.			

Wing lug design and comparison

9. Fuel Tanks

➢ Fuel Tank Design

- Fuel tanks for aircraft may be constructed of aluminum alloy, fuel-resistant materials, or stainless steel.
- Tanks that are an integral part of the wing are of the same material as the wing and have the seams sealed with fuel proof sealing compound.
- In the earlier day, many aircraft used synthetic-rubber bladders for fuel cells in the wing box and even today many fighters still use bladders in fuselage fuel tanks for combat bullet-proof purposes

9. Fuel Tanks

➢ Fuel Tank Design

- Metal fuel tanks generally are required to withstand an internal test pressure of 3.5 psi without failure or leakage.
- Furthermore, they must withstand without failure any vibration, inertia loads, and fluid and structural loads to which they may be subjected during operation of the aircraft.
- Fuel tanks located within the fuselage of a transport aircraft must be capable of withstanding rupture and retaining the fuel underneath the inertia forces that may be encountered in an emergency landing.

9. Fuel Tanks

➢ Transport Fuel Tank Design

- The definition of transport wing box is a thicker airfoil with bigger wing planform which the interior can be accessible through access holes for tank sealing and repairing.
- Doublers, or other flat metal strengthening members, are to be so designed that sealing material can be applied where these members intersect or parallel other structure.
- Flange spar caps, ribs and bulkheads, should be kept away from the tank cavity. The tank cavity must be accessible for the replacement of all rivets or other attachments. It should be possible to make any spot repair in the tank within one hour.

9. Fuel Tanks

➢ Transport Fuel Tank Design

- All tank walls should be accessible on both the interior and exterior surfaces so that leakage detection and repair can be readily accomplished.
- Fewer parts mean fewer seams to leak, fewer fasteners penetrating the seal plane, fewer fillets to apply, and less chance of channeling in case of a leak.
- Avoid abrupt section changes and sharp corners in the vicinity of a seal.
- Tank wall intersections of less than 90°increase the difficulty of cleaning, sealing, and repairing seals and therefore decrease the seal plane reliability

