AIRFRAME STRUCTURAL DESIGN

COURSE CODE:A72118

IV B. Tech I semester
Department of Aeronautical Engineering

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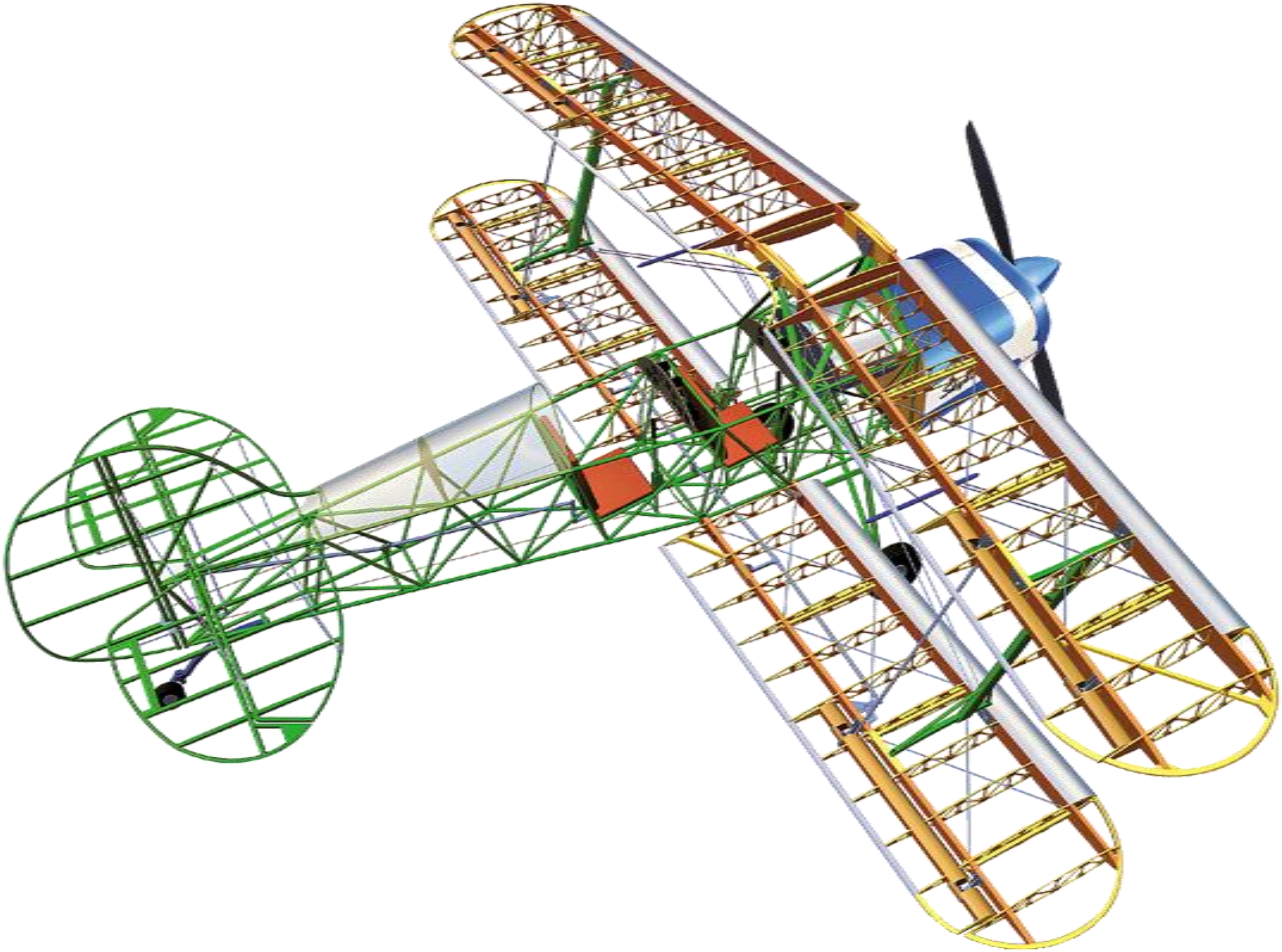
UNIT-I

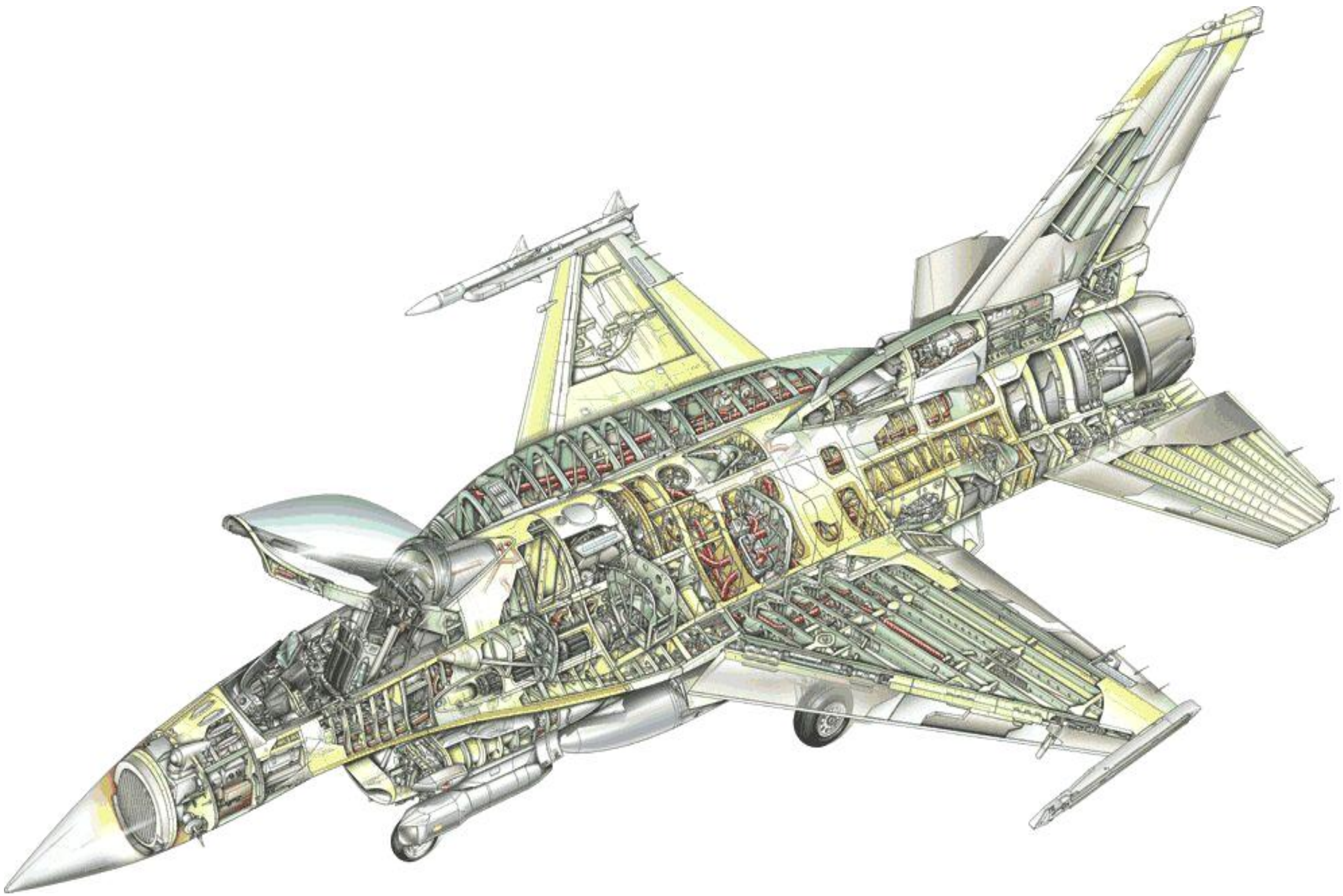
INTRODUCTION AIRWORTHINESS REQUIREMENTS

BASIC AIRCRAFT STRUCTURE



Outline of Presentation

- Aircraft Components
- Material use in Airframe Construction
- Example of Material use in Airframe Construction
- Fuselage Structure
    - Truss Type
        - Pratt Truss
        - Warren Truss
    - Monocoque
    - Semi-Monocoque
- Basic Structure Member Terms
- Wing Structure
- Empennage Structure
- Power Plant
    - Wing Pod Mount
    - Fuselage Mount
- Landing Gear Structure



Aircraft Components

A. Fuselage

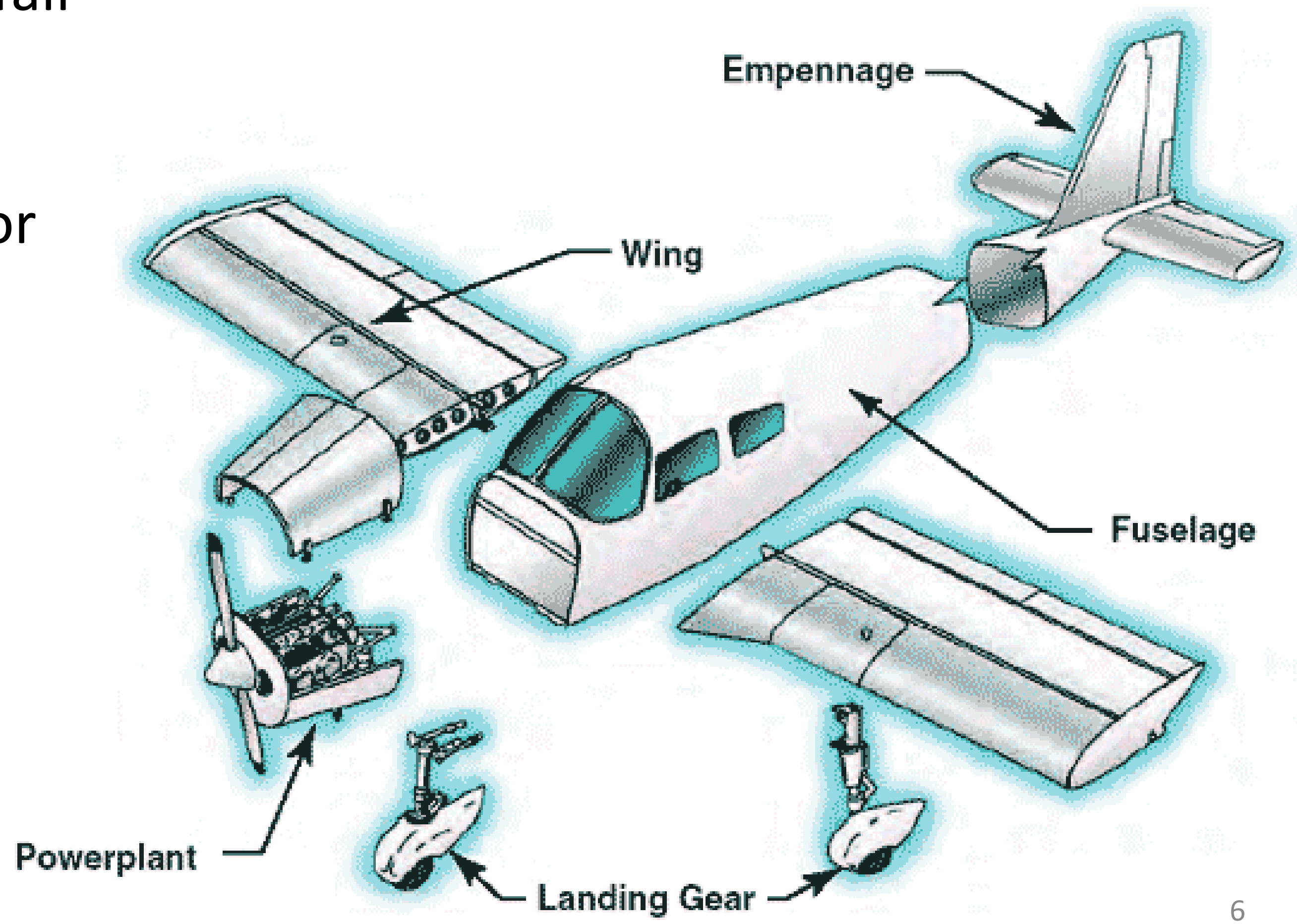
B. Wings

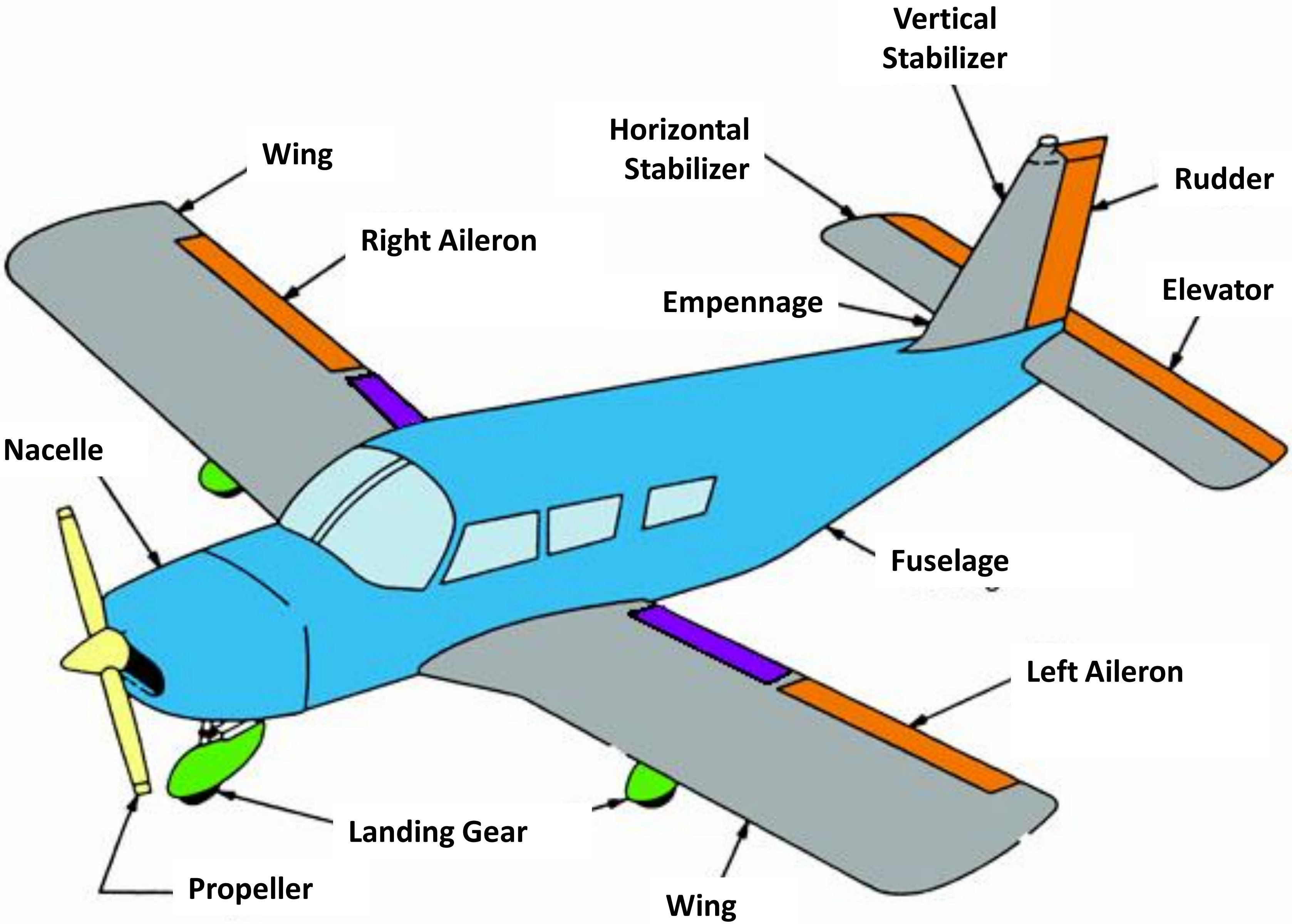
C. Empenage or Tail

D. Power Plant

E. Landing Gear or

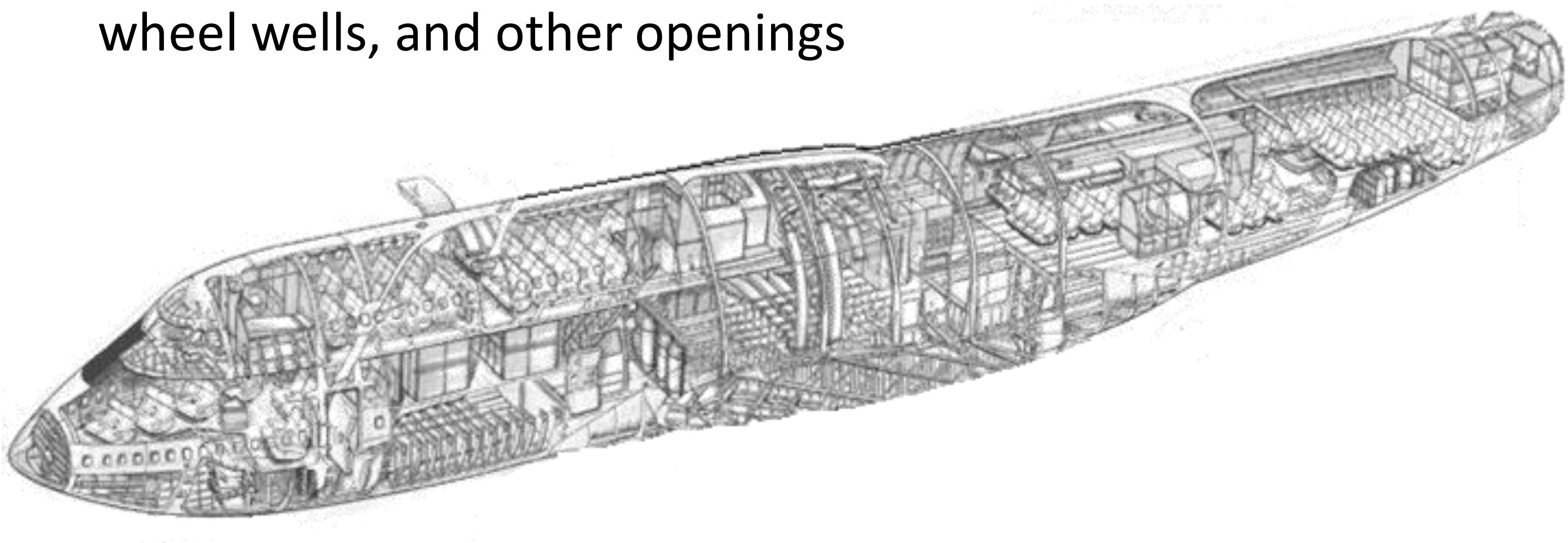
Undercarriage




Vertical Stabilizer
Horizontal Stabilizer
Wing
Rudder
Right Aileron
Empennage
Elevator
Nacelle
Fuselage
Left Aileron
Landing Gear
Propeller
Wing

Fuselage

- Main body of airplane
- Pilot & cargo compartments
- Generally constructed in two or more sections
- Carries accessories and other equipments
- Includes numerous access doors, inspection plates, landing wheel wells, and other openings

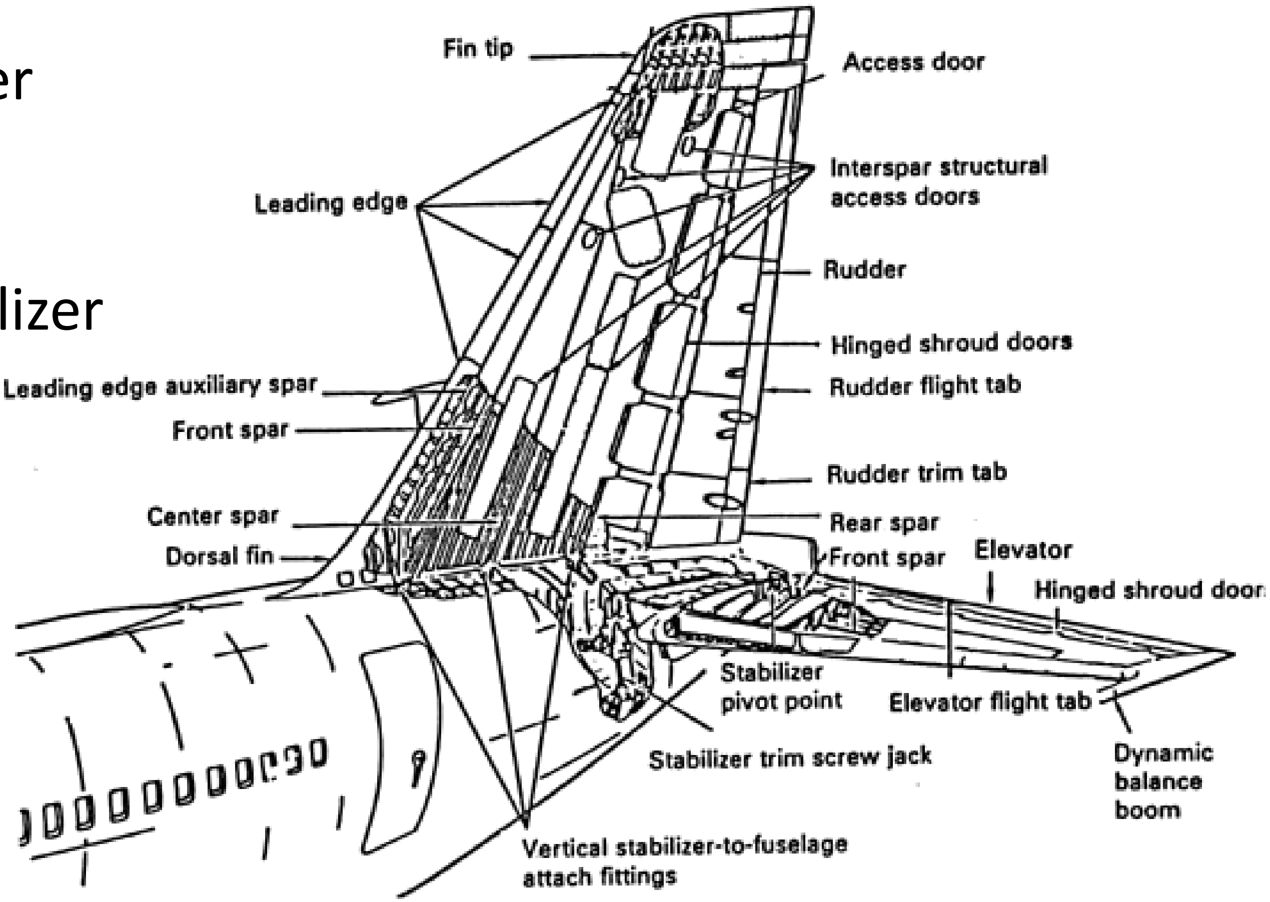


WING

- Airfoils attached to each side of the fuselage
- Main lifting surfaces
- Various design size and shape
- May be attached at the top, middle, or lower portion of the
- fuselage
- High-wing
- mid-wing
- low-wing
- The number of wings can also vary
- Monoplanes
- biplanes

Empennage

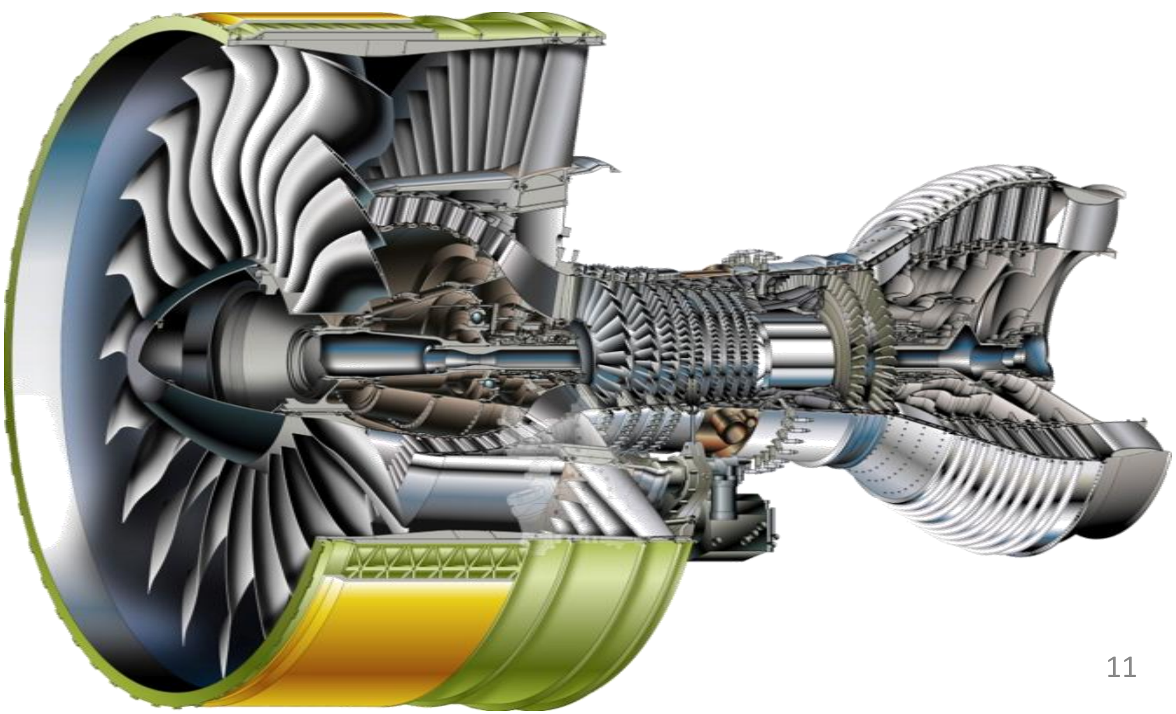
- Know as tail section
- Consist of
  - Vertical Stabilizer
  - Rudder
  - Horizontal Stabilizer
  - Elevators



(a) Convair 880

Power Plant

A unit or machine that converts chemical energy contains in the fuel to thrust force. Thrust force is essential for moving the airplane forward and producing lift force. With the piston engine, the propeller is used to convert torque at engine shaft to be thrust. With the jet engine, the jet engine output is the thrust force.



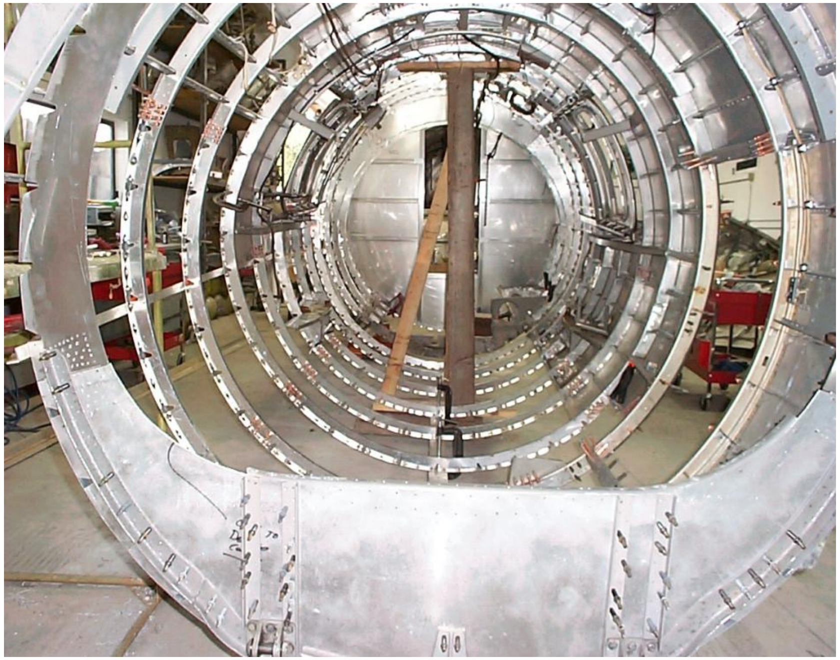
Landing Gear

- Located underneath of the fuselage with shock strut
- Fixed / Retractable
- Provides means of landing taxiing
- Tri- cycle –Conventional type
- Floating gear for seaplane /ski-equipped for ice surface landing etc..