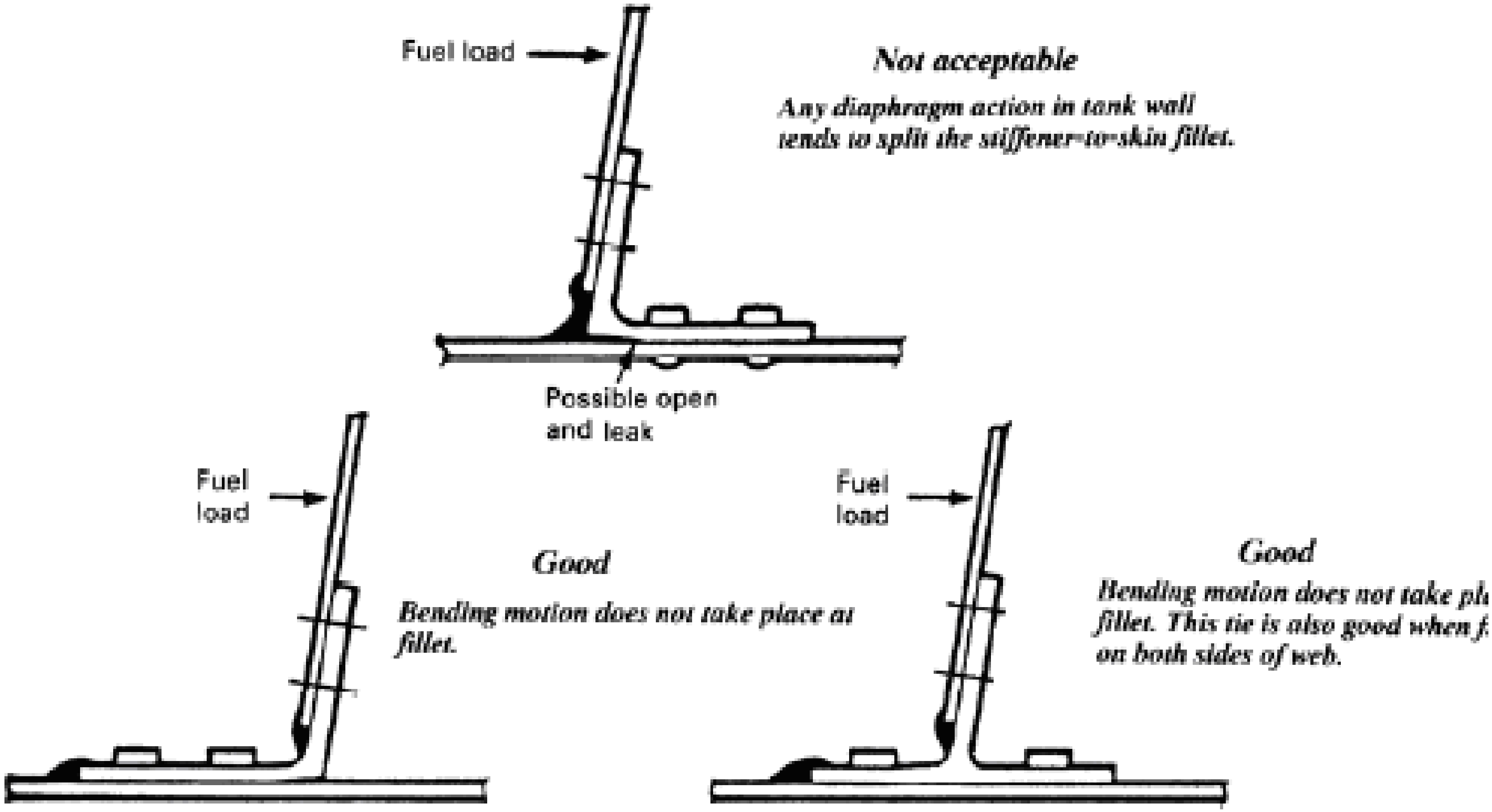
9. Fuel Tanks

➢ Transport Fuel Tank Design

- ➢ It is of utmost importance to design integral fuel tank subassemblies (that is , skin panels, spars, tank end ribs) so that they may be as structurally complete on the seal plane as possible prior to major assembly.
- ➢ This will generally allow the use of fasteners or bolts to obtain the primary seal gaps, and will greatly facilitate sealing operations.
- ➢ All portions of tank should be readily accessible by convenient access doors. Having to crawl through one compartment to reach another may be considered.
- ➢ Tubing and equipment should be kept away from tank walls to increase accessibility to scaled walls.