Material use in Airframe Construction

Airframe Materials Properties

- High Strength to Weight ratio
- Light weight
- Corrosion Resistant
- Should be non flammable
- High quality



Example of Material use in Airframe Construction

- WOOD (Spruce)
- STEEL & ITS ALLOYS (Strong)
- ALUMINIUM & ITS ALLOY (Commonly use)
- TITANIUM ALLOYS (Heat Barriers)
- MAGNESIUM ALLOYS (3 times lighter than AL)
- PLASTICS & COMPOSITE MATERIAL

Fuselage Structure

BASIC STRUCTURE TYPES

- **TRUSS TYPE**

  - PRATT TRUSS

  - WARREN TRUSS

- **MONOCOQUE**

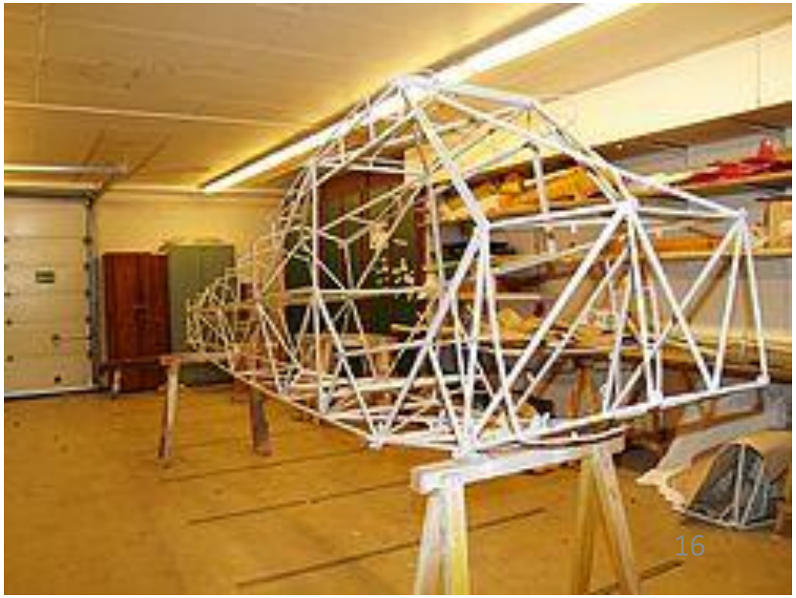
- **SEMI-MONOCOQUE**

TRUSS TYPE

Most early aircraft used this technique with wood and wire trusses and this type of structure is still in use in many lightweight aircraft using welded steel tube trusses. The truss type fuselage frame is assembled with members forming a rigid frame e.g. beams, bar, tube etc… Primary members of the truss are 4 longerons. There are two types of truss structure.

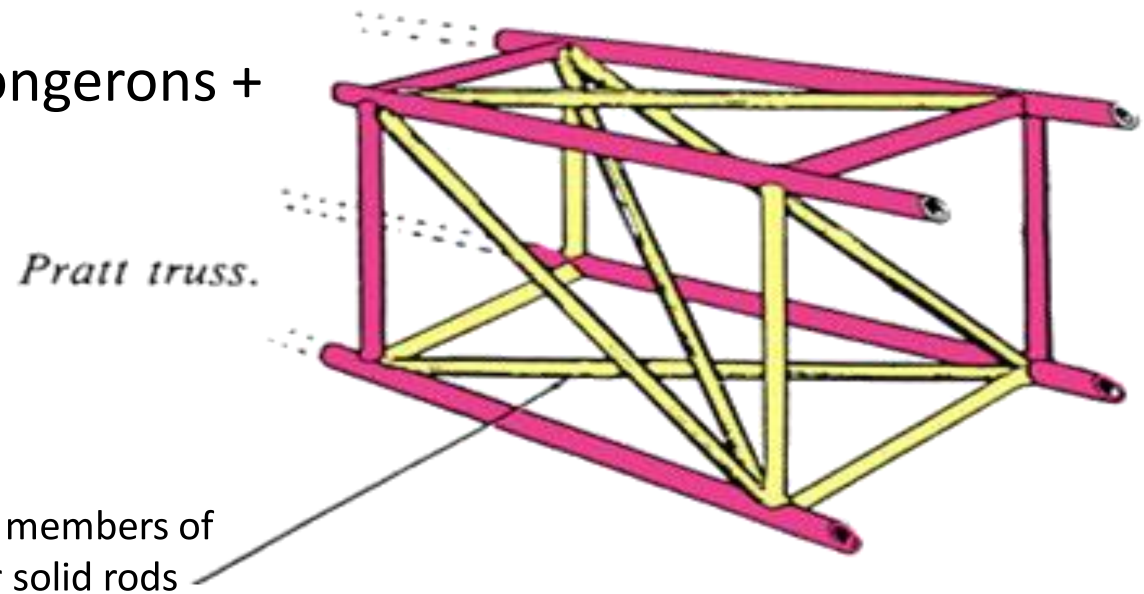
- PRATT TRUSS

- WARREN TRUSS



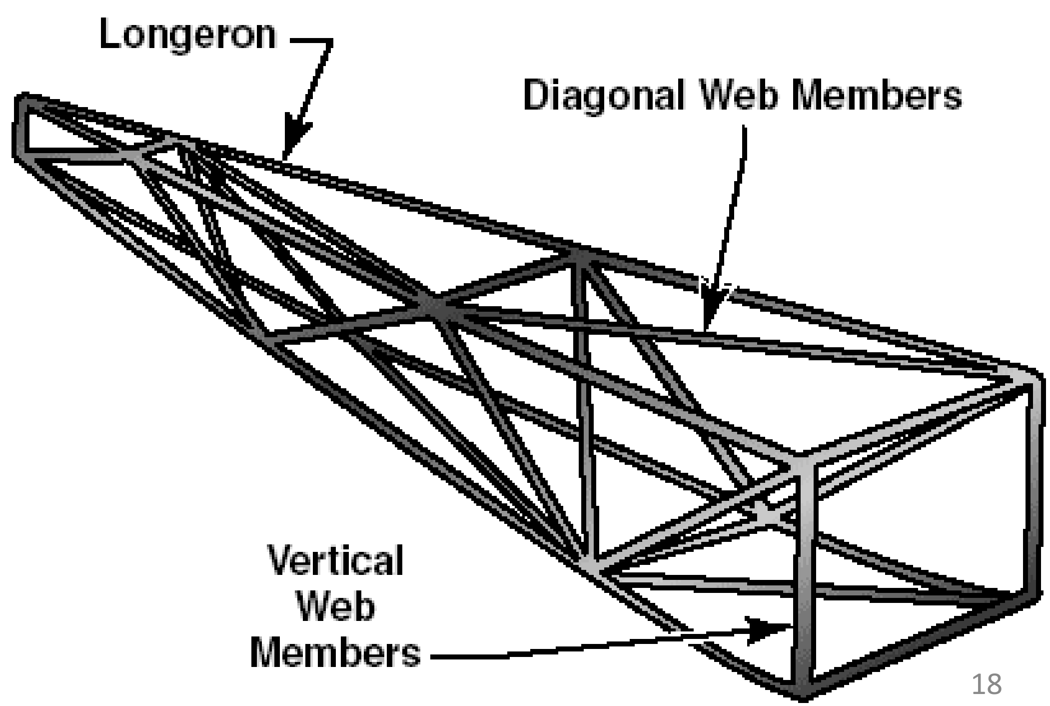
PRATT TRUSS

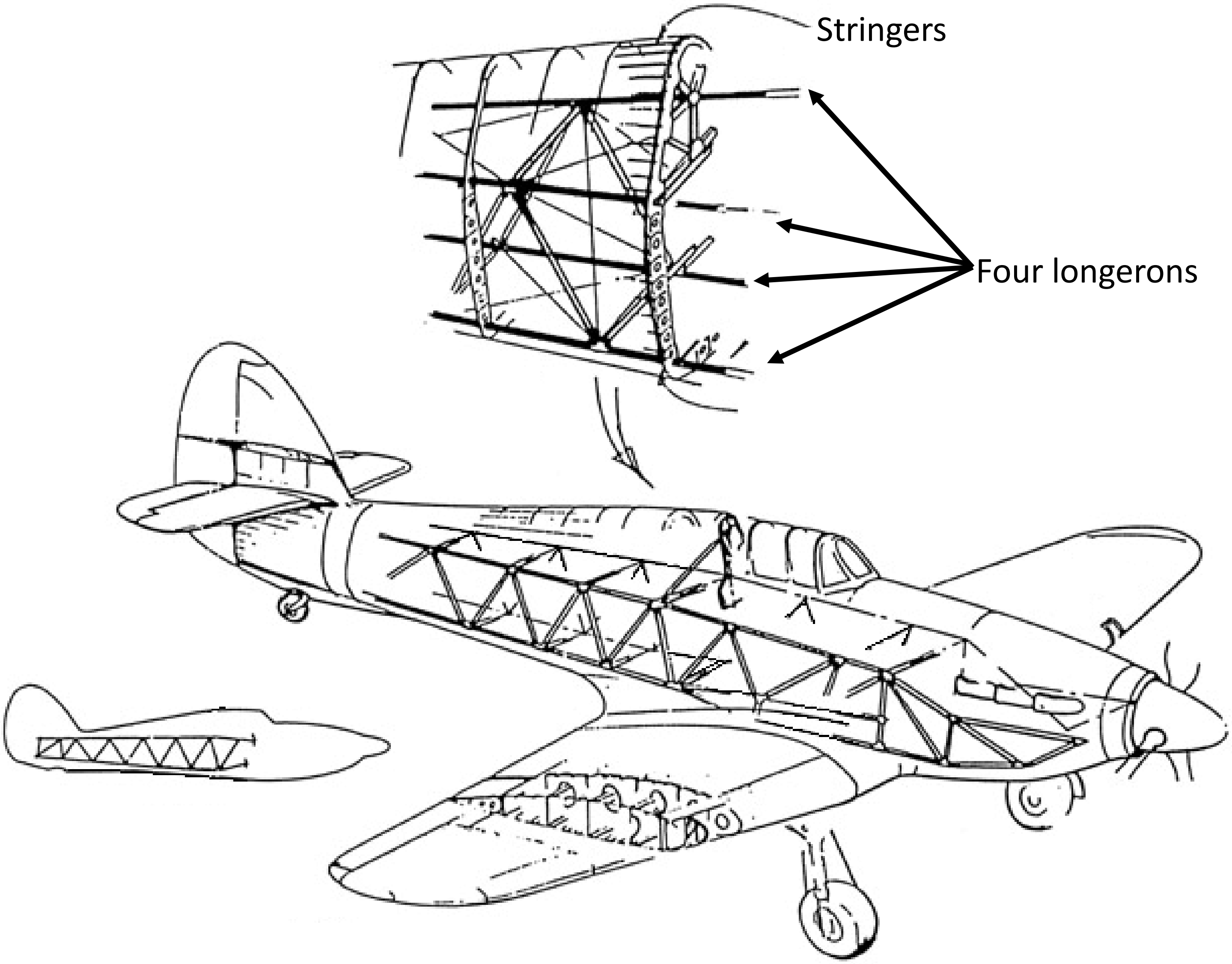
- Early days
- Wooden or metal structure
- Great weight
- Difficult to streamline
- Box with tubular longerons + vertical members



WARREN TRUSS

- Longerons + only Diagonal Members
- Force transfer to every others structure
- Capable to carry tension + compression
- Reduce amount of webs work
- More space , strength , rigidity
- Better streamline



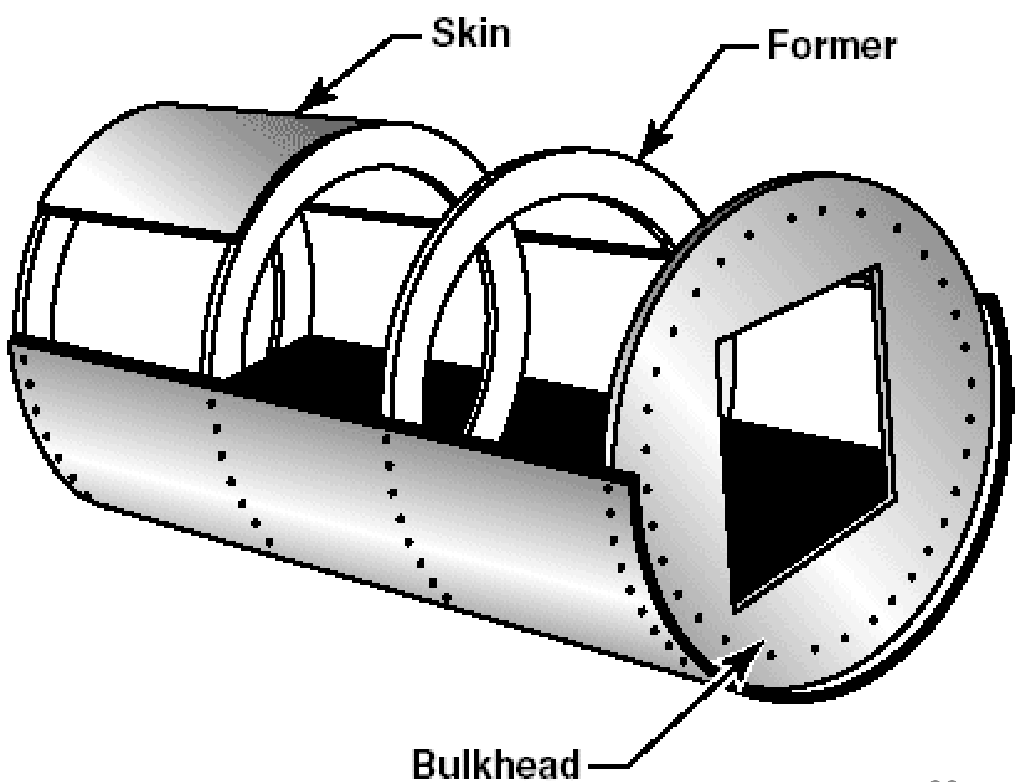


Warren Truss Structure of an airplane

MONOCOQUE

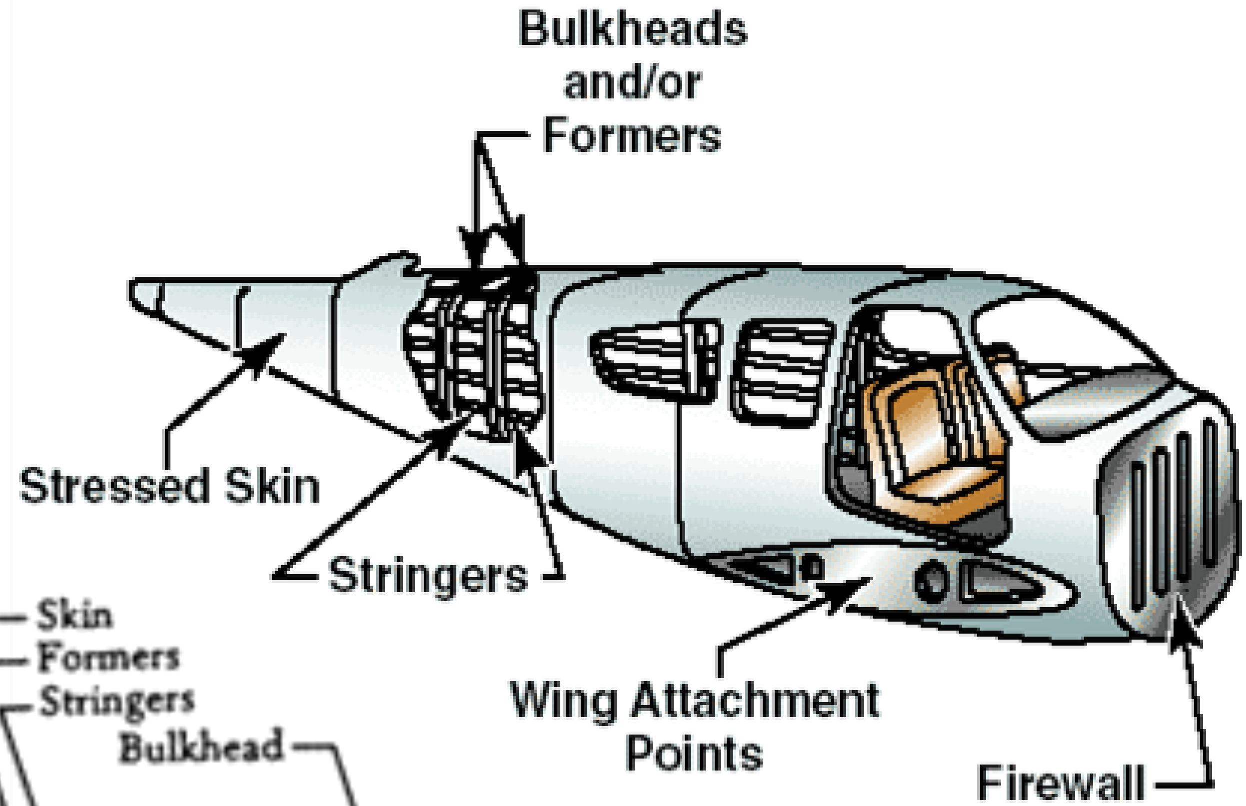
In this method, the exterior surface of the fuselage is also the primary structure. A typical early form of this was built using molded plywood.

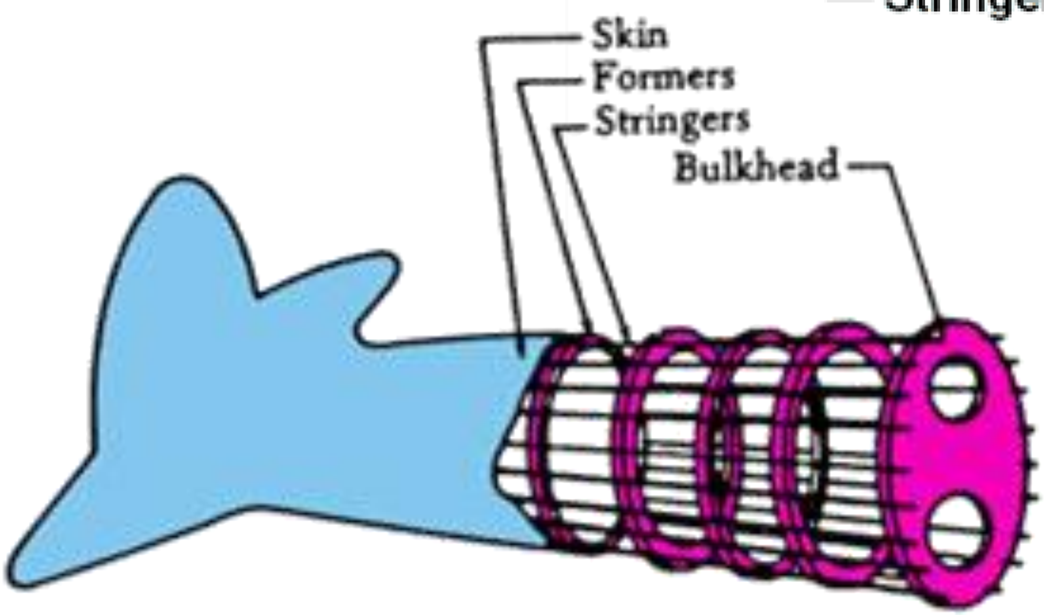
A later form of this structure uses fiberglass cloth impregnated with polyester or epoxy resin, instead of plywood, as the skin.



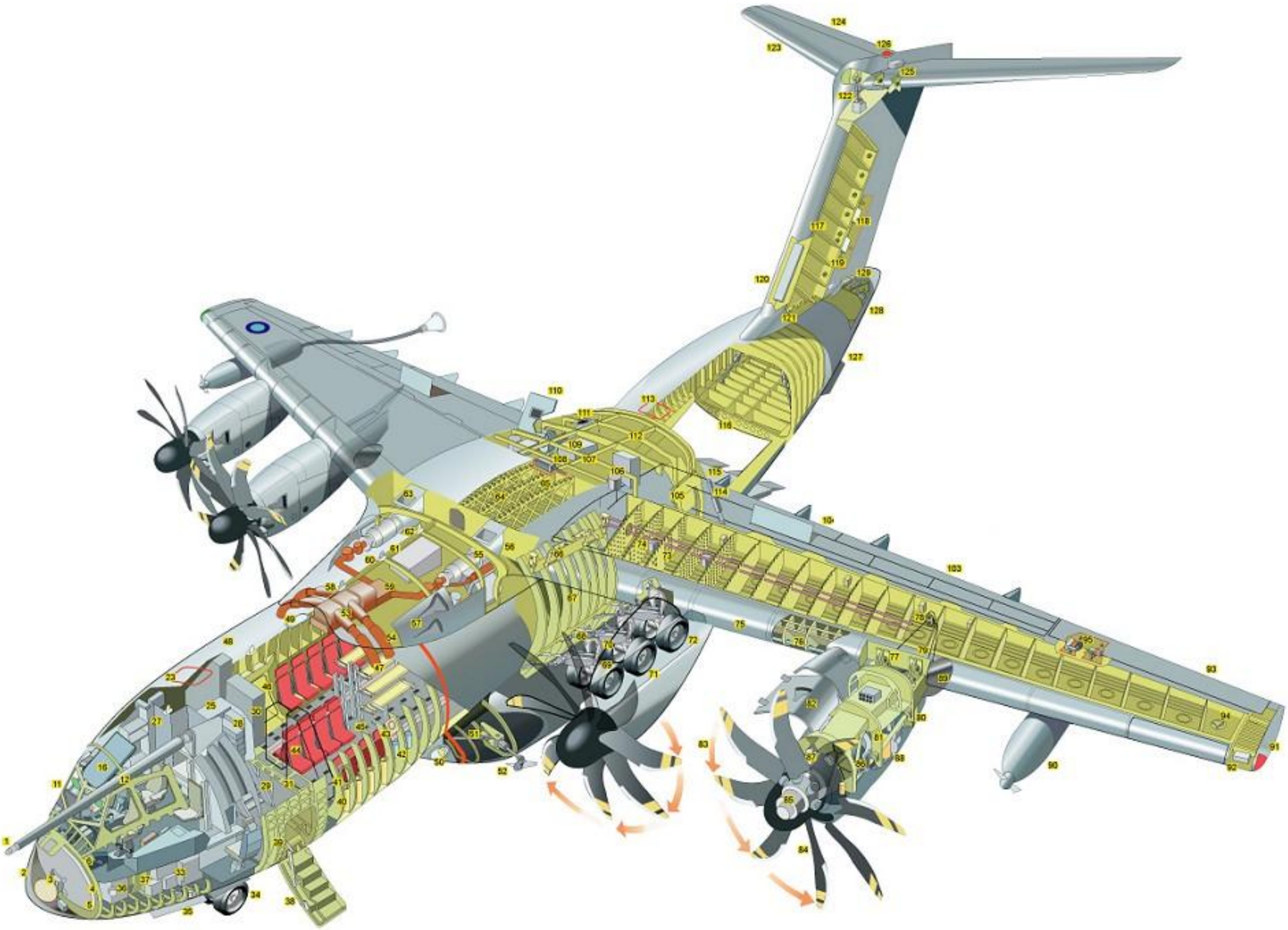
SEMI-MONOCOQUE

This is the preferred method of constructing an all-aluminum fuselage. First, a series of frames in the shape of the fuselage cross sections are held in position on a rigid fixture, or *jig*. These frames are then joined with lightweight longitudinal elements called stringers. These are in turn covered with a skin of sheet aluminum, attached by riveting or by bonding with special adhesives. Most modern large aircraft are built using this technique, but use several large sections constructed in this fashion which are then joined with fasteners to form the complete fuselage.