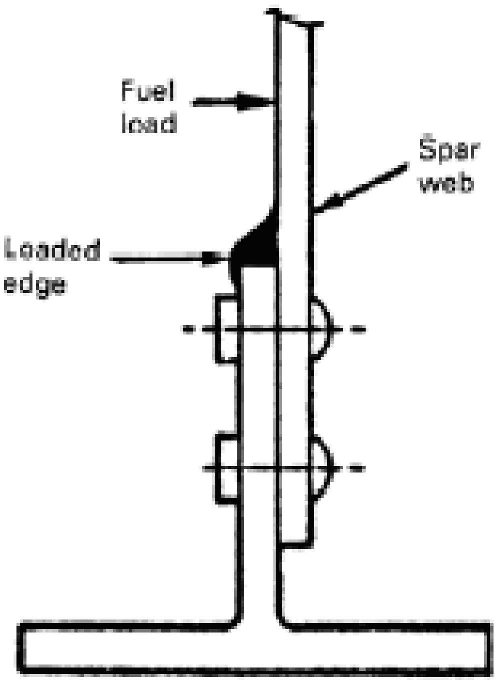
9. Fuel Tanks

- **Transport Fuel Tank Design**

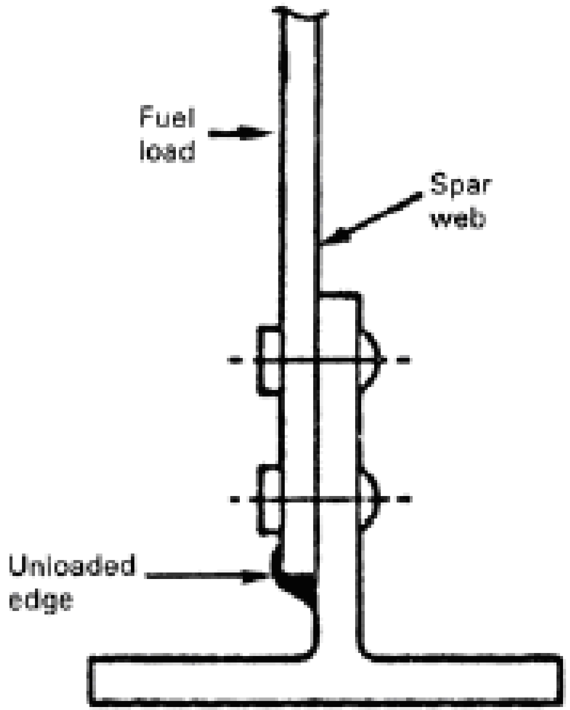


9. Fuel Tanks

- **Transport Fuel Tank Design**



Poor design



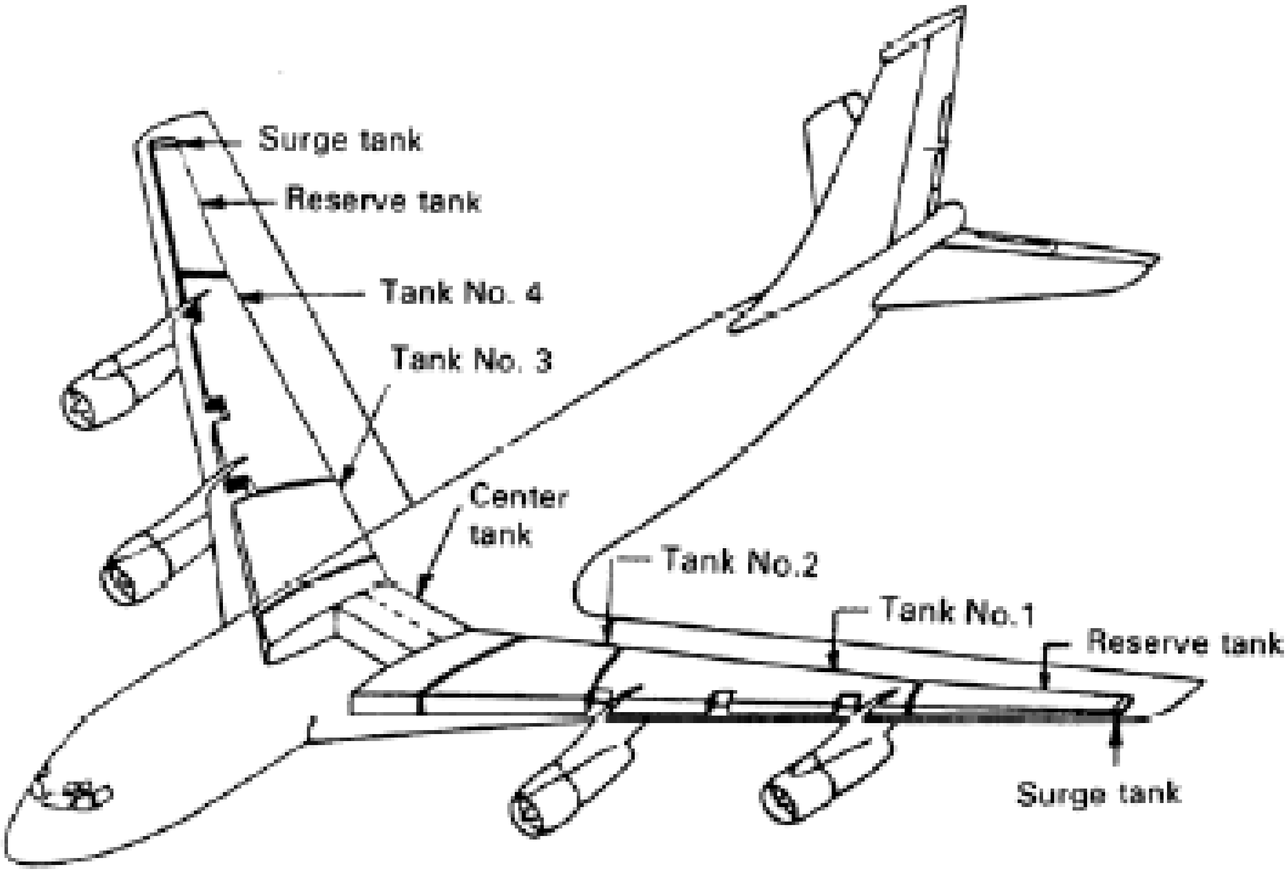
Good design

9. Fuel Tanks

- **Fuel Management**
  - Fuel management is an important consideration in the structural design of an aircraft.
  - The c.g. fuel management is important with internal fuel tanks.