Semi-monocoque Structure of an airplane



Semi-monocoque Structure of an airplane

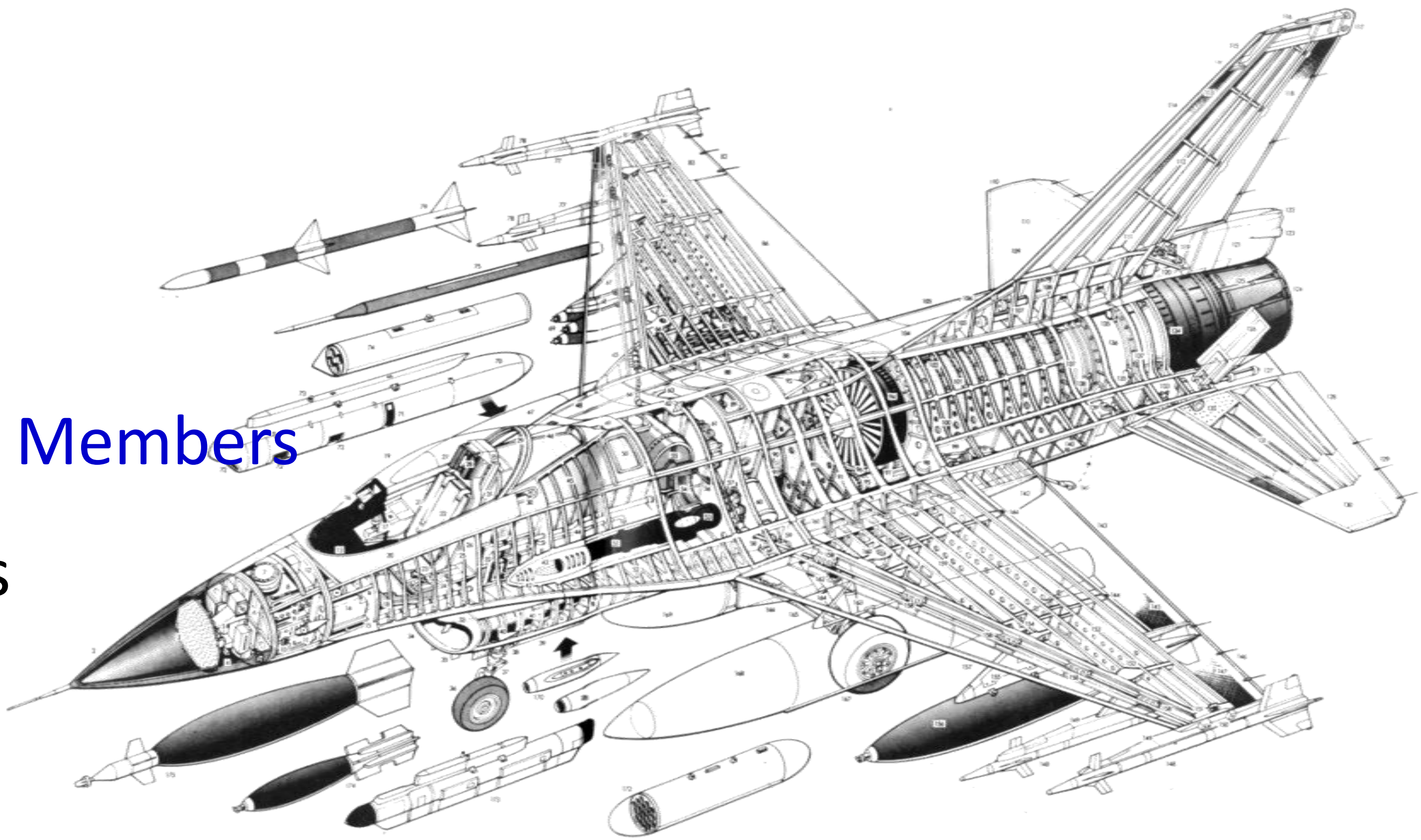
Basic Structure Member Terms

Vertical Members

- Formers
- Frame
- Ring
- Bulkhead

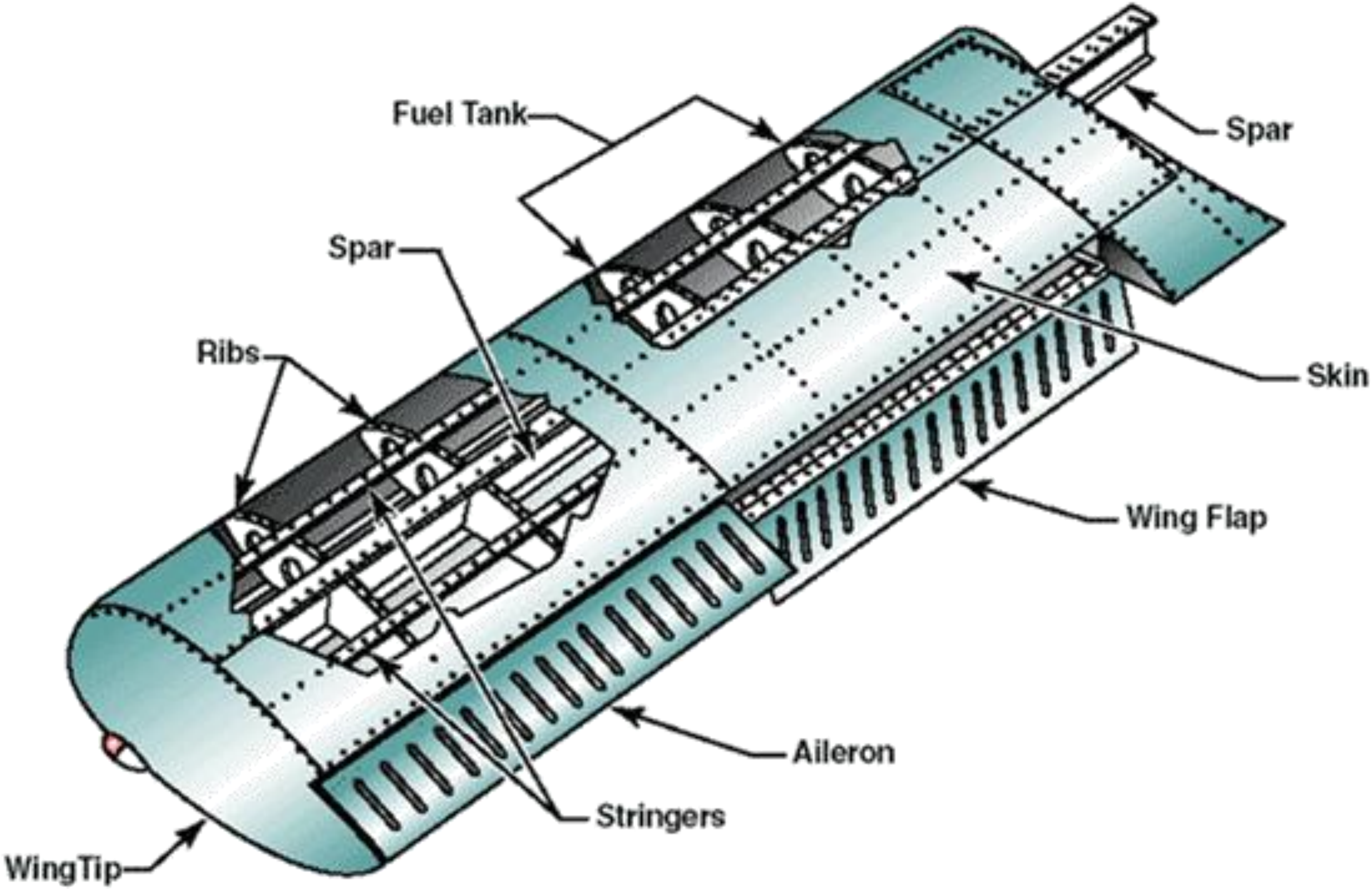
Longitudinal Members

- Longerons
- Stringers



Wing Structure

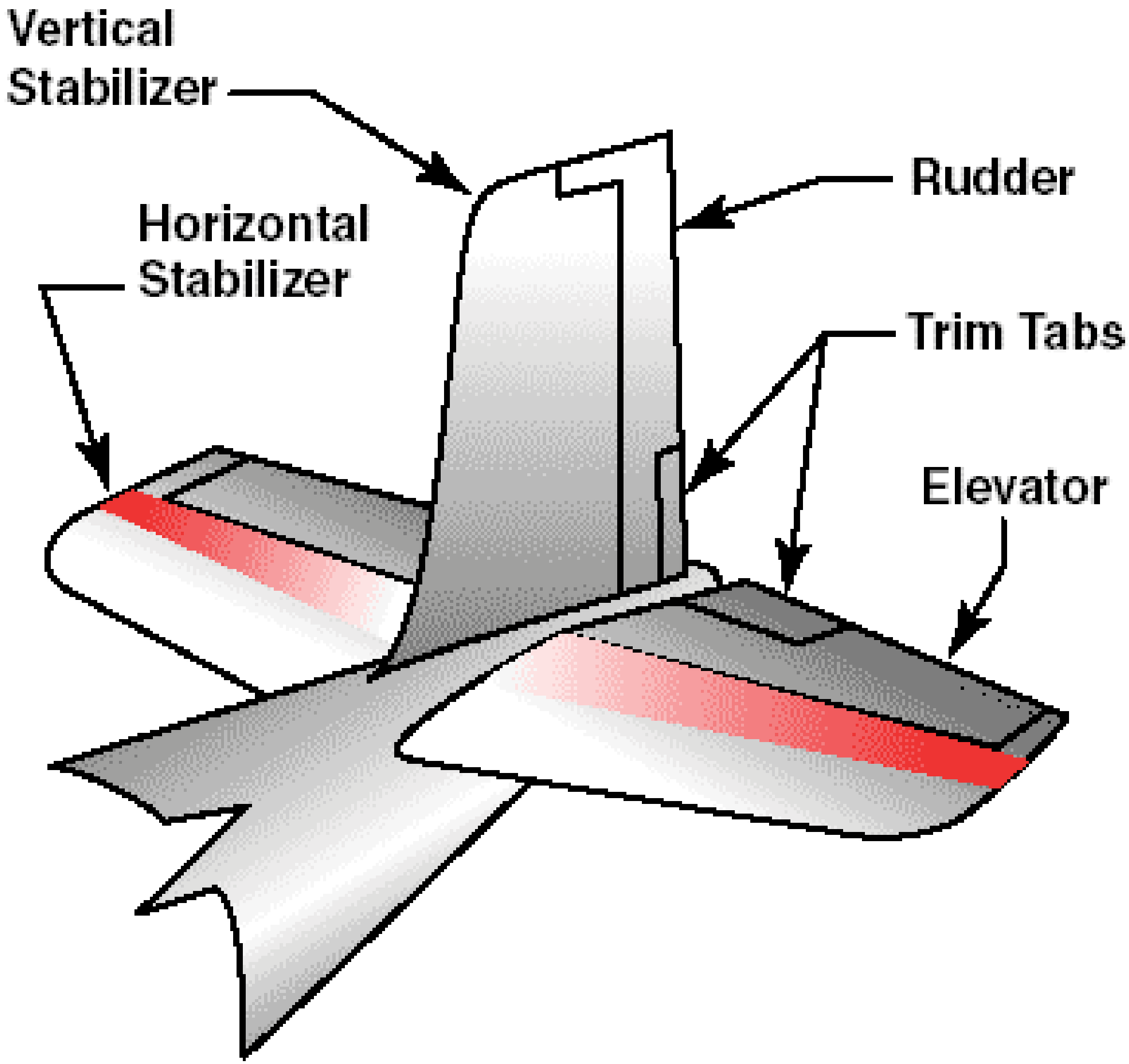
Many high-wing airplanes have external braces, or wing struts, which transmit the flight and landing loads through the struts to the main fuselage structure. Since the wing struts are usually attached approximately halfway out on the wing, this type of wing structure is called *semi-cantilever*. A few high-wing and most low-wing airplanes have a *full cantilever* wing designed to carry the loads without external struts. The principal structural parts of the wing are spars, ribs, and stringers. These are reinforced by trusses, I-beams, tubing, or other devices, including the skin. The wing ribs determine the shape and thickness of the wing (airfoil).



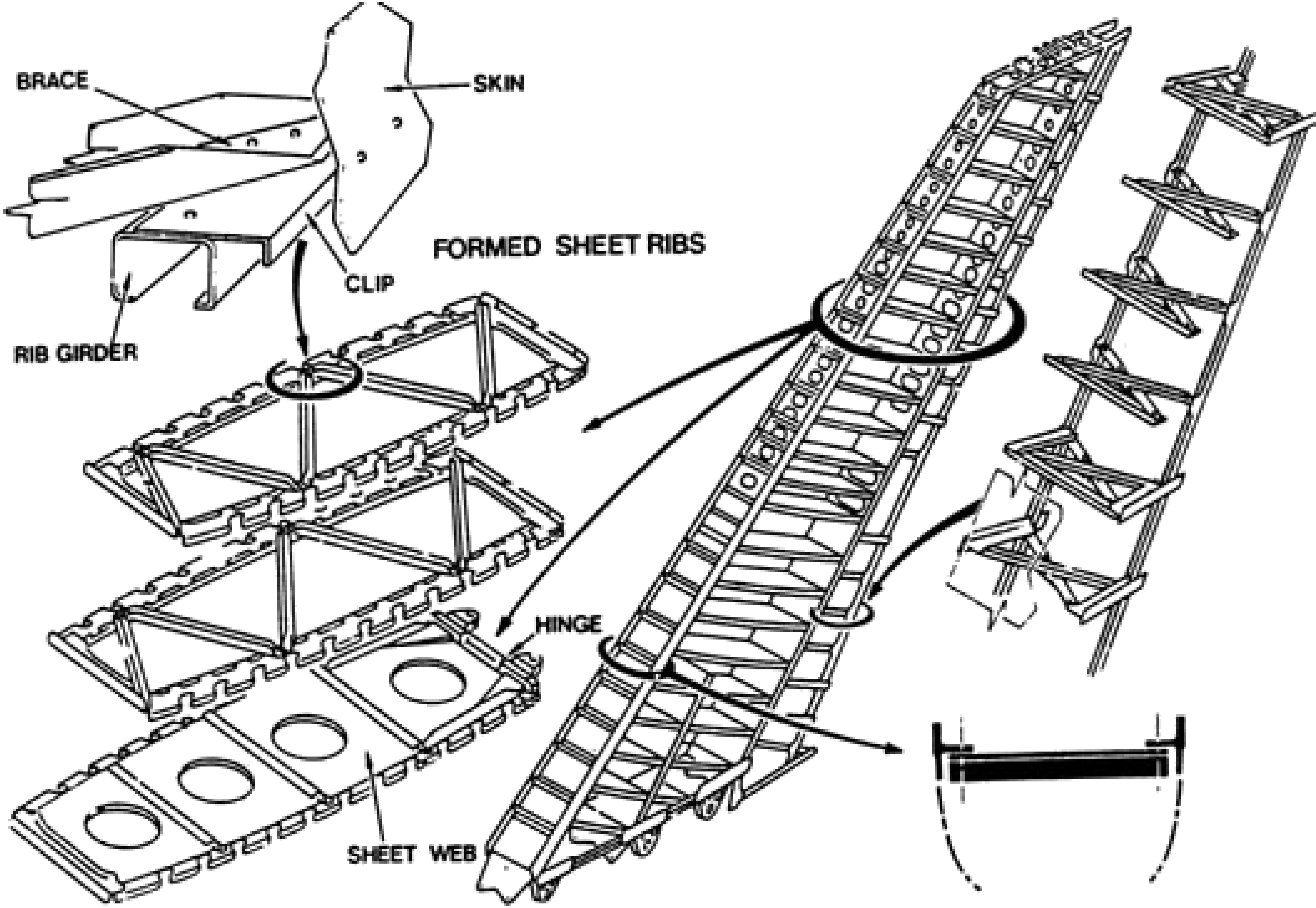
Wing Structure of an airplane

Empennage Structure

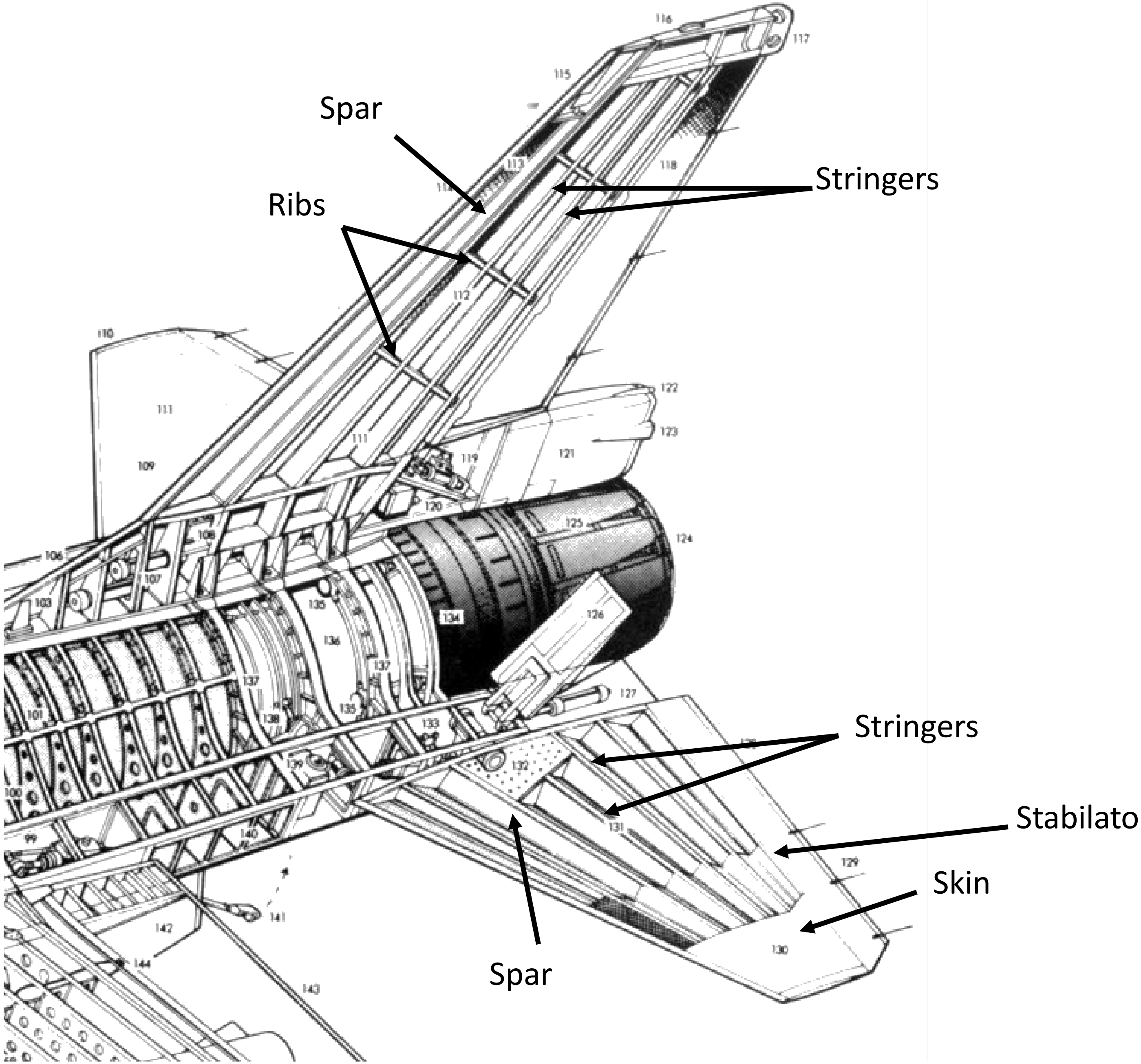
The correct name for the tail section of an airplane is empennage. The empennage includes the entire tail group, consisting of fixed surfaces such as the vertical stabilizer and the horizontal stabilizer. The movable surfaces include the rudder, the elevator, and one or more trim tabs. A second type of empennage design does not require an elevator. Instead, it incorporates a one-piece horizontal stabilizer that pivots from a central hinge point. This type of design is called a *stabilator*, and is moved using the control stick, just as you would the elevator.



Empennage of an airplane



Empennage Structure of an airplane



Empennage Structure of an airplane

Landing Gear Structure

The landing gear is the principle support of the airplane when parked, taxiing, taking off, or when landing. The most common type of landing gear consists of wheels, but airplanes can also be equipped with floats for water operations, or skis for landing on snow. The landing gear consists of three wheels — two main wheels and a third wheel positioned either at the front or rear of the airplane. Landing gear employing a rearmounted wheel is called conventional landing gear.

Landing Gear Structure

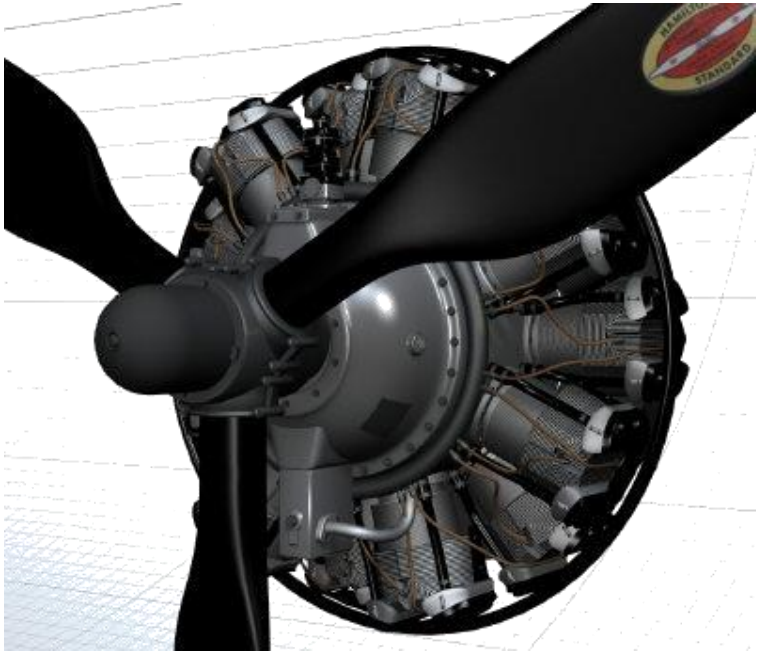
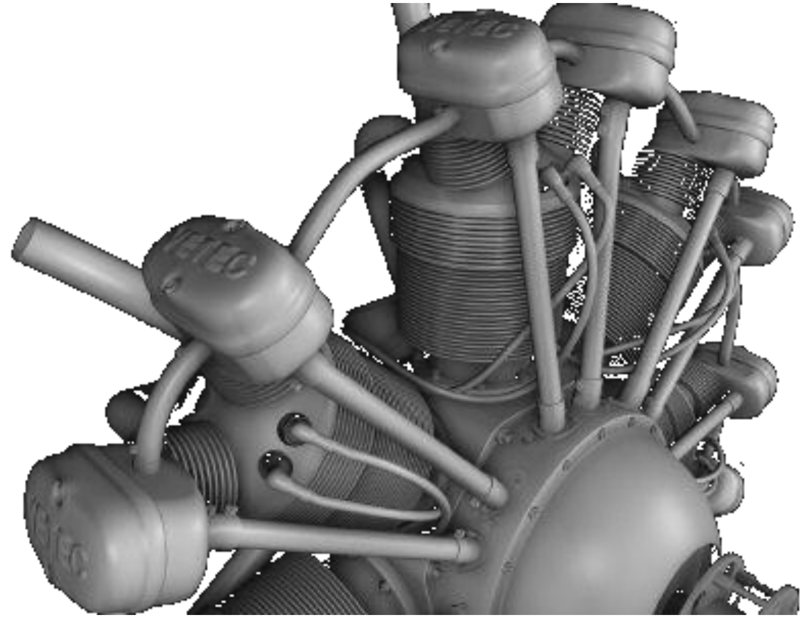
Airplanes with conventional landing gear are sometimes referred to as tail wheel airplanes. When the third wheel is located on the nose, it is called nose wheel, and the design is referred to as a tricycle gear. A steerable nose wheel or tail wheel permits the airplane to be controlled throughout all operations while on the ground.

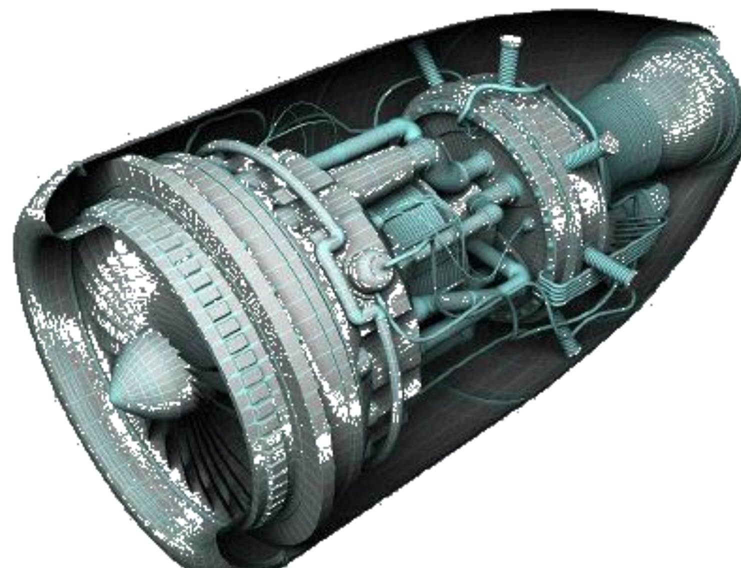
Power Plant

•The power plant usually includes both the engine and the propeller. The primary function of the engine is to provide the power to turn the propeller.

• It also generates electrical power, provides a vacuum source for some flight instruments, and in most single-engine airplanes, provides a source of heat for the pilot and passengers. The engine is covered by a cowling, or in the case of some airplanes, surrounded by a nacelle.

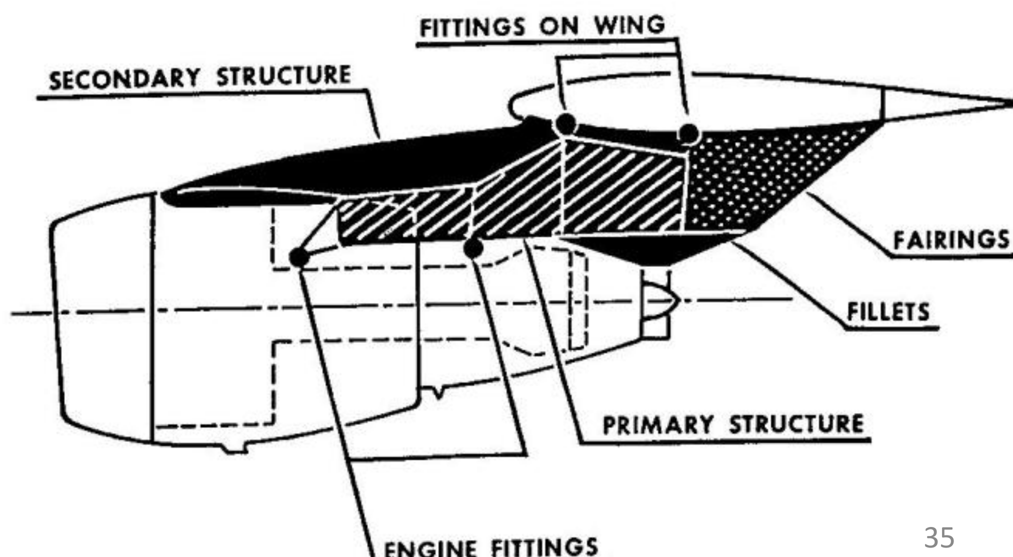
•The purpose of the cowling or nacelle is to streamline the flow of air around the engine and to help cool the engine by ducting air around the cylinders.



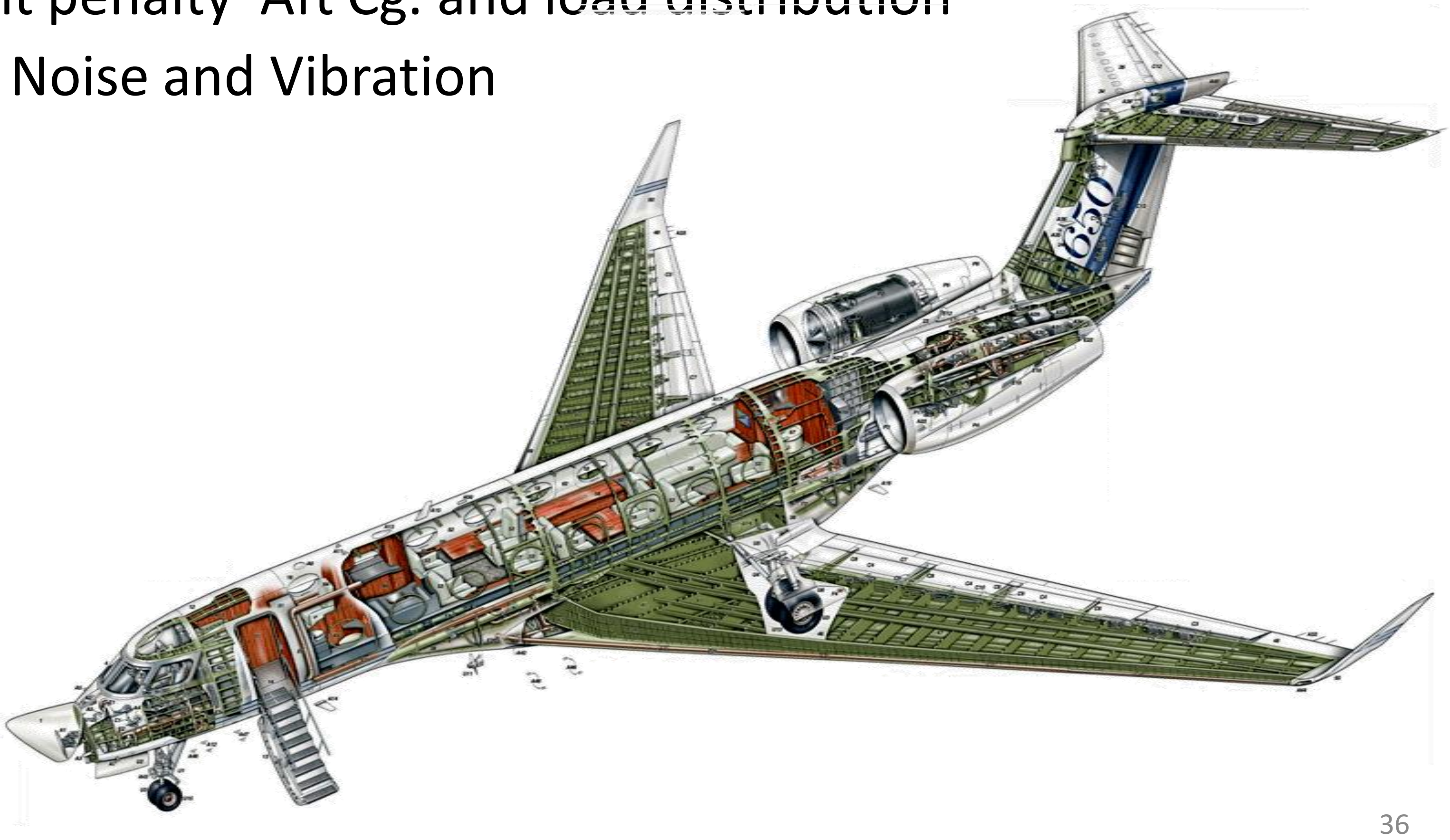
Wing Pod Mount

- Commonly use on commercial airplane since fuel is carry on wing
- Less noise
- CL max is not as good as fuselage mount
- Yawing moment effect
- Ground clearance limitation higher gear strut



Fuselage Mount

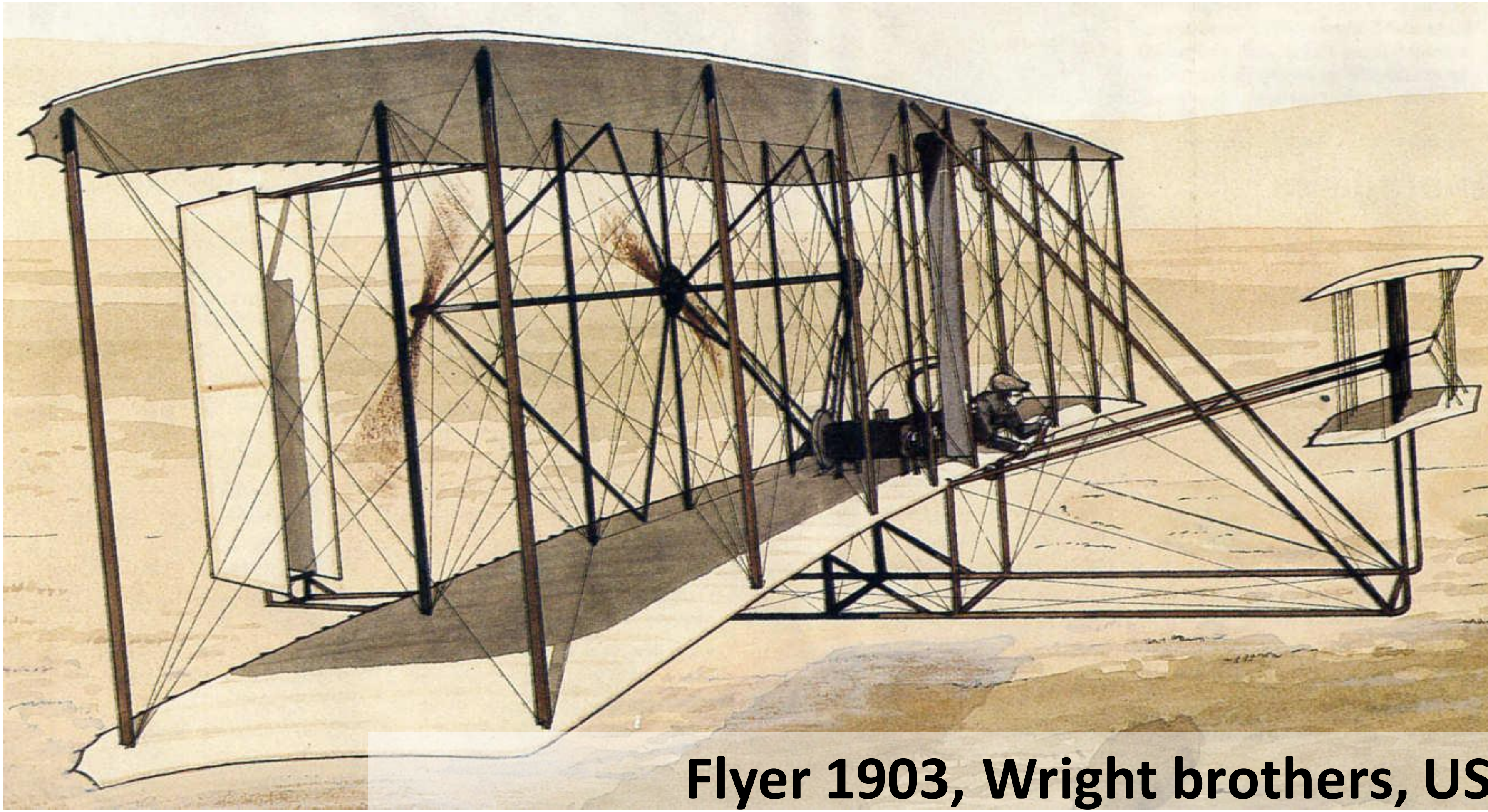
- Clean wing ,high CL Max , shorter take off.
- No ground clearance limitation
- Less yawing effect
- Weight penalty Aft Cg. and load distribution
- Cabin Noise and Vibration



Historical progress of aircraft structures. Structural layout and design models

HISTORICAL PROGRESS OF AIRCRAFT STRUCTURES

1903-1920. Frame structures, unstressed skin



Flyer 1903, Wright brothers, USA
Take-off mass 283 kg, wingspan 12 m

HISTORICAL PROGRESS OF AIRCRAFT STRUCTURES

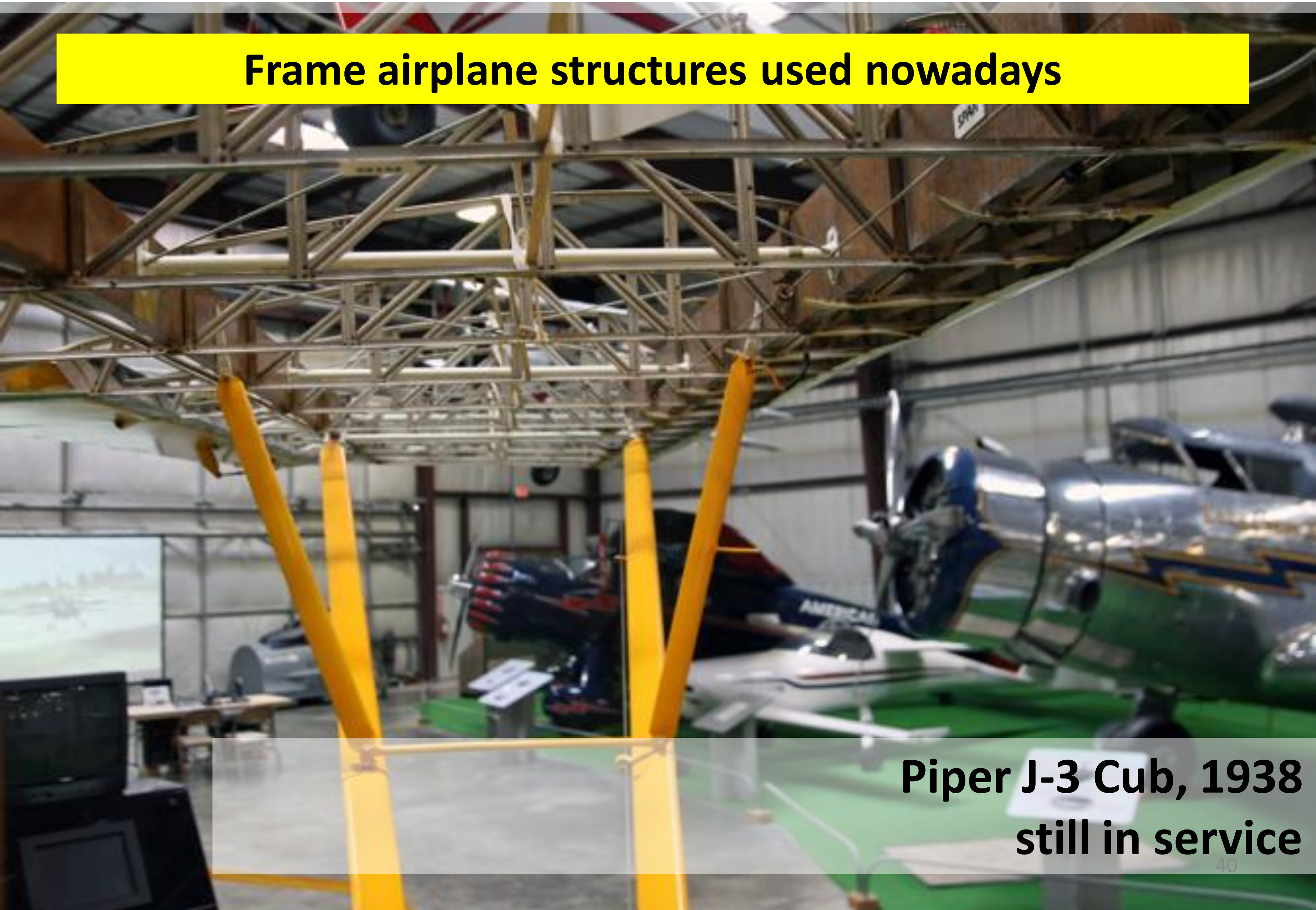
1903-1920. Frame structures, unstressed skin

Ilya Muromets, Russian Empire, 1913

Take-off mass 7 000 kg, wingspan 31.1 m

HISTORICAL PROGRESS OF AIRCRAFT STRUCTURES

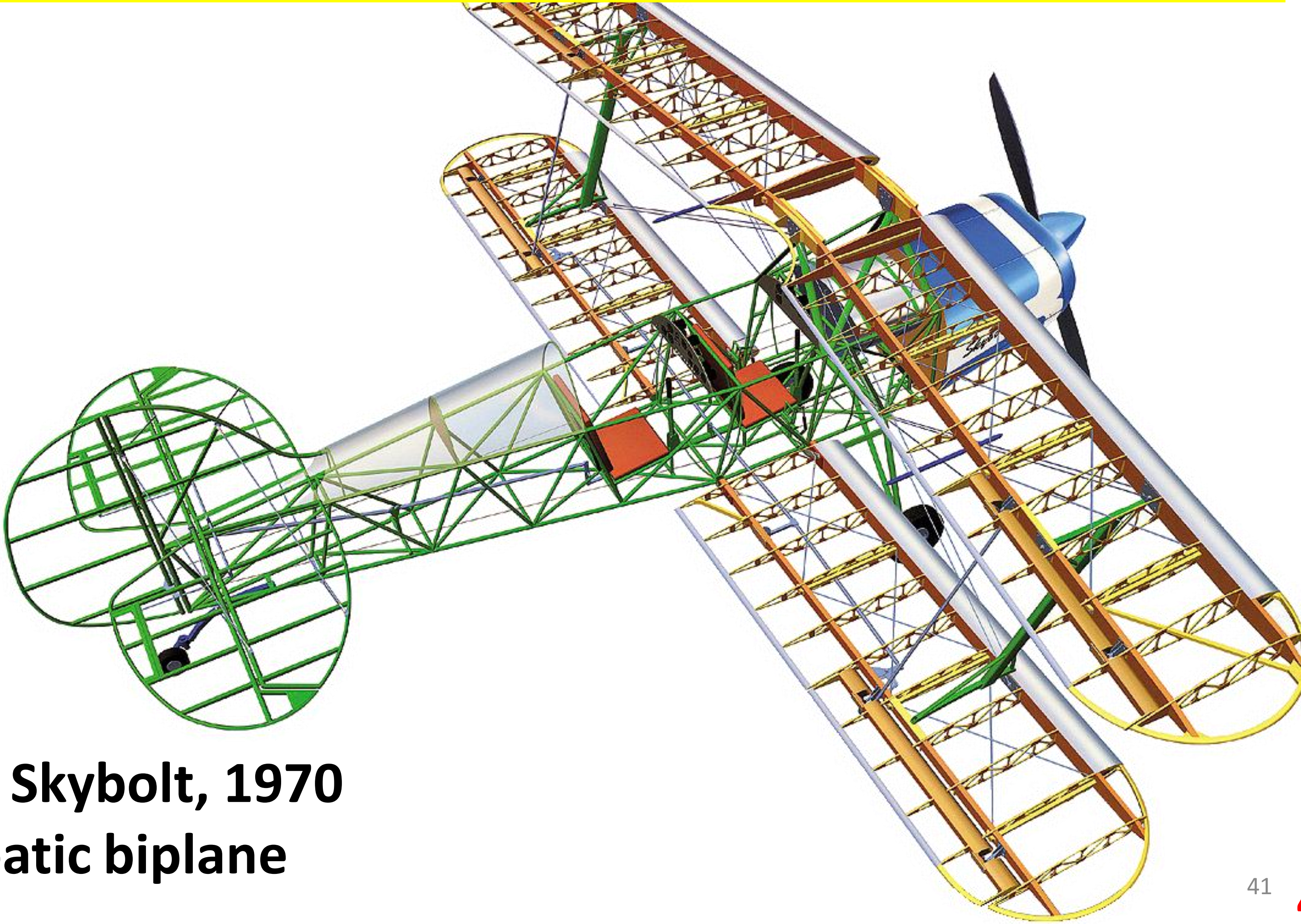
Frame airplane structures used nowadays



Piper J-3 Cub, 1938
still in service

HISTORICAL PROGRESS OF AIRCRAFT STRUCTURES

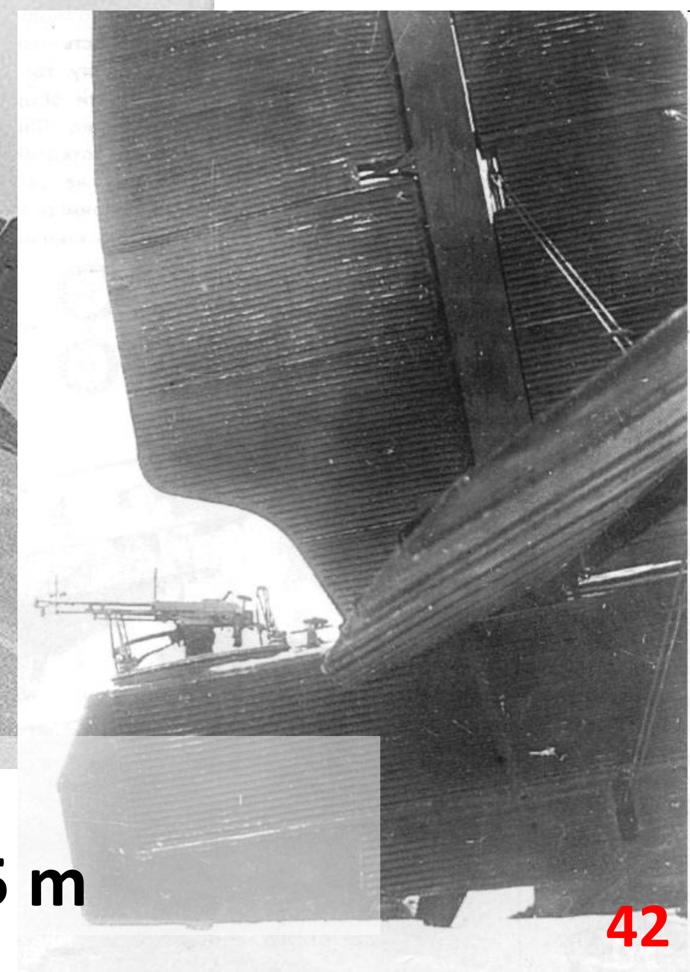
Frame airplane structures used nowadays



Steen Skybolt, 1970
aerobatic biplane

HISTORICAL PROGRESS OF AIRCRAFT STRUCTURES

1920-1930. Monoplanes and corrugated skin introduced



Tupolev TB-3, Soviet Union, 1932

Take-off mass 19 500 kg, wingspan 39.5 m

HISTORICAL PROGRESS OF AIRCRAFT STRUCTURES

1920-1930. Monoplanes and corrugated skin introduced

KhAI-1, Soviet Union, 1932

Take-off mass 2 600, max. speed 324 km/h

43

HISTORICAL PROGRESS OF AIRCRAFT STRUCTURES

1930-1940. Aluminium extensively used, stressed skin. Method of reduction coefficients developed (1932).

Messerschmitt Bf.109, Germany, 1935
Take-off mass 3 375 kg,
max. speed 720 km/h

HISTORICAL PROGRESS OF AIRCRAFT STRUCTURES

1940-1950. Sweptback wings, thick stressed skin, thin-walled beam structure.

Mikoyan-Gurevich MiG-15, Soviet Union, 1949
Take-off mass 4 917 kg, wingspan 10 m

HISTORICAL PROGRESS OF AIRCRAFT STRUCTURES

1950-1960. Triangle wings, specific passenger aircraft. Rise of fatigue, vibration and aeroelasticity problems

Mikoyan-Gurevich MiG-21, Soviet Union, 1959
Take-off mass 10 100 kg, max.speed 2230 km/h

HISTORICAL PROGRESS OF AIRCRAFT STRUCTURES

1950-1960. Triangle wings, specific passenger aircraft. Rise of fatigue, vibration and aeroelasticity problems

De Havilland DH.106 Comet, Great Britain, 1949

Take-off mass 73.5 ton, wingspan 35 m

HISTORICAL PROGRESS OF AIRCRAFT STRUCTURES

1950-1960. Triangle wings, specific passenger aircraft. Rise of fatigue, vibration and aeroelasticity problems

Antonov An-10, Soviet Union, 1957
Take-off mass 51 ton, wingspan 38 m

HISTORICAL PROGRESS OF AIRCRAFT STRUCTURES

1960-1970. Variable sweep wings, new heat-resistant materials. Rise of passenger fleet.

Mikoyan-Gurevich MiG-23, Soviet Union, 1967
Take-off mass 20 100 kg, max.speed 2500 km/h

HISTORICAL PROGRESS OF AIRCRAFT STRUCTURES

1970-1980. Wide-body passenger aircraft

Boeing 747, USA, 1969

Take-off mass 340.2 ton, wingspan 59.6 m

HISTORICAL PROGRESS OF AIRCRAFT STRUCTURES

1980-1990. Extra-large cargo aircraft

Antonov 124, USSR, 1982
Take-off mass 402 ton, payload 150 ton, wingspan 73.3 m

HISTORICAL PROGRESS OF AIRCRAFT STRUCTURES

1990-nowadays. Wide use of new materials (composite materials, titanium alloys)

Boeing 787 Dreamliner, USA, 2009

Take-off mass 245 ton, wingspan 60 m

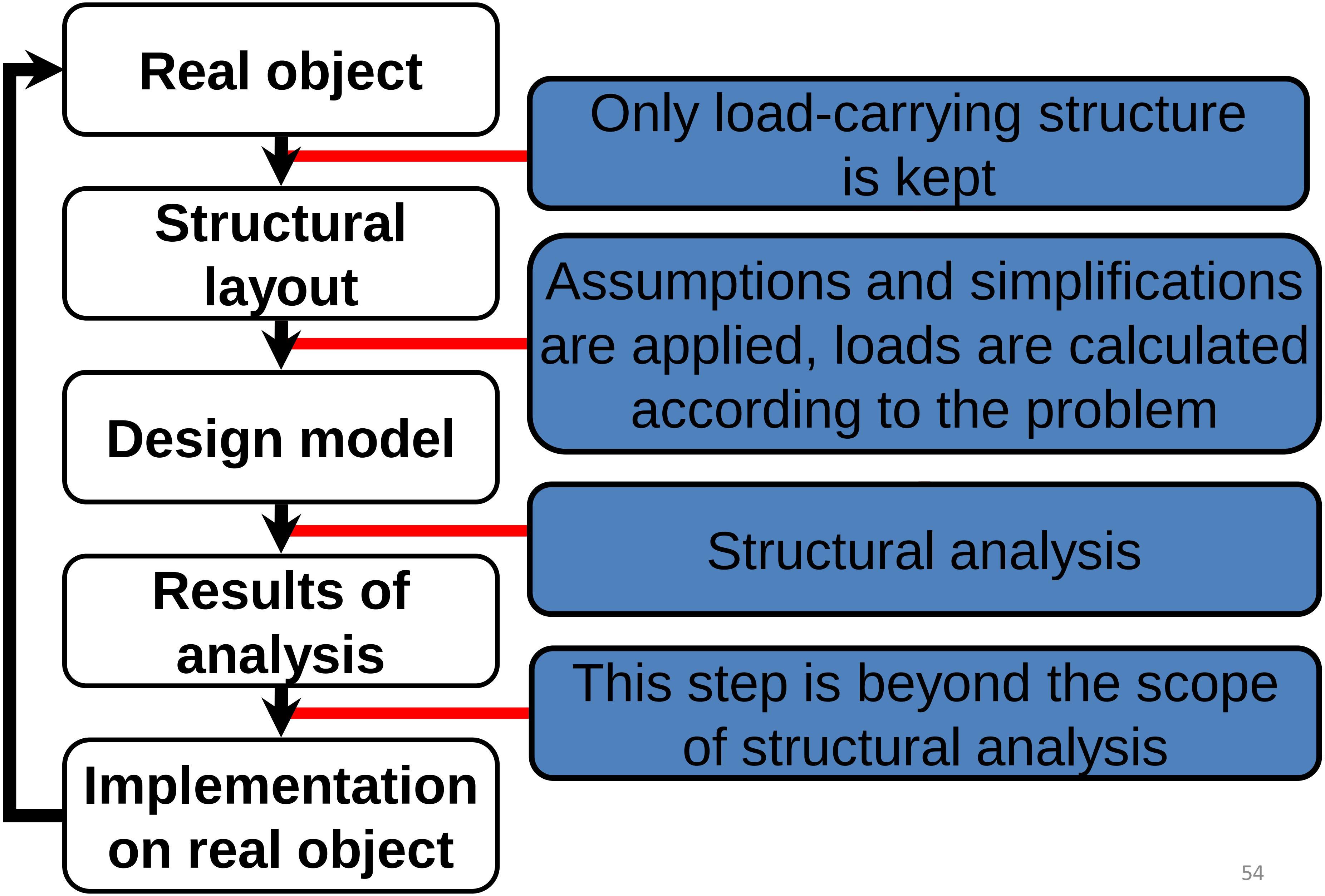
GOALS AND OBJECTIVES

Structural analysis is the determination of the effects of loads on physical structures and their components.

As a science, structural analysis covers principles and methods of strength, rigidity and stability calculations.

The goal of structural analysis is to get the efficient structure and verify its fitness for use.

FLOWCHART OF STRUCTURAL ANALYSIS



FLOWCHART OF STRUCTURAL ANALYSIS

Real object

↓

Structural layout

↓

Design model

↓

Results of analysis

↓

Implementation on real object

FLOWCHART OF STRUCTURAL ANALYSIS

Real object

↓

Structural layout

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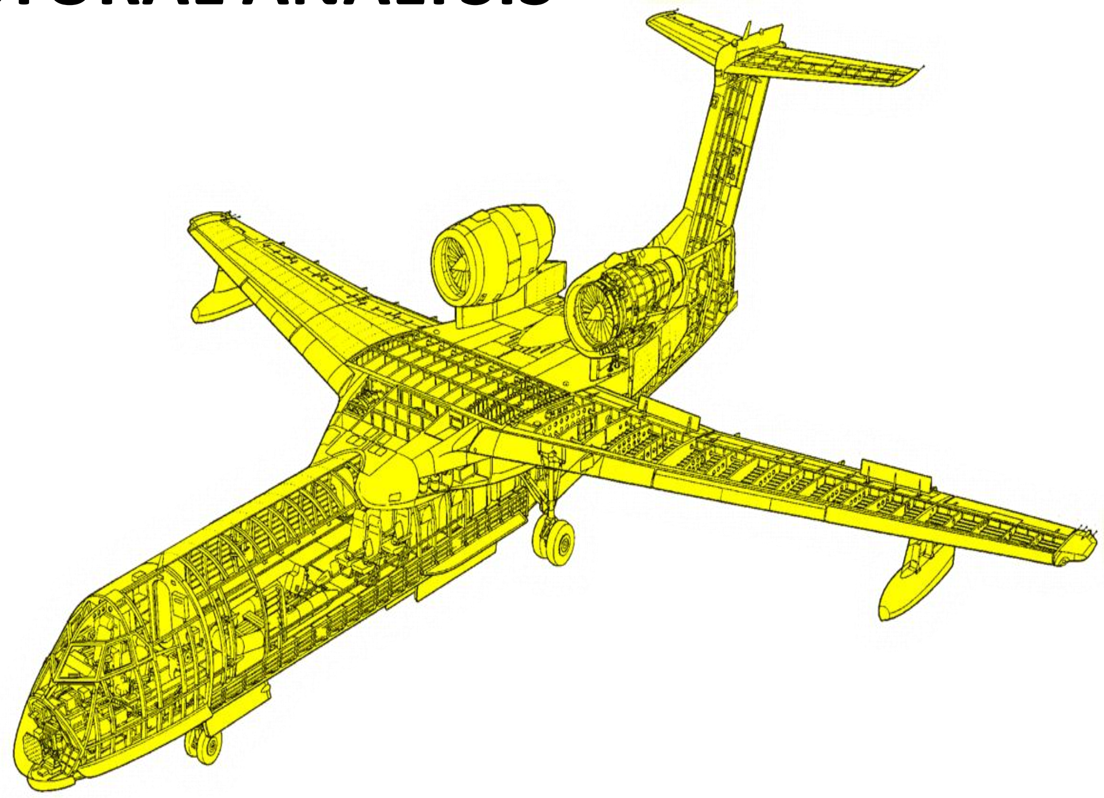
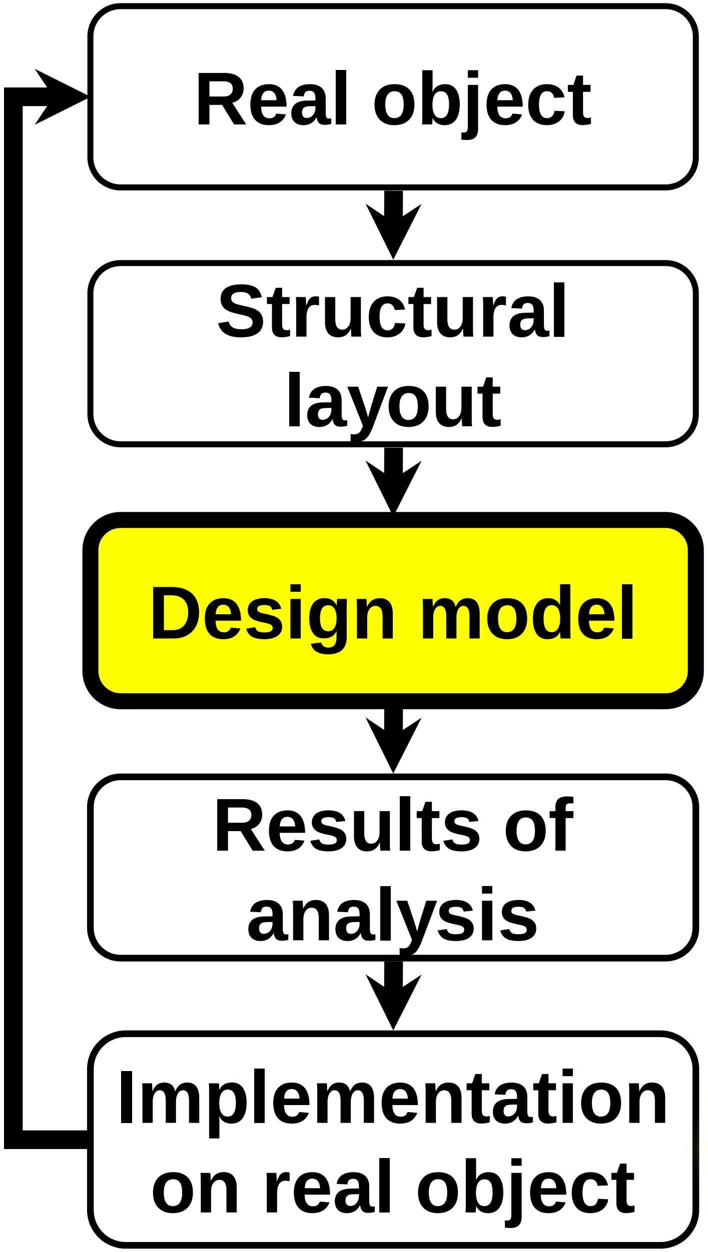
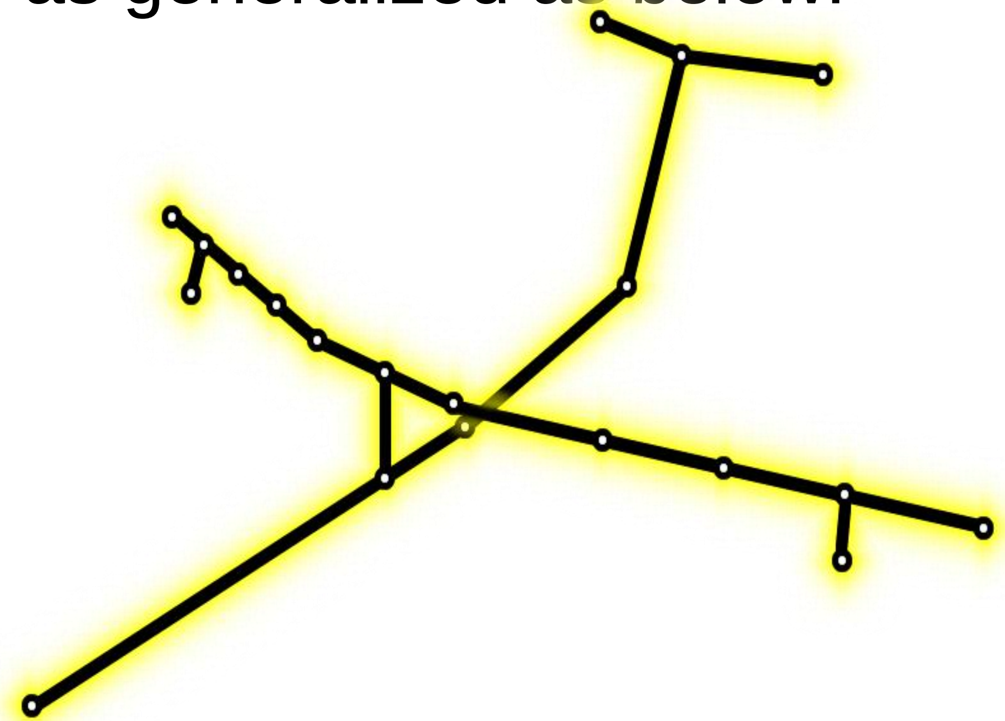
Implementation on real object



FLOWCHART OF STRUCTURAL ANALYSIS



Depending on the kind of problem which is solved, the design model could be either as detailed as structural layout, or as generalized as below:



METHODS OF STRUCTURAL ANALYSIS

Analytical methods	Numerical methods
Best for designing calculations, suit for checking calculations with certain limitations	Best for checking calculations, practically effete for designing calculations
Solutions exist for partial cases (specific objects)	Versatile and flexible
Need much work to be developed, but only simple software for application	Need expensive and complex software and hardware

METHODS OF STRUCTURAL ANALYSIS

Analytical methods	Numerical methods
Methods of Mechanics of Materials, methods for statically indeterminate structures (method of forces, method of displacements), beam theory, method of reduction coefficients etc.	Finite Element Method (FEM, best for solid mechanics), Finite Difference Method (FDM), Movable cellular automaton (MCA, best for fracture, crack propagation) etc.