  - The weight of the fuel supply acts down at its c.g. This creates a counterclockwise bending moment at the root. These moments are subtracted to obtain the final root bending moment.

9. Fuel Tanks

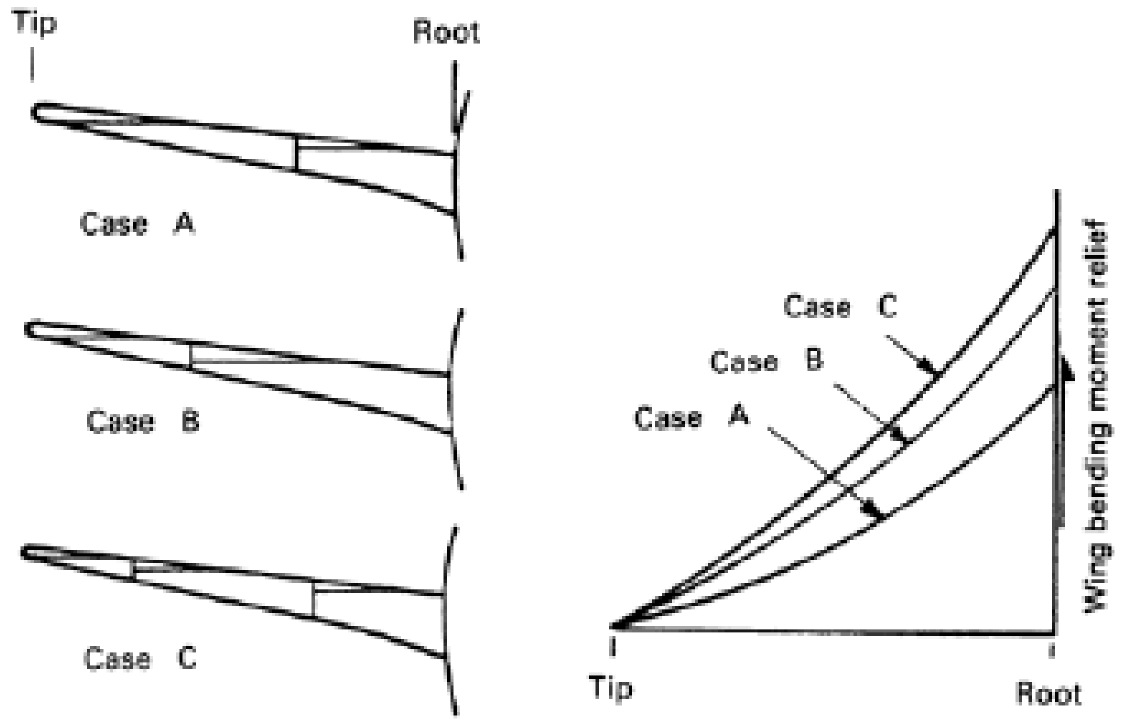
➢ **Fuel Management**



(a)Fuel tank installation

9. Fuel Tanks

- **Fuel Management**



(b)Fuel tank geometry vs. wing relief

Fig. 8.8.4 Transport fuel tank geometry vs. wing load relief.