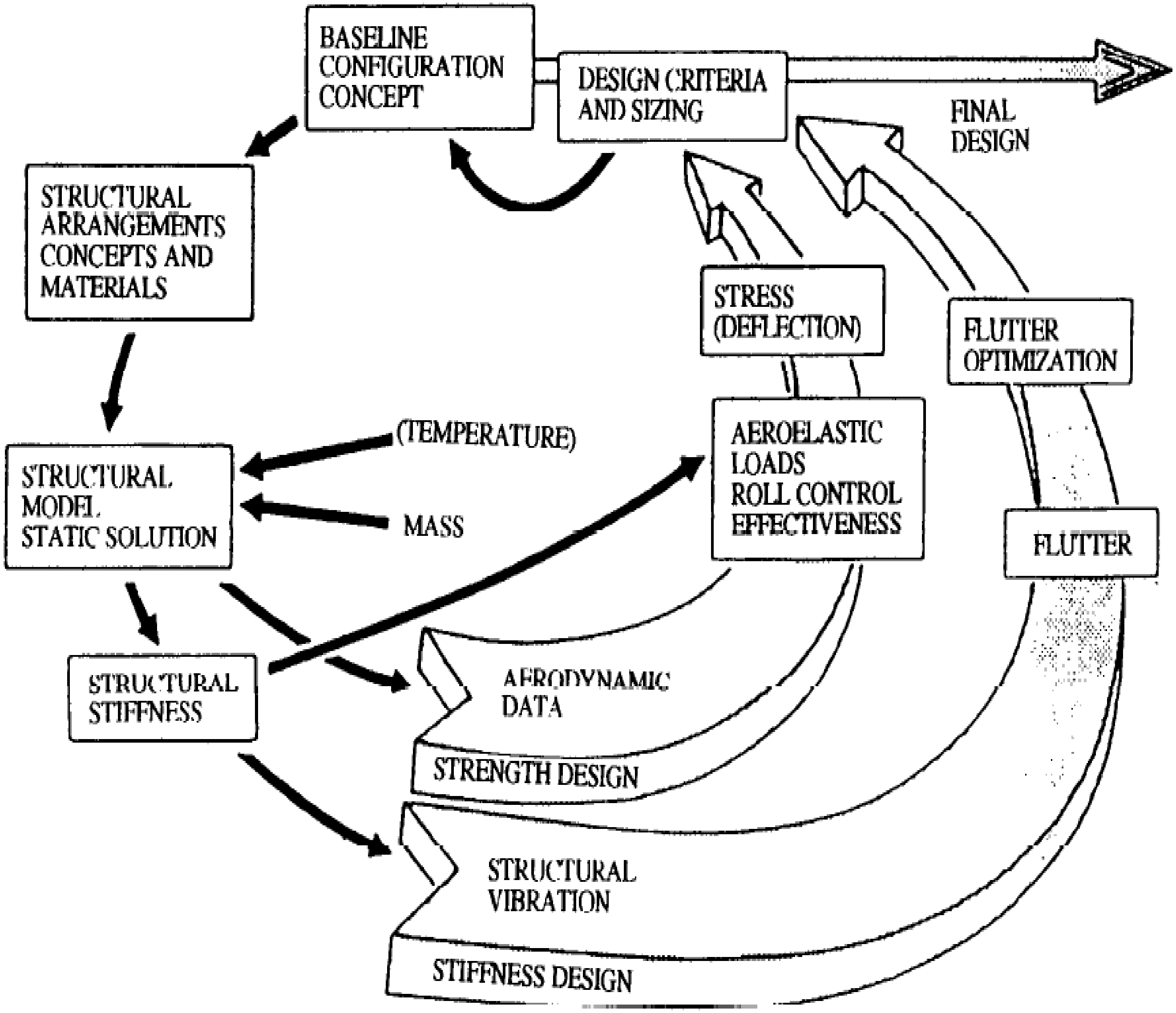
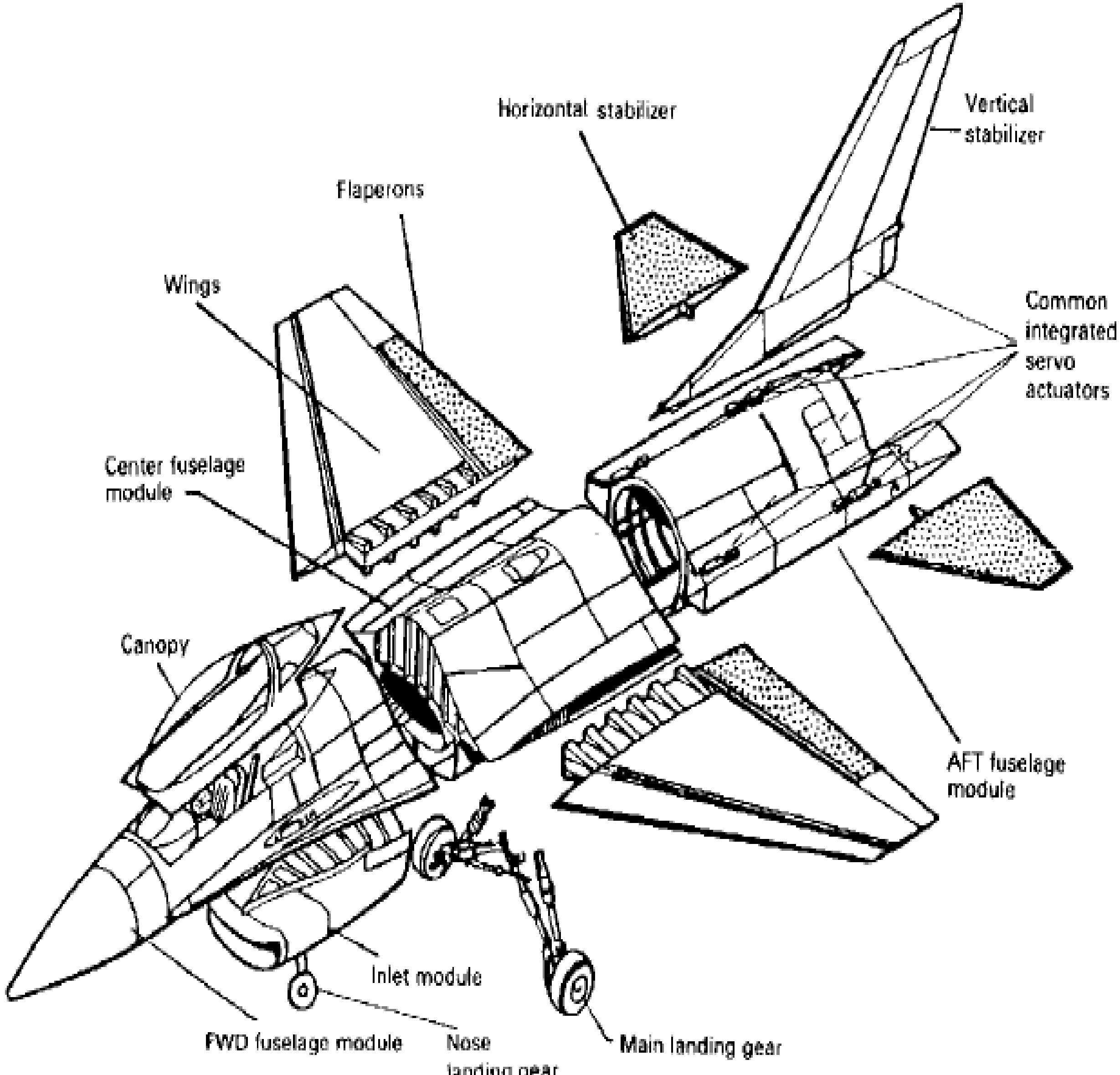


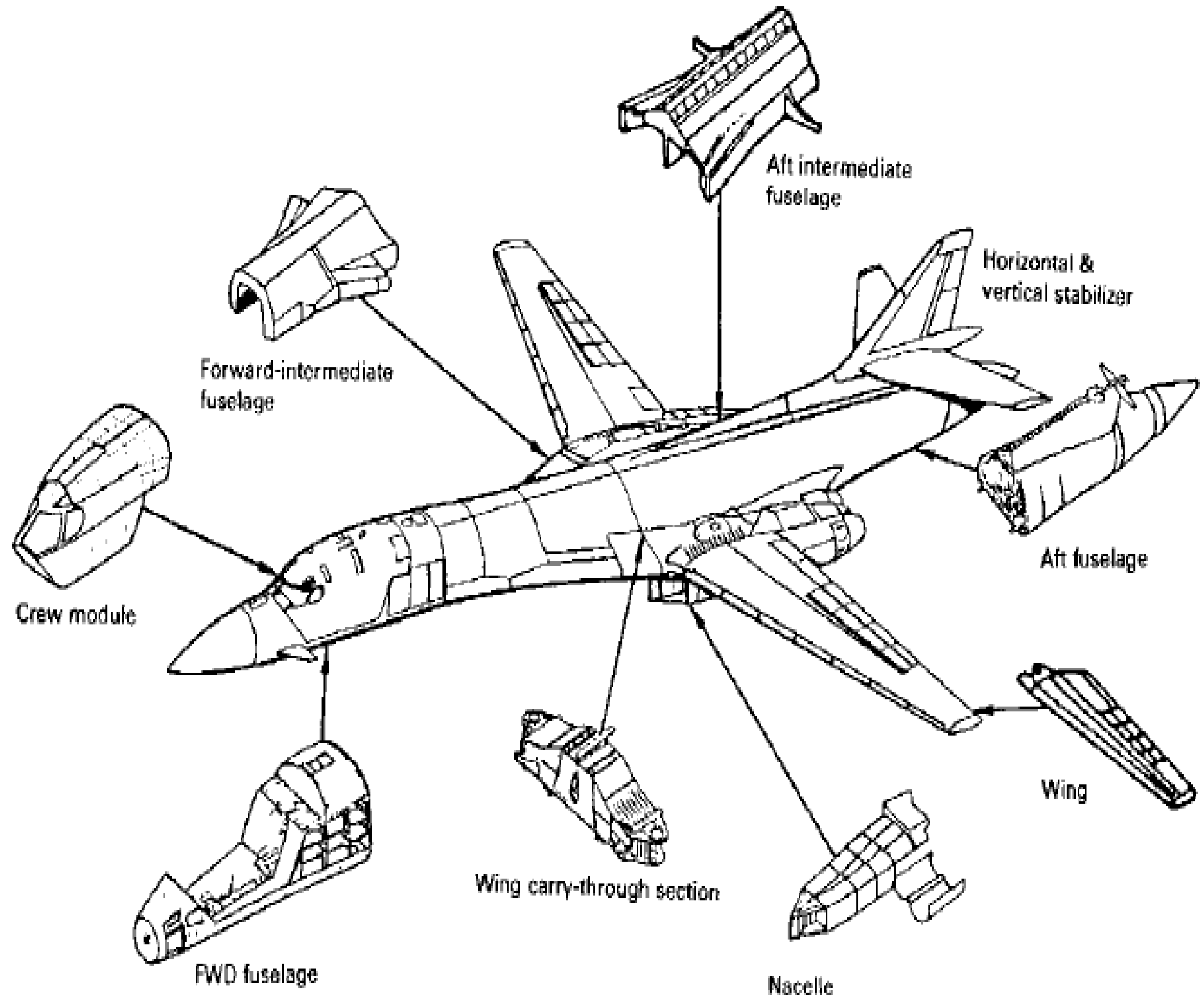
Fig. 1.1.1 Structural Analytical Design Cycles

Structural arrangement of typical fighter aircraft



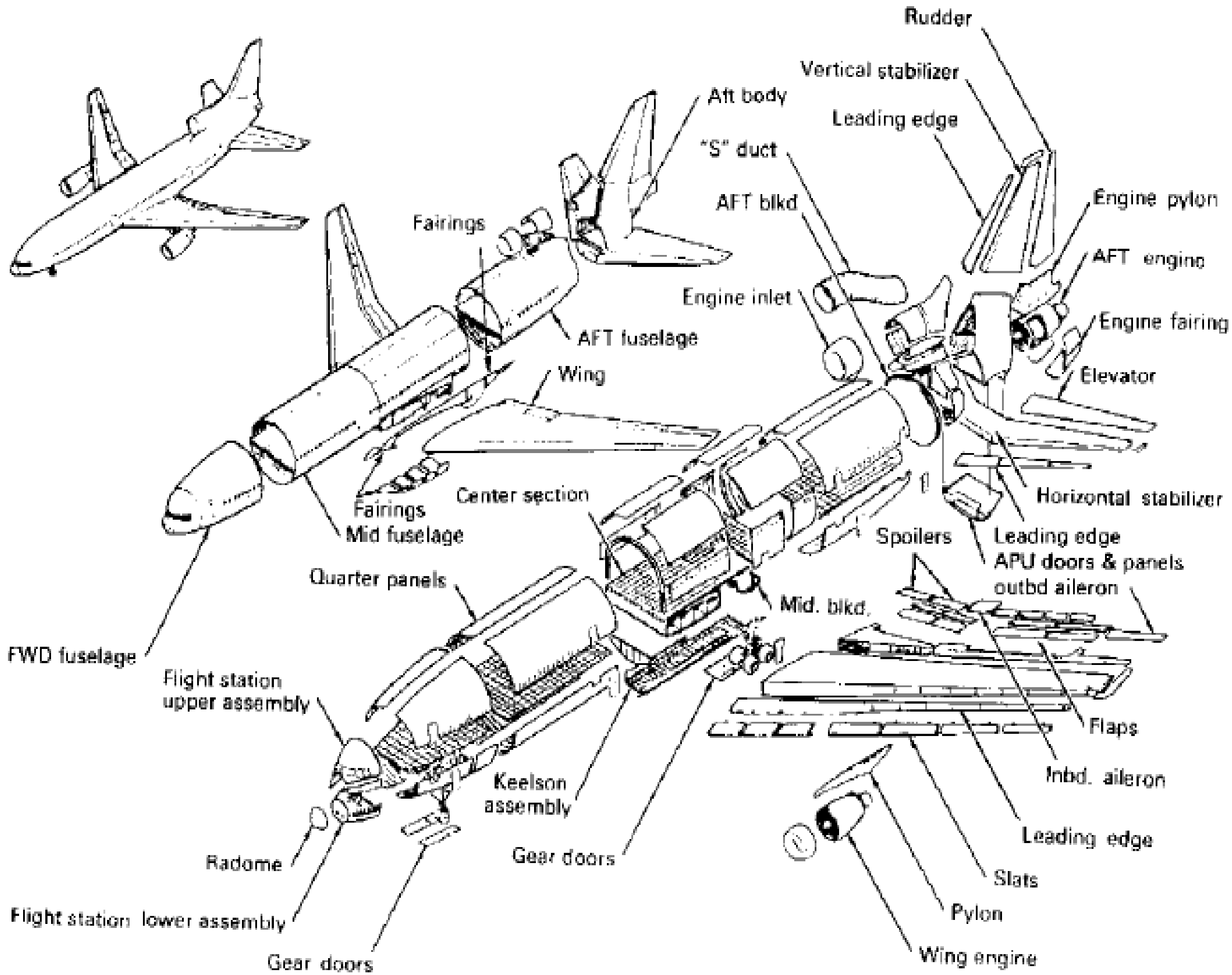
(a) *Military fighter*

Structural arrangement of typical fighter aircraft



(b) Military bomber

Structural arrangement of typical transport aircraft



(c) *Commercial airliner*

Design, development and testing of Airplane

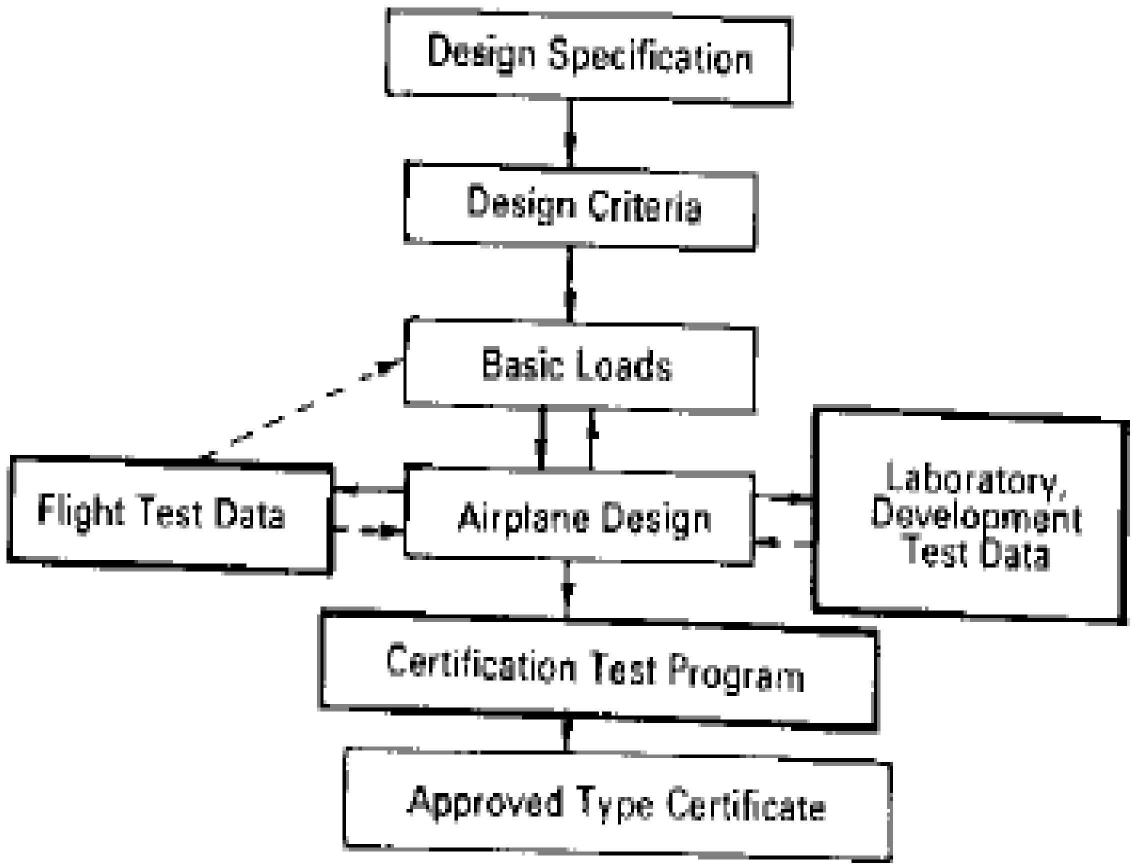


Fig. 1.2.2 Airplane design, development and certification.

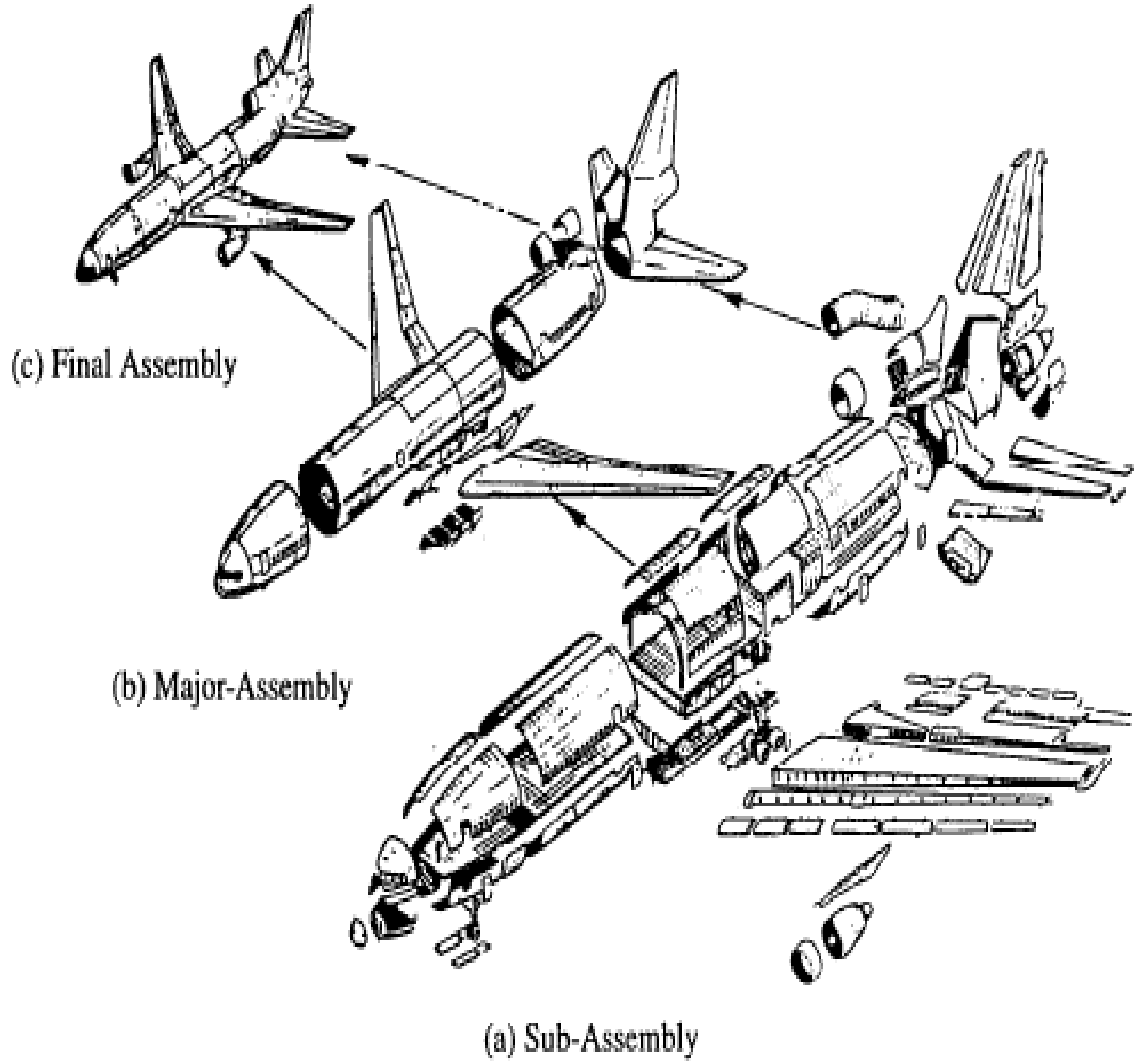
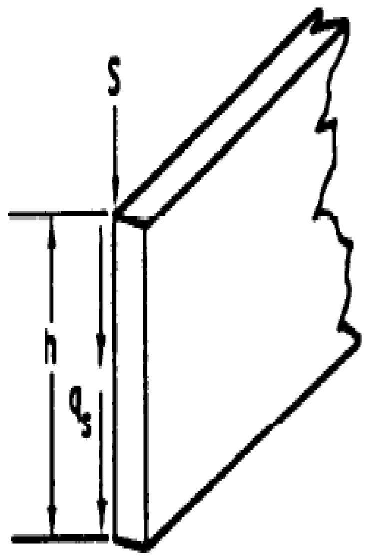


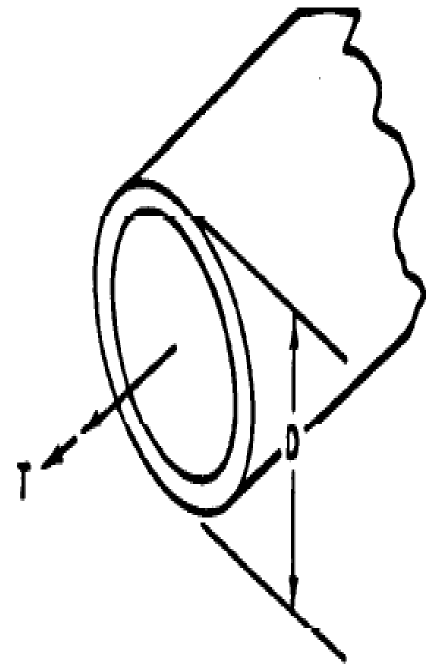
Fig. 1.4.2 Lockheed L-1011's Sub-assemblies and Final Assembly

Structural Indexes



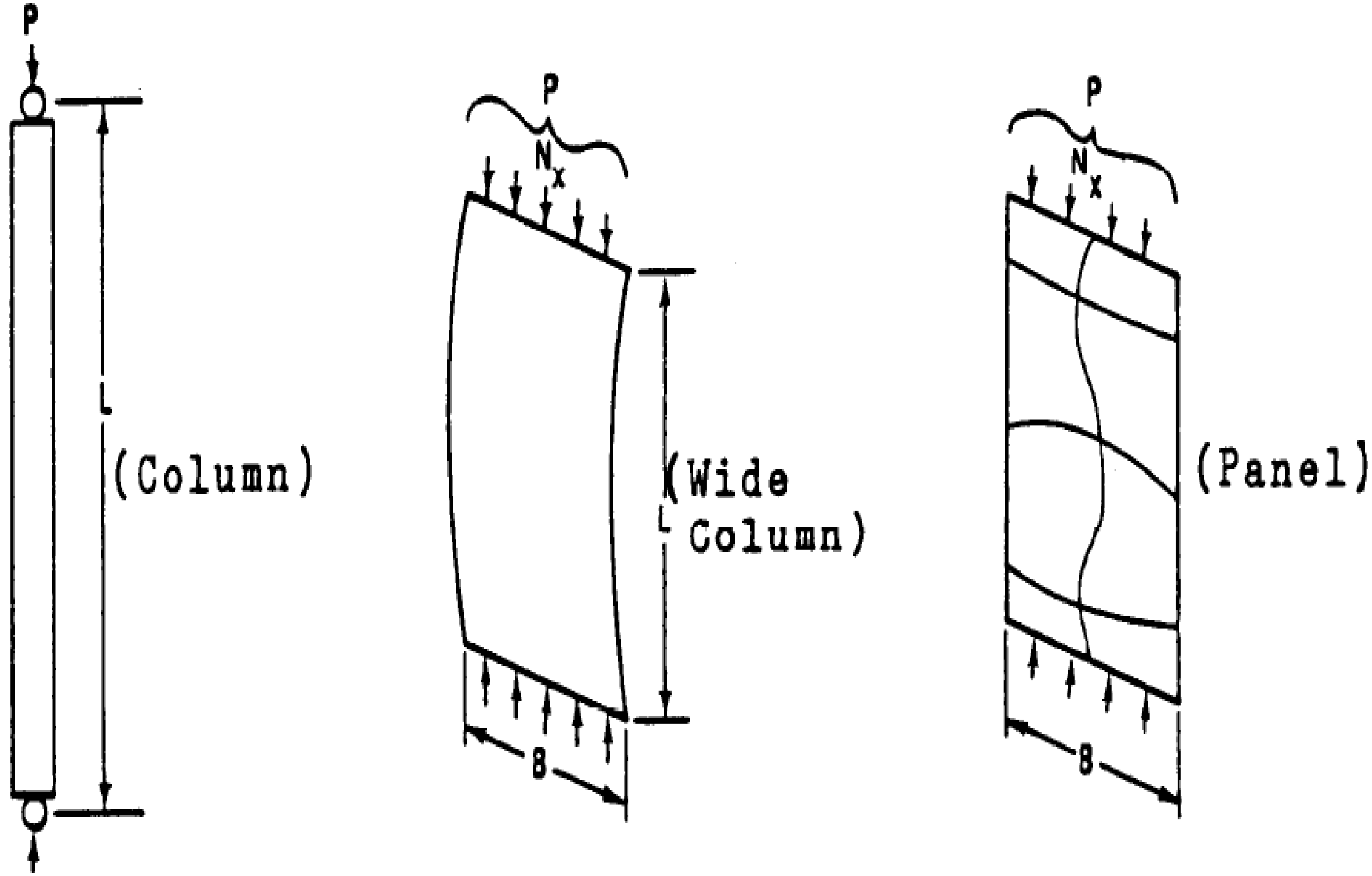
$$\frac{q_s}{h} = \frac{S}{h^2}$$

(A) SHEAR



$$\frac{T}{D^2}$$

(B) TORSION

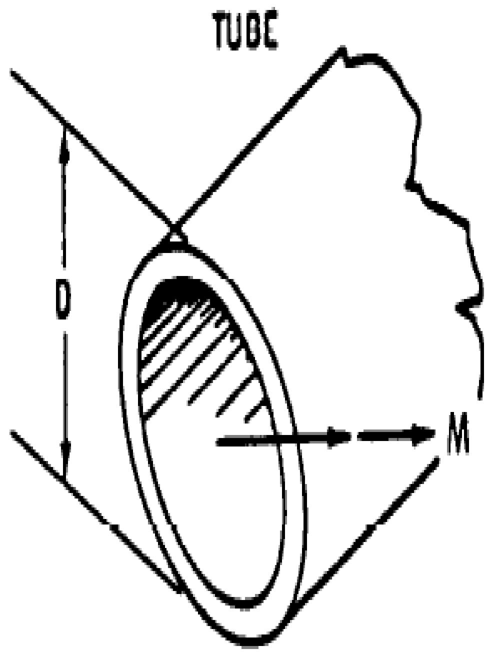


$$\frac{P}{L^2}$$

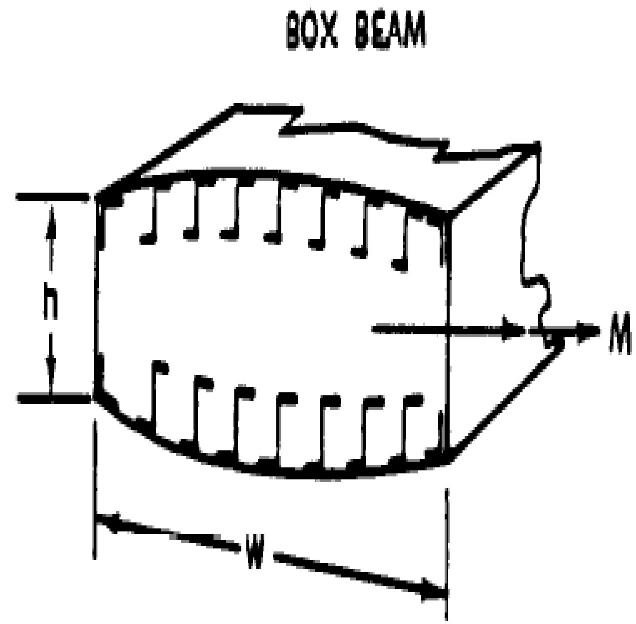
$$\frac{N_x}{L^2} = \frac{P}{BL^2}$$

$$\frac{P}{B^2} = \frac{N_x}{B}; \text{ where } N_x = \frac{P}{B}$$

(C) COMPRESSION MEMBERS



$$\frac{M}{D^3}$$



$$\frac{M}{wh^2} = \frac{N_x}{h}$$

(D) BENDING

Fig. 1.2.2 Structural Index

UNIT-II

EXTERNAL LOADS-ESTIMATION, FASTENERS AND STRUCTURAL JOINTS

Airframe Design


HC

Introduction

•A typical aircraft is made of many thousands of individual parts. Some parts could be made from larger pieces – why do you think manufacturers make the aircraft in so many separate parts?

– Through use, components will wear out, so we need to be able to replace them.

– Some components will inevitably become damaged, so again, they will need replacing.

– Some components are made out of several sub-assemblies in case one part fails, the other components will stop the aircraft from crashing.

Airframe Components

- Any airframe is made up of several ‘major’ components. Try and name some.

Fuselage

Engines

Cockpit/Flight Deck

Rudder

Wings

Flaps

Elevators

Fin

Ailerons

Tailplane

Fuel Tanks

Landing Gear

But can you identify them!

All the suggestions you gave are valid, but for the purposes of this ACP, we will discuss the following 4 major components in more detail later.

Surely that's not them all though!

Engines & Cockpit

- Now, you may think that this ACP is missing a couple of important components; Engines and a Cockpit.

The Viking glider is an aircraft, and it is fairly obvious that it does not have an engine.

Unmanned Aerial Vehicles (UAVs) for reconnaissance and weapons delivery. They are still aircraft, but have no pilot, therefore do not need a cockpit.

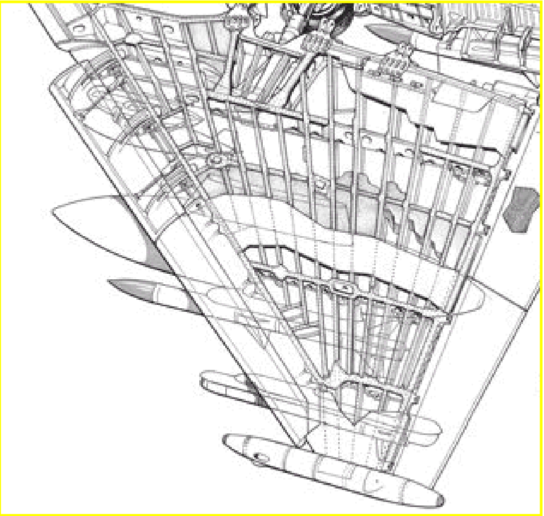
Structural Loads

•All the loads that the structure of the airframe carries are resisted by components that are shaped and formed to resist those forces.

•Can you think of types of forces (or loads) that would be present in components in an aircraft wing?

Squashing

Bending



Tearing

Pulling

Twisting

Structural Elements

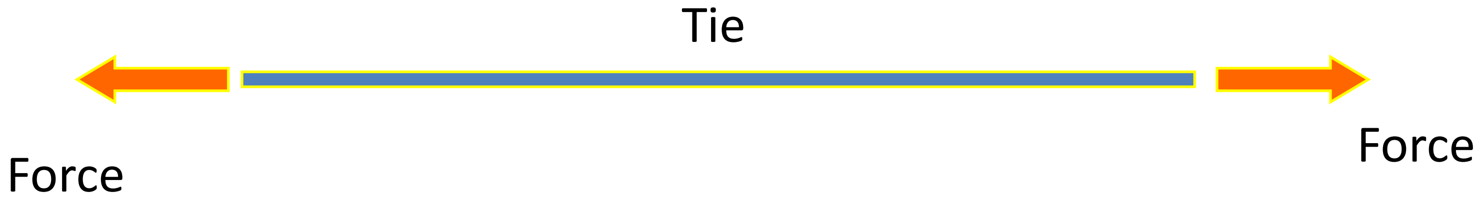
•The airframe designer has 4 types of structural element that can be used to resist these forces – they are;

- **Ties:** These resist tension or *‘pulling’* forces
- **Struts:** These resist compression or *‘squashing’* forces
- **Beams:** These resist *‘bending’* forces
- **Webs:** These resist *‘twisting’* and *‘tearing’* forces

•These elements are often also referred to as structural members

Ties

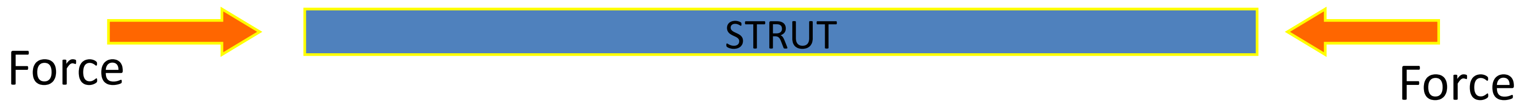
•Ties are members subject purely to tension (pulling). A tie can be a rigid member such as a tube, or simply a wire.



•Can you see any elements of the room you are currently in that could be a 'tie'?

Struts

- Struts are members in compression (squashing). It is much more difficult to design a strut than a tie, because a strut is liable to bend or buckle.



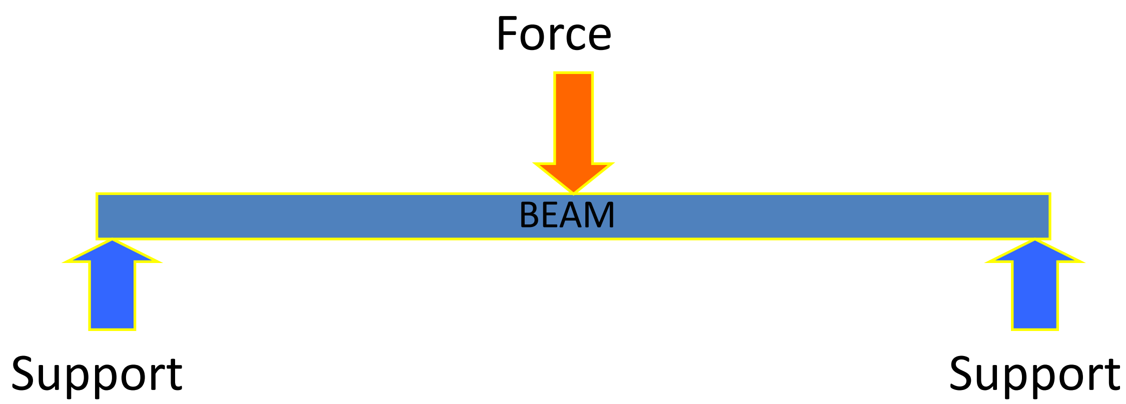
- If a strut is put under compression until it fails, a long strut will always buckle, a short strut will always crack (crush) and a medium strut will either buckle or crack, or sometimes both.

•Hollow tubes generally make the best struts.

Beams

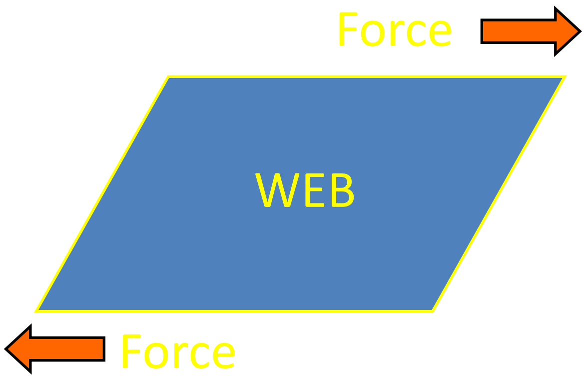
•Beams are members that carry loads at an angle (generally at right angles) to their length, and take loads in bending.

•The beams in an airframe include most of the critical parts of the structure, such as the wing main spars and stringers. Even large structures in the aircraft are acting as a beam, for instance, the fuselage.



Webs

- Webs (or shear webs) are members carrying loads in shear, like tearing a piece of paper. The ribs and the skin within the wing itself are shear webs.



- Have a look around the room you are now in, and see if you can spot any of the members we have looked at used in normal everyday things?

Practical Examples

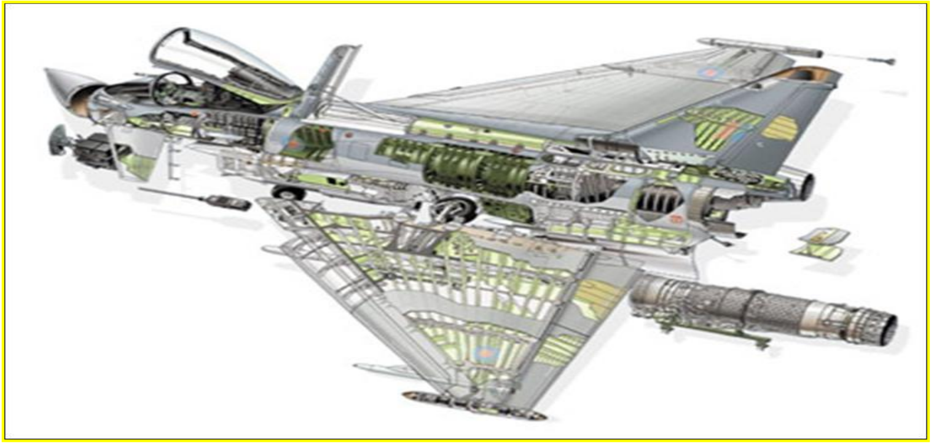
- **Table Leg:** Strut
- **Table Top/Door:** Shear Web
- **Table Top Rail/Door Lintel:** Beam

•But did you spot any **Ties**?

• These are not so common in a normal room, but keep an eye out whilst in the rest of the building, and see if you spot anything.

Airframe Structures

•You may get the idea that each part of an airframe is either a **Tie**, a **Strut**, a **Beam** or a **Web**, but this is not always the case.



•Some items, such as wing spars, act almost entirely as one type of member, but others act as different members for different loads. For instance, the main spar near the fuselage will transmit load in bending and in shear.

Airframe Structures

- By carefully mixing these members, and making sure that each part of each member is taking its share of the loads, the designer will achieve the greatest strength with minimum weight, and so get the best operating efficiency and maximum safety.

- As an example, let us look at how we could reduce the weight of a solid metal beam being used as a bridge across a stream.

The Cantilever

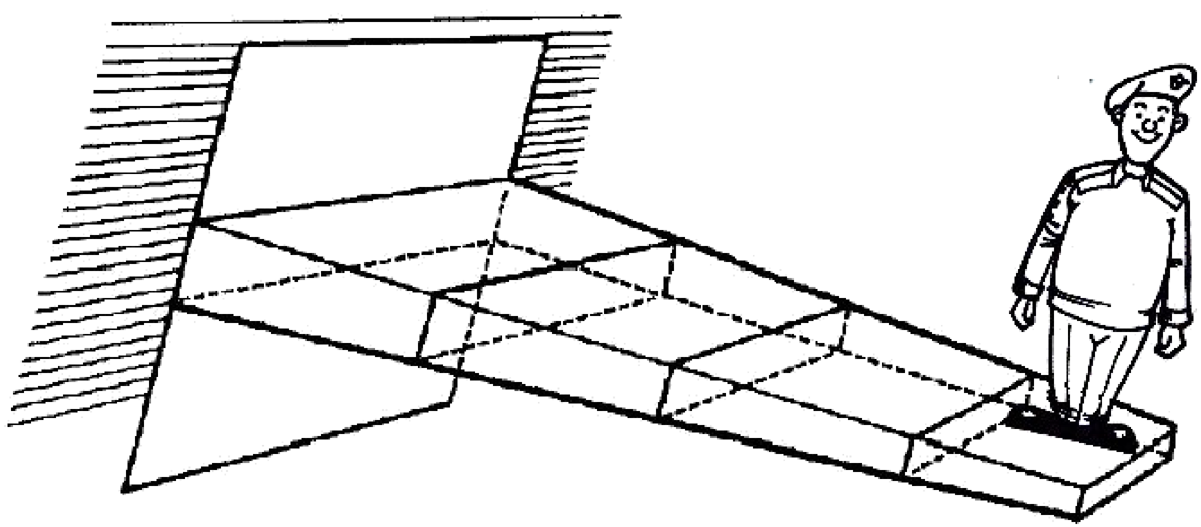
- The supported end needs to be strong enough to carry the weight and bending from the cadet *plus* the whole of the structure.

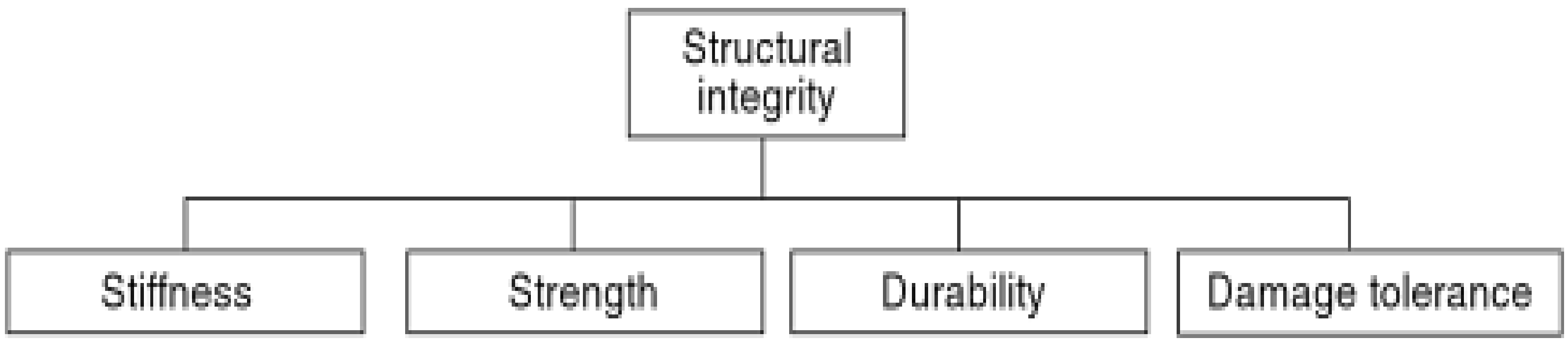
- We would want to make this bigger than our previous bridge.

- The strongest, lightest structure to do the job of our diving board would look like the previous picture. This is called a ***cantilever structure***.

What is a Cantilever

- Like the supported structure, the cantilever will still bend downwards, but this time the top will be in tension (like a tie) and the bottom in compression.





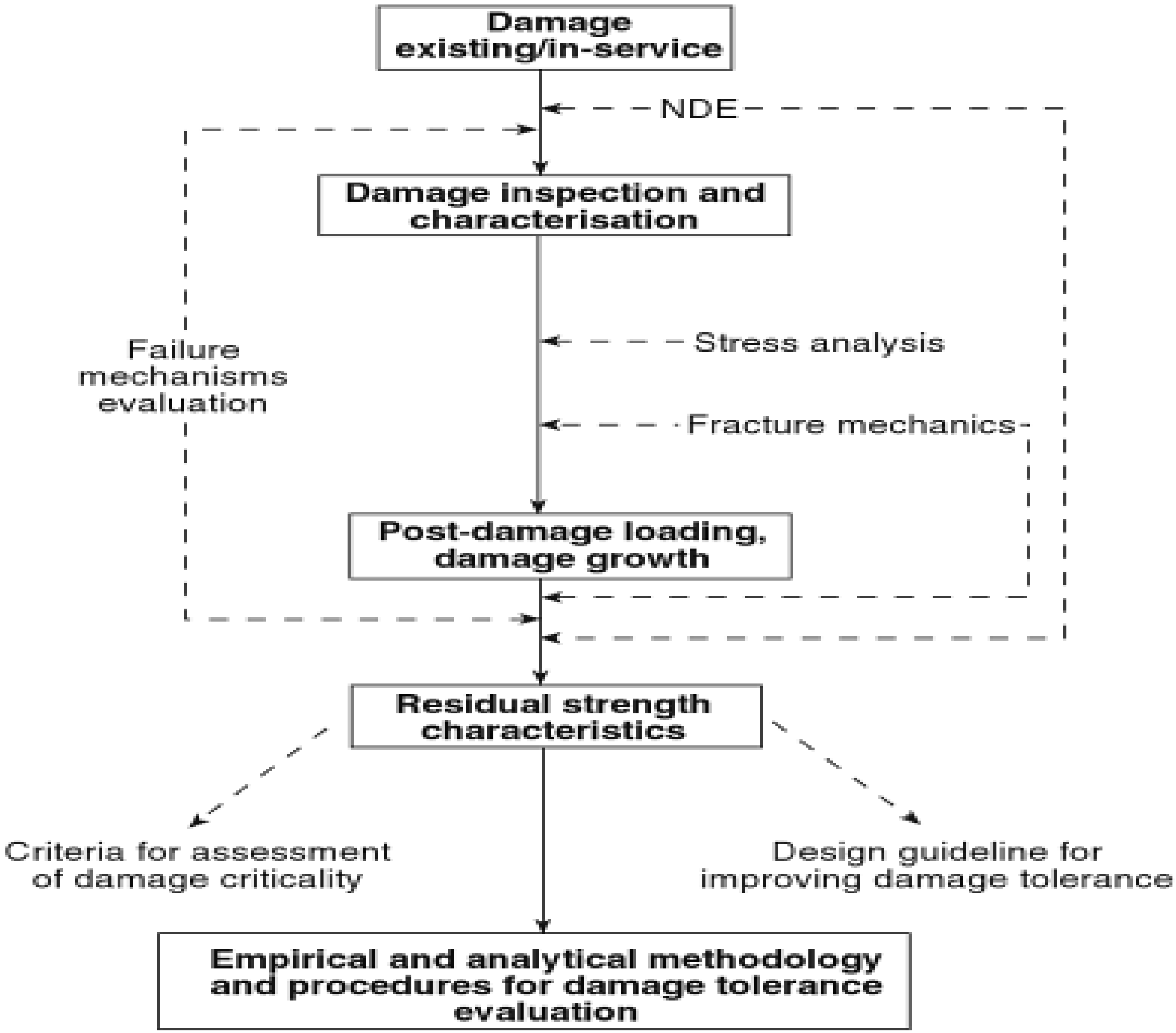
Structural integrity issues.

Damage Tolerance

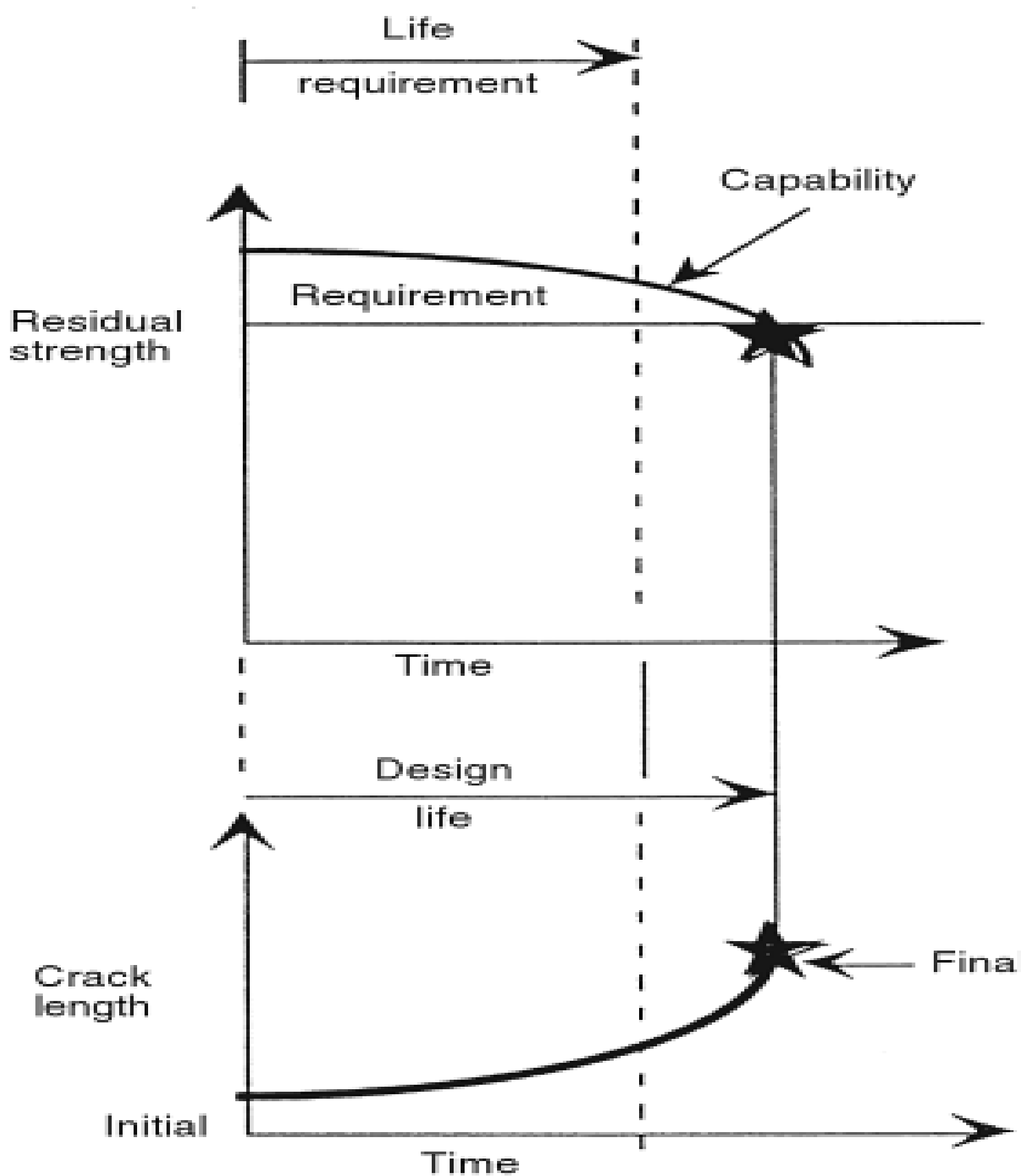
- The term damage tolerance as known today was traced during 15th century and Leonardo Da Vinci's notebook on the design of flying machines.
- He addressed the safety aspects of structural design for wings by including a built in redundancy in the design.
- If one cord of a wing structure failed, a second would be in position to serve the same function as the failed component. – FAIL SAFE concept of DESIGN

- Damage Tolerance concept for design are

1. The acceptance that damage will occur.
2. That an adequate inspection system is available to detect the damage.
3. That adequate strength can be maintained in the damaged structure.



Damage tolerance concepts.



Residual strength, damage, service life.

UNIT-III

DESIGN OF WING, TAIL UNIT STRUCTURES

DESIGN LOADS

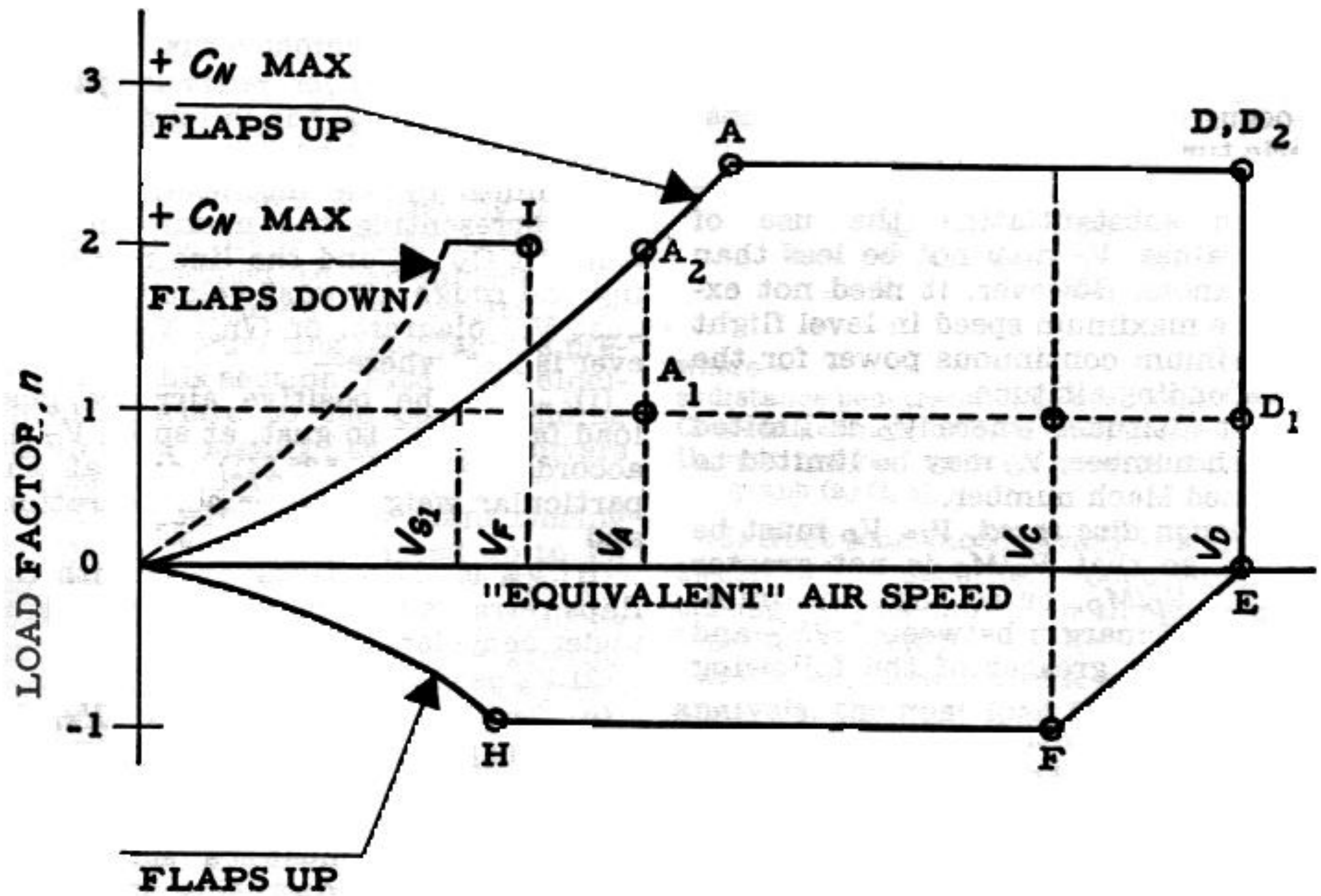
- **Flight Maneuver & Gust**
- **Ground Loads**
- **Landing loads**
- **Ground handling loads**
- **Taxi & ground maneuver**
- **Towing loads**
- **Jacking & tie-down loads**
- **Control Surface & System Loads**
- **Emergency Landing Conditions**
- **Supplementary Conditions**
- **Fatigue Evaluation**
- **Lightning Protection**

MANEUVER LOADS

- **Response to Control Input or Command**
  - **Pilot**
  - **Automatic flight control system**

- **Symmetric**
  - **Balanced maneuvers**
    - **Steady state**
      - **Zero pitching acceleration**
  - **Checked maneuvers**
    - **Rational pitch vs. time profile**
  - **Unchecked maneuvers**
    - **Maximum control deflection**

Maneuver Design Load Factors



GUST LOADS

- **Gust is an Atmospheric Disturbance**
  - **Direction - change in angle of attack**
  - **Velocity - change in local airspeed**
- **Result of Gust is Change in Aerodynamic Force Acting on Airplane**
  - **Acceleration - change in load factor**
- **Two Structural Load Components**
  - **Rigid body response**
  - **Dynamic response due to airplane flexibility and gust velocity profile**

GROUND LOADS

- Ground Loads are Computed using Weights and Centers of Gravity Which Result in Maximum Design Loads in Each Landing Gear Element
  - Forward, aft, vertical and lateral centers of gravity locations must be considered

Landing Conditions

- Level landing (nose landing gear arrangement)
  - Main gear in contact, nose gear clear
  - All three gear in contact
- Tail down landing
- One-gear landing
- Drift landing
- Rebound landing

Ground Handling Loads

- Taxi, takeoff and landing roll
  - Roughest ground reasonably expected
- Braked roll
  - Main gear in contact, nose gear clear
  - All three gear in contact
- Turning
  - Side load due to centrifugal load factor
- Nose wheel yaw & steering
  - Side load on nose gear
- Pivoting
  - Landing gear torque
- Reversed braking

SUPPLEMENTARY CONDITIONS

- Engine Torque
  - Operating torque
  - Engine acceleration
  - Sudden engine stoppage
- Side Loads on Engine Mounts
- Pressurized Compartments
- Unsymmetrical Loads Due to Engine Failure
- Gyroscopic Loads
- Speed Control Devices

DAMAGE TOLERANCE & FATIGUE EVALUATION OF STRUCTURE

“An evaluation of the strength, detail design, and fabrication must show that catastrophic failure due to fatigue, corrosion, manufacturing defects, or accidental damage, will be avoided throughout the operational life of the airplane”

- Damage Tolerance Evaluation
  - Address catastrophic failures due to fatigue, corrosion & accidental damage
    - Crack growth analysis and/or tests
    - Residual strength evaluation
    - Inspection & maintenance procedures
  - Applied to single load path structure
  - Applied to multiple load path and crack arrest “fail safe” structure where it cannot be demonstrated that failure will be detected during normal maintenance

- Fatigue (Safe Life) Evaluation
  - May be used when the application of the damage tolerance requirements is impractical
- Sonic Fatigue Strength
  - Sonic fatigue cracks are are not probable in flight structure subject to sonic excitation, or
  - Catastrophic failure is not probable if sonic fatigue cracking occurs
- Instructions for Continued Airworthiness
  - The data developed to demonstrate compliance with this requirement forms the basis for the airframe instructions for continued airworthiness

LIGHTNING PROTECTION

- The Airplane Must be Protected Against Catastrophic Effects of Lightning
  - Electrical bonding
  - Design of components to preclude the effect of a strike
  - Diverting electrical current

PROOF OF STRUCTURE

- Requirement
  - Limit load
    - No detrimental permanent deformation
    - Deflections may not interfere with safe operation
  - Ultimate load
    - Structure must be able to support the load for 3 seconds
  - Dynamic testing may be used

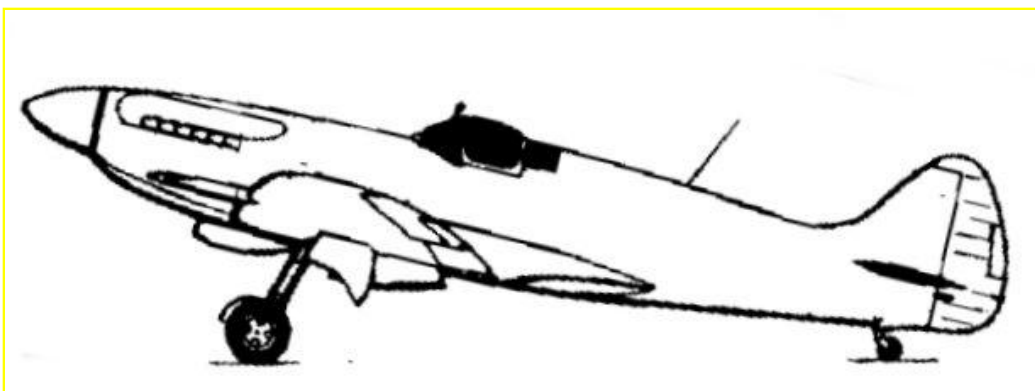
UNIT-IV

DESIGN OF FUSELAGE, LANDING GEAR, ENGINE MOUNTS

The *‘Tail Sitter’* Undercarriage

Historically, early aircraft had a tail wheel arrangement instead of the nosewheel.

These aircraft are referred to as ***‘Tail Sitters’*** due to the attitude they took when on the ground.



Tri-cycle Undercarriage

Most modern aircraft are usually supported on the ground by three units - two main wheels and a nose wheel.

Advantages of Tri-cycle Layout

The main advantages of employing a tri-cycle undercarriage layout are;

- Ground manoeuvring is easier with a steerable nose wheel.
- The pilot’s view is improved during taxying.
- The aircraft floor is horizontal when it’s on the ground.
- Aerodynamic drag on take-off is reduced, giving much better take-off performance.
- Directional stability on the ground is improved, because the CG is forward of the main wheels.
- Braking is more straight forward, and brake parachutes can be used.
- There is less tendency to float and bounce on landing, making landing easier.

Disadvantages of Tri-cycle Layout

Despite all the advantages of utilising the tri-cycle undercarriage layout within the airframe design, there are some disadvantages;

- Nose wheels need to be stronger and therefore heavier than tail wheels.

- More damage is done to the aircraft if the nose wheel collapses

Large Aircraft Undercarriage

Types of Oleo Leg

Most service aircraft, as well as most civil transports, are fitted with **oleo-pneumatic** or **oil-compression** type undercarriages.

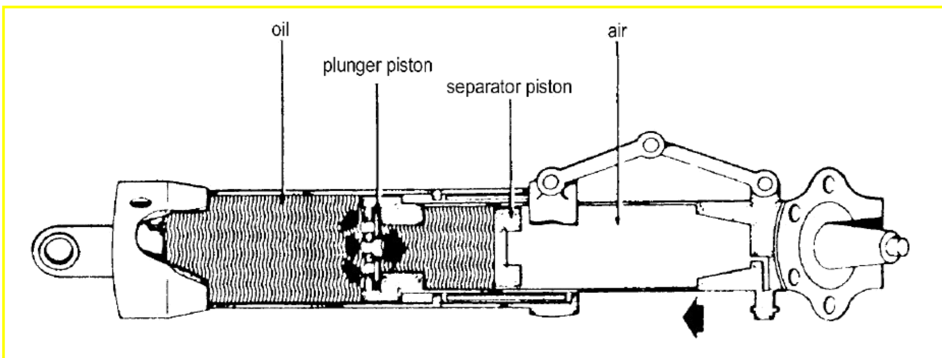
The operation of both units is very similar.

- An **oleo-pneumatic** unit compresses air or nitrogen gas.
- An **oil-compression** unit (often known as liquid spring) works by compressing oil.

How an Oleo Works

- Compressing the strut reduces the volume inside and compresses the gas or oil, like operating a bicycle pump.

- Any tendency to bounce is prevented by forcing the damping oil through small holes, so that the strut can only extend quite slowly.

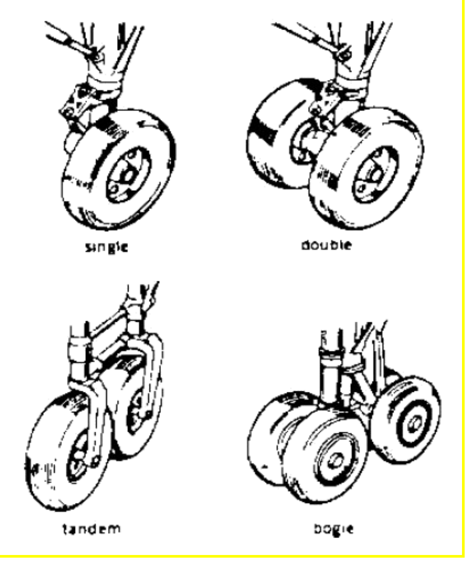


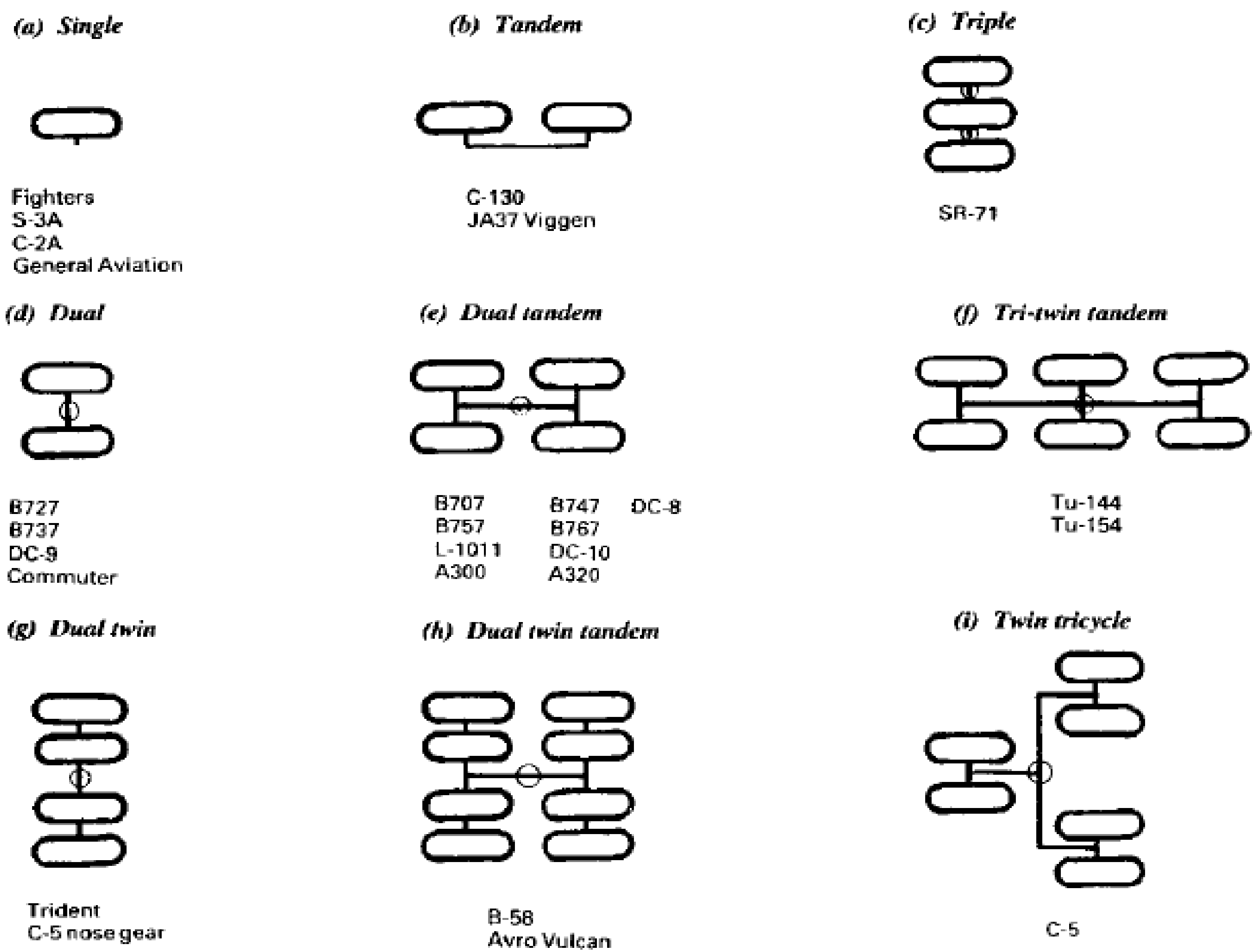
- The gas or oil will stay slightly compressed when it has the weight of the aircraft on it, so it is cushioned whilst taxying.

Wheel Units

All of these factors mean that the undercarriage positions must be very carefully designed.

Each main-wheel unit consists of a single, double, tandem or bogie unit, of four or more wheels.

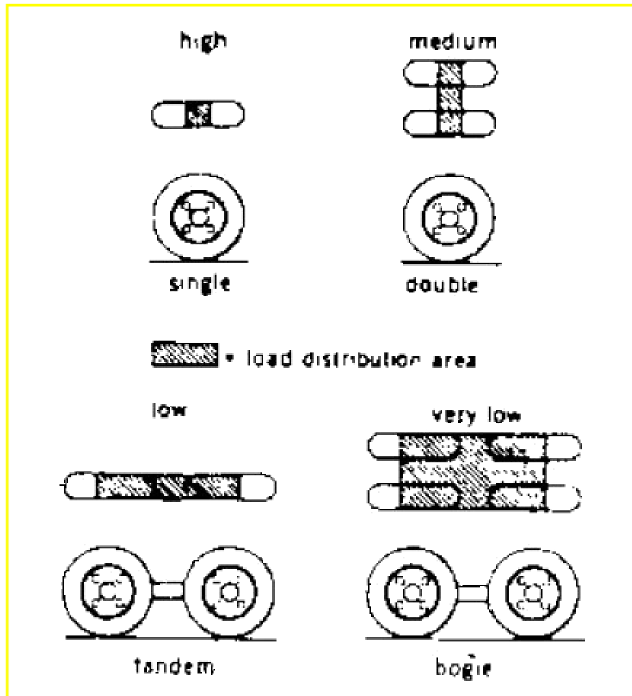




Different types of Wheel Arrangement

Load Distribution

By having the weight spread over a number of wheels, the contact pressure of the undercarriage is reduced. This leads to reduced undercarriage weight and increased safety if a tyre bursts on landing.



Civil Aircraft Examples

The images below show the more robust wheel units as utilised on civil aircraft designs.

In this case, both images are of main wheel units as fitted to the Airbus A380

Jockey Wheel Units

- A variation of the tandem arrangement is the ***Jockey Unit***, which comprises two or three levered legs in tandem on each side of the fuselage, sharing a common horizontal shock absorber.
- Amongst the advantages of this design are excellent rough-field performance and the ability to lower the aircraft down (kneeling) for easier loading.
- The units also retract into a small space, without penetrating into the load space.
- This makes this arrangement ideal for transport aircraft like the Hercules.

Jockey Wheel Unit Example

A ***Jockey Unit*** on the Antonov AN-225 Mriya transport aircraft.

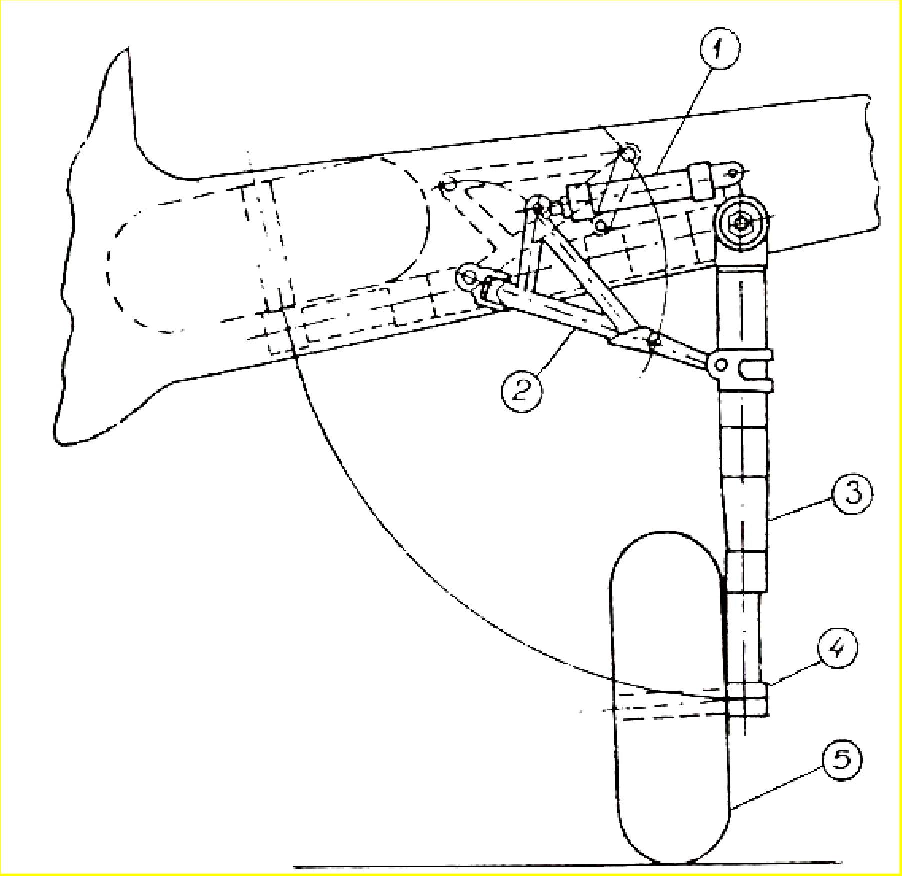
Undercarriage Retraction

- An undercarriage causes a lot of drag in flight, so it is retracted into the wings or fuselage in most aircraft, except when needed.
- In most cases, a hydraulic jack is used to pull the undercarriage legs, about a pivot at the top.
- The doors to the undercarriage well may be attached to the legs, or may use separate jacks to open and close them.
- In many cases the undercarriage needs to fit into a very small space, and the units may be turned, twisted or folded to enable this to be done.

Retraction System Components

The components of a simple landing gear and retraction system

1. Retraction Jack
2. Down-lock
3. Oleo Leg
4. Axle
5. Wheel



Undercarriage Doors

It is important that the doors open before the undercarriage units extend or retract, and close afterwards.

Undercarriage System Failure

So what happens if the hydraulic system fails – how does the undercarriage get lowered?

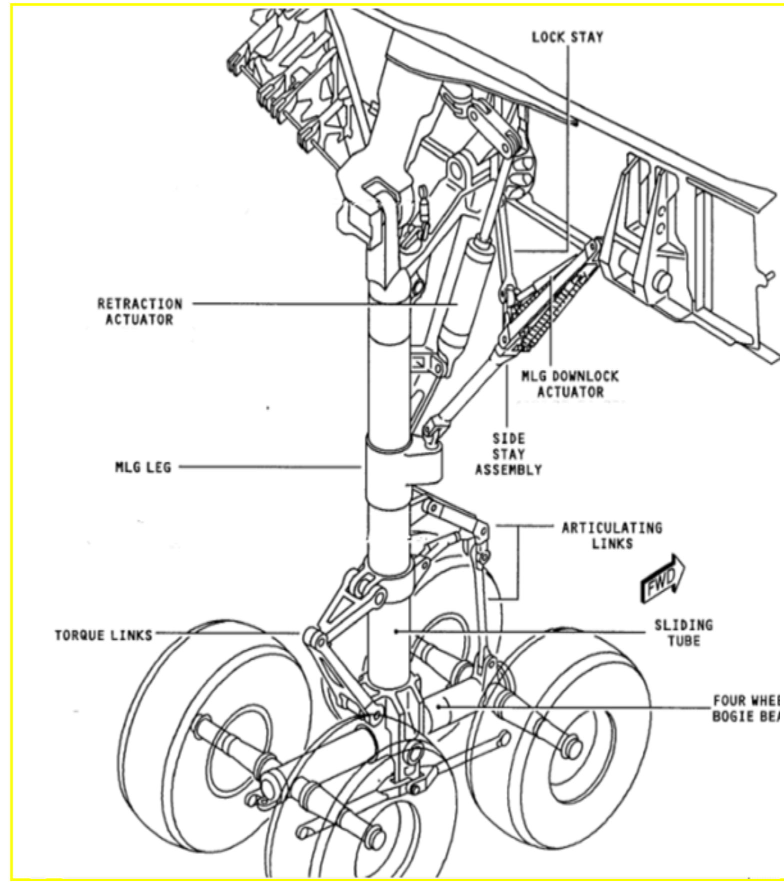
Airframe designers must consider the potential for failure, so that the aircraft can be landed safely.

- It is common for pressure bottles to be fitted, which store enough pressure to allow the undercarriage to be extended once, if the system fails.
- The undercarriage must then lower to it's full extension under it's own weight.
- **Nose Wheels** are normally retracted forwards and in an emergency, the aerodynamic drag will assist them to reach full extension.

Undercarriage Locks

To prevent undercarriage collapsing on the ground, and to hold it firmly in position in flight, ***uplocks*** and ***downlocks*** are fitted.

It would be catastrophic if the undercarriage were retracted accidentally with the aircraft on the ground, so additional locks are fitted, disabling the retraction mechanism.



Brake Systems

Modern large aircraft often land at high weights and speeds.

This means that the braking system must be capable of absorbing and dissipating very large amounts of heat, as the energy of motion is converted into heat.

Types of Brakes

There are two main types of brake:

- Drum Brakes
- Disc Brakes

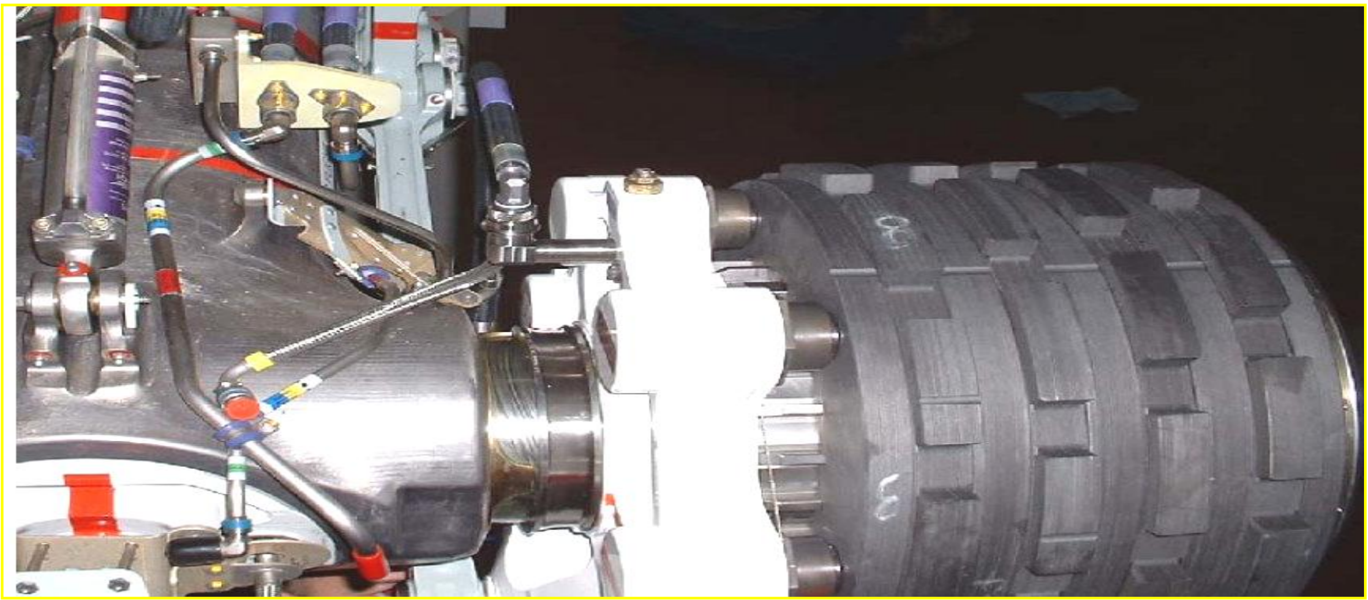
The **Drum Brake** is rarely used, because it suffers from poor heat dissipation, causing the brakes to **overheat** and **fade**.

Fading is where the brakes lose their braking effectiveness as their temperature increases.

The **Disc Brake** is much more effective at dispersing the heat produced, and maintain their effectiveness during long periods of heavy braking.

Disc Brakes

Large aircraft may have quite a number of discs in each wheel, to get the required braking forces and heat dissipation.



Multi-disk brake unit – Airbus A380

Anti-Skid

- An anti-skid unit, called a **Maxaret** unit, prevents skidding by detecting when the wheel or wheels on any unit stop turning, and momentarily releases brake pressure on that unit only.

- This gives the aircraft the ability to stop in the shortest possible distance without loss of control.

- Similar units, known as **ABS**, are fitted to many cars, and work in the same way.

Alternative Braking Methods

- Another form of braking is air brakes, used in flight, which consist of large plates fitted to the fuselage (or wings – Viking and Vigilant) which can be lifted into the airflow when required.

- They cause a large increase in drag to slow the aircraft.

- After touch-down, reverse thrust can be deployed, by moving doors into the jet exhaust to deflect the flow forwards.

- Turbo-prop engines can achieve a similar effect by changing the pitch of the propeller to reverse the airflow.

Alternative Undercarriage Types

Over the years, many different designs have been tried.

- An experiment was tried in the 50's, when an aircraft with no undercarriage was tested – the idea was quickly abandoned.

- Another experiment was with tracked undercarriages for soft field landing on the Convair B-36 – again this idea wasn't pursued.

Airbus A330, **Picture from wikipedia website**

Aircraft Landing Gear

Landing Gear Failure

Landing Gear Failure

Landing Gear Failure

Picture from www.allstar.fiu.edu/aero/flight14.htm
Improperly loaded Boeing 747

Three common types of landing gear

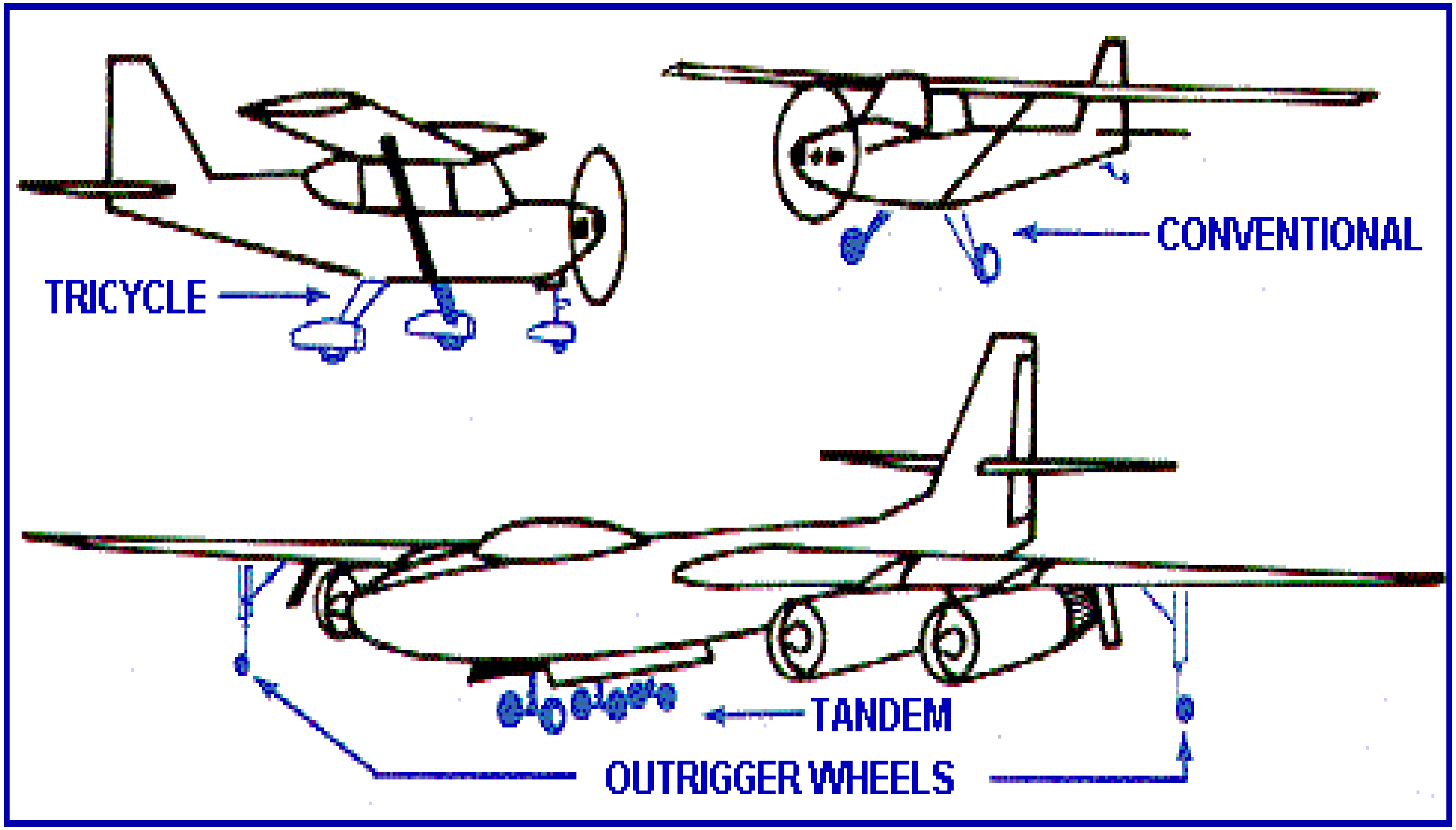
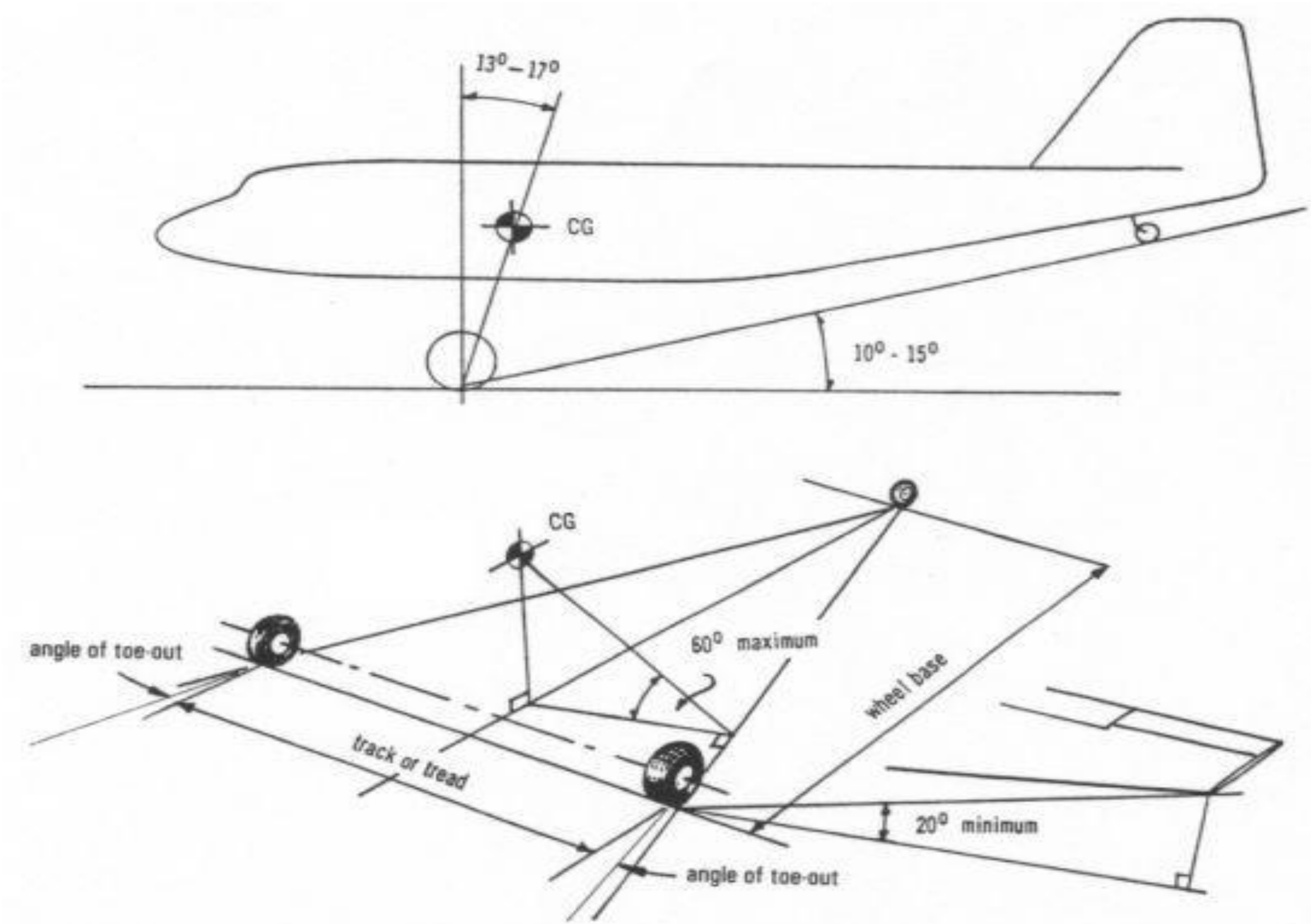


Figure 1-8 Three basic types of landing gear arrangements

Purpose of Landing Gear

- To provides structural support to the aircraft for ground operation
- To provides maneuverability for ground operation
- To provides a mean to absorb unusually loads incurred during landing and ground operation

Design considerations



Design considerations

- Maximum strength
- Minimum weight
- High reliability
- Overall aircraft integration
- Low cost
- Airfield compatibility
- Landing Gear should locate near the center gravity (CG) of the plane
- CG location are depended on aircraft configuration, loading, fuel state.

Landing Gear Developments

Noise Reduction

- As engines become quieter, landing gear is now making a dominating component of noise in large commercial aircraft
- European co-financed research project Silencer is trying to create low noise landing gear design
- Desires 10db reduction in landing gear noise by 2020, has only dropped 3db so far

Gear up landing prevention system

- NTSB reports that the majority of gear up landings are due to equipment malfunctions.
- Gear up landing prevention systems will disengage autopilot and alarm at a preset safety altitude if every piece of landing gear is not extended and locked.
- It can be disengaged if a belly landing is the only option.

Materials

- Composites will be integrated into gear because they are stronger and cheaper than the current used high strength steels and titanium

Materials

- Ultra-High Tensile Steels are already being integrated into the A400M and the B-787 landing gear, replacing the low-alloy steels.
- Research into organic matrix composites and metal matrix composites using titanium are promising, though still very expensive.

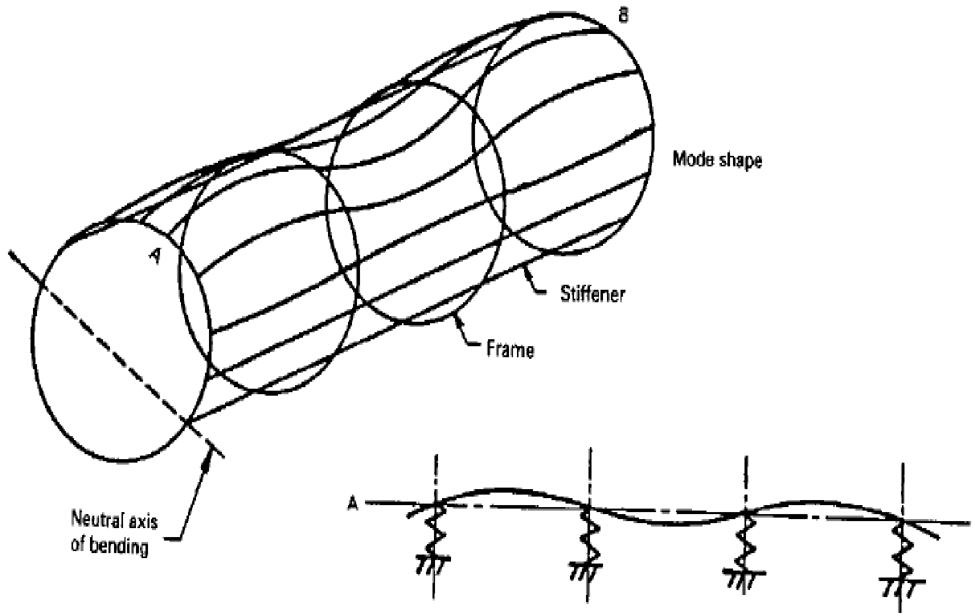
Corrosion

- Many modern aircraft have cadmium in the landing gear to prevent corrosion and chrome plating to reduce friction wear.
- Advancements in stainless steels and titanium will replace the cadmium in landing gear.

UNIT-V

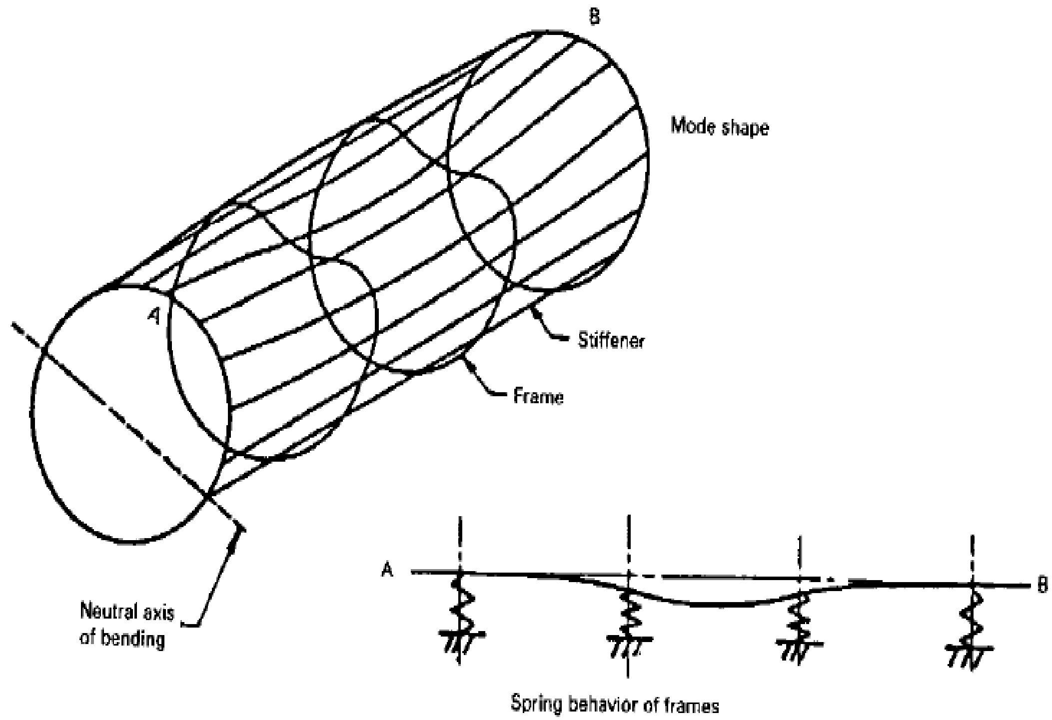
FATIGUE LIFE, DAMAGE TOLERANCE, FAIL-SAFE DESIGN-WEIGHT CONTROAND BALANCE

Panel Instability



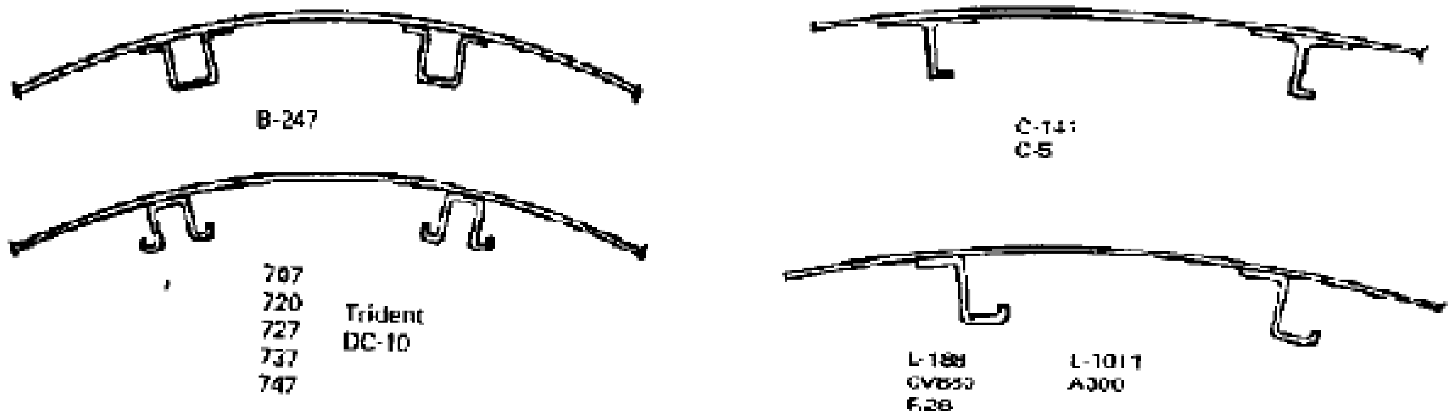
(a) *Panel instability*

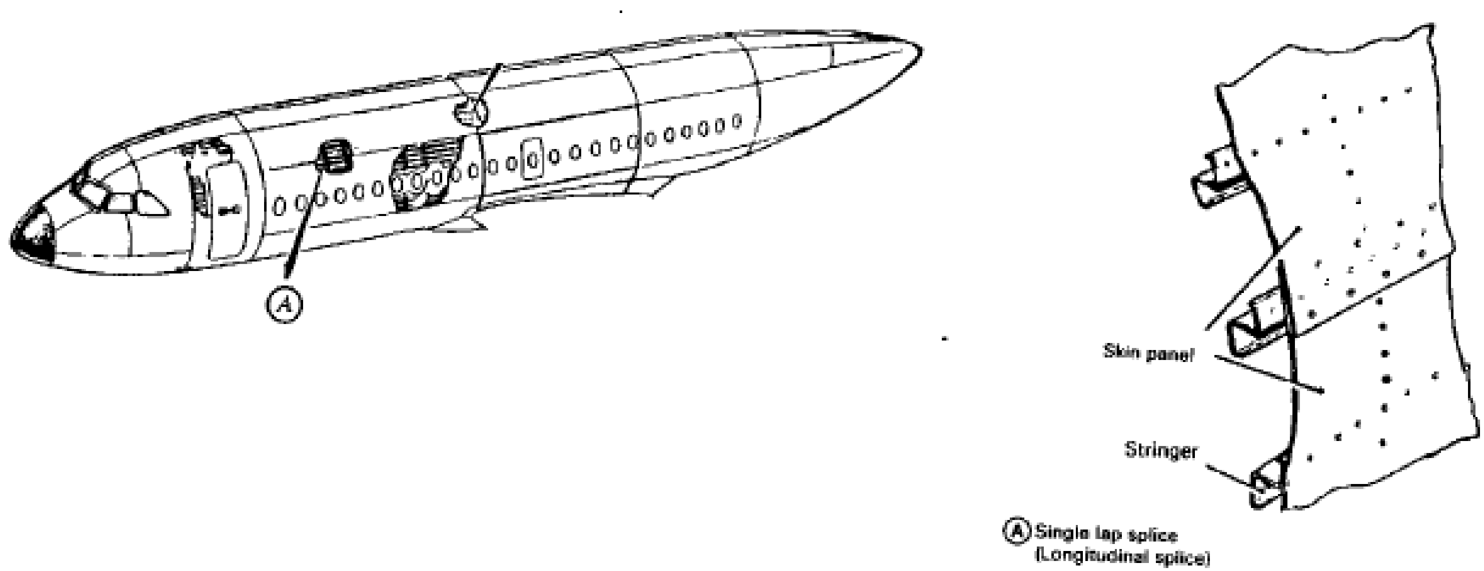
General Instability



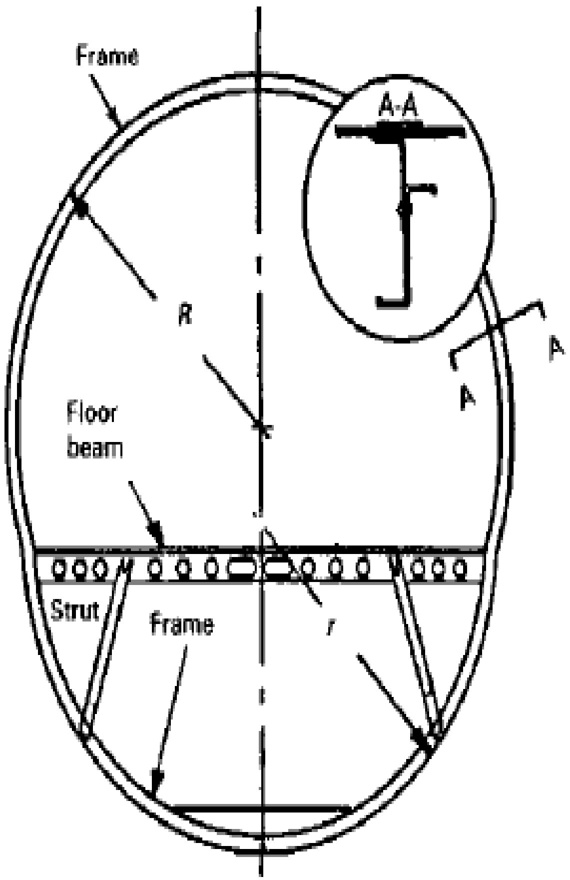
(b) General instability

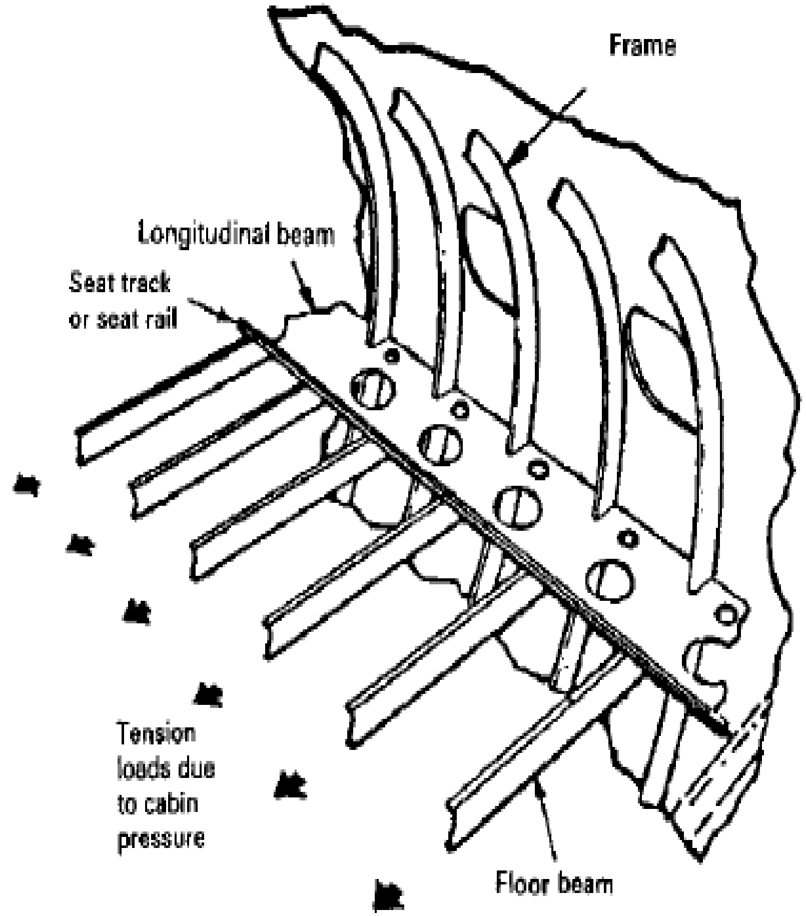
Principal Structural Components

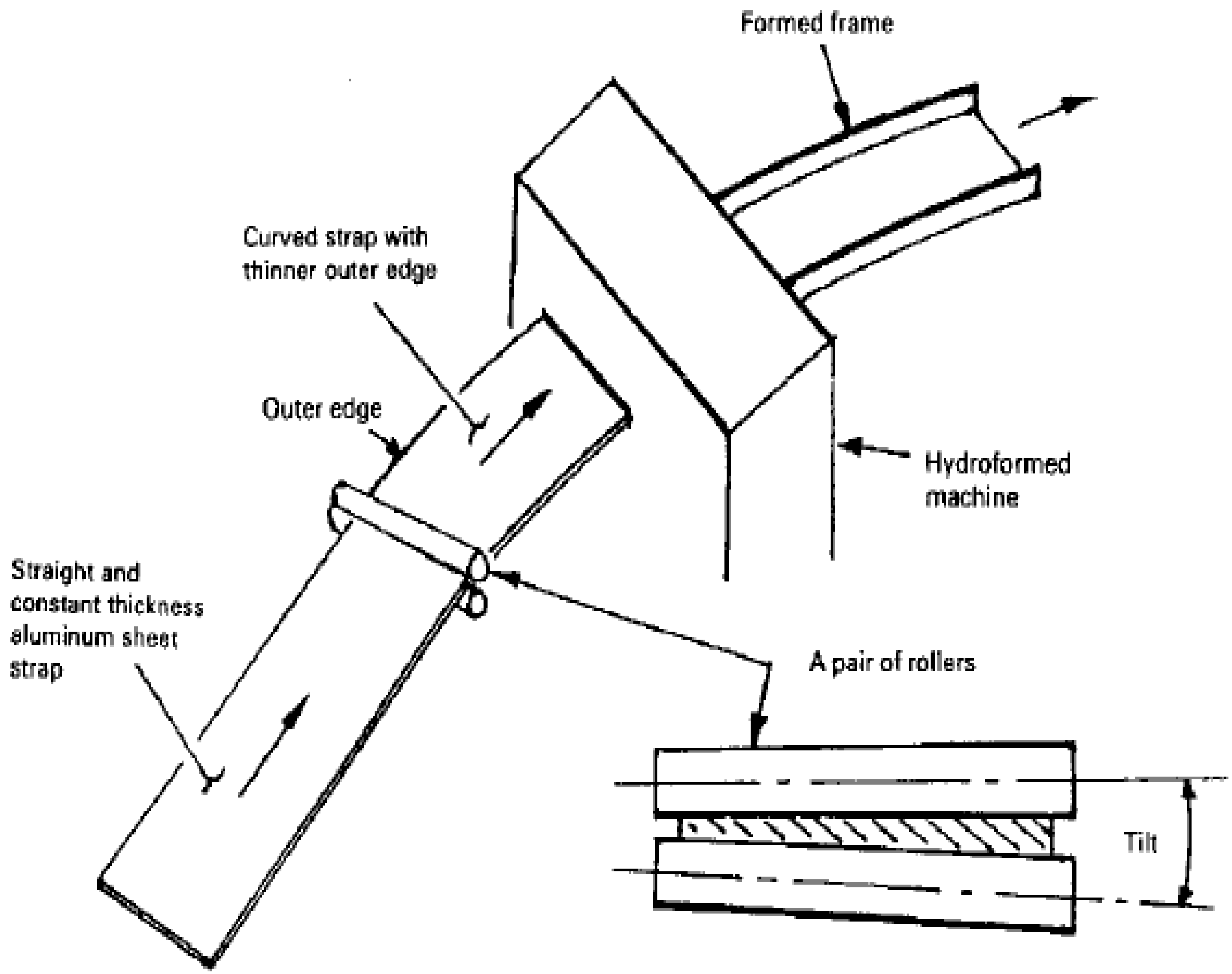




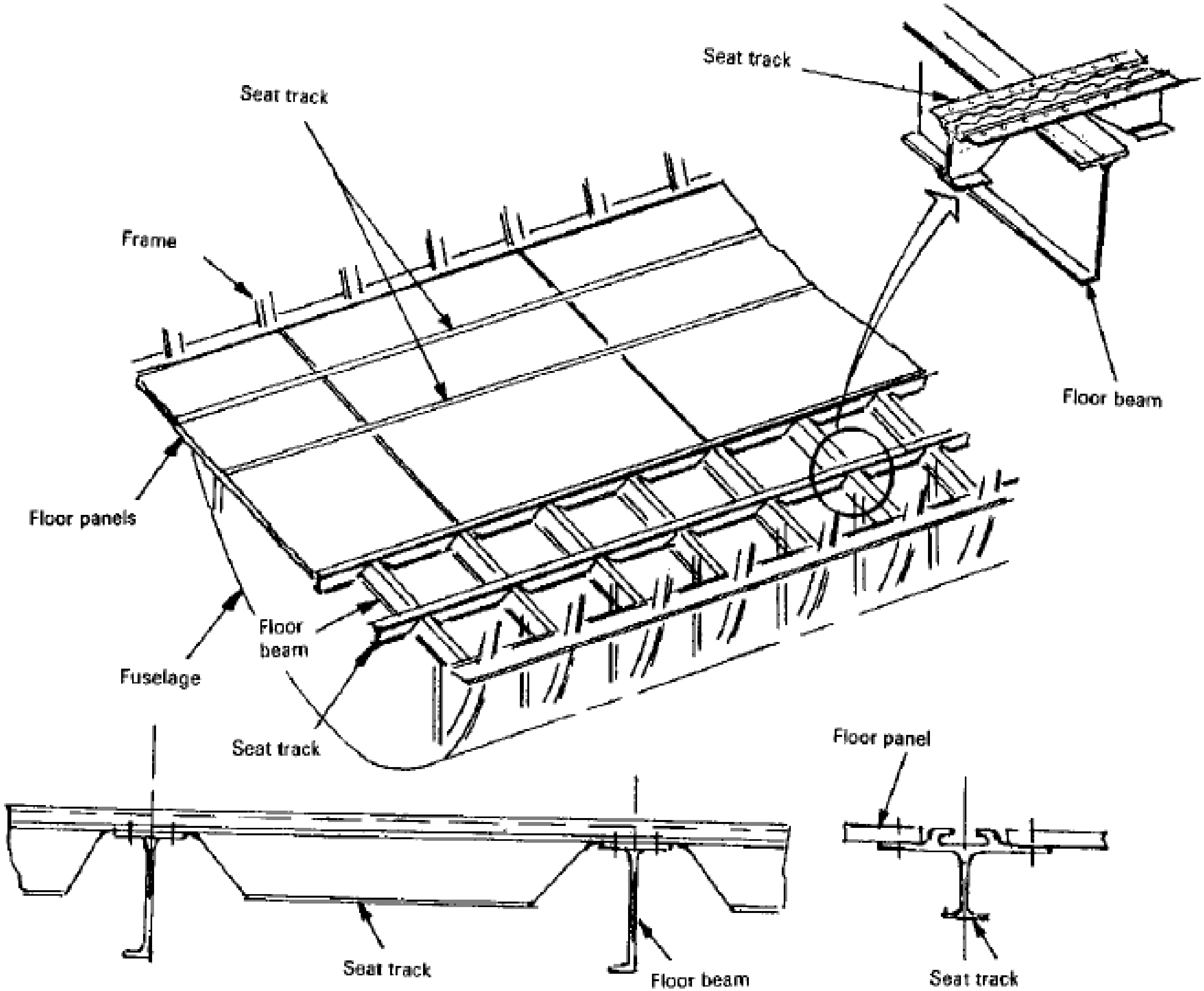
• Frame and Floor Beam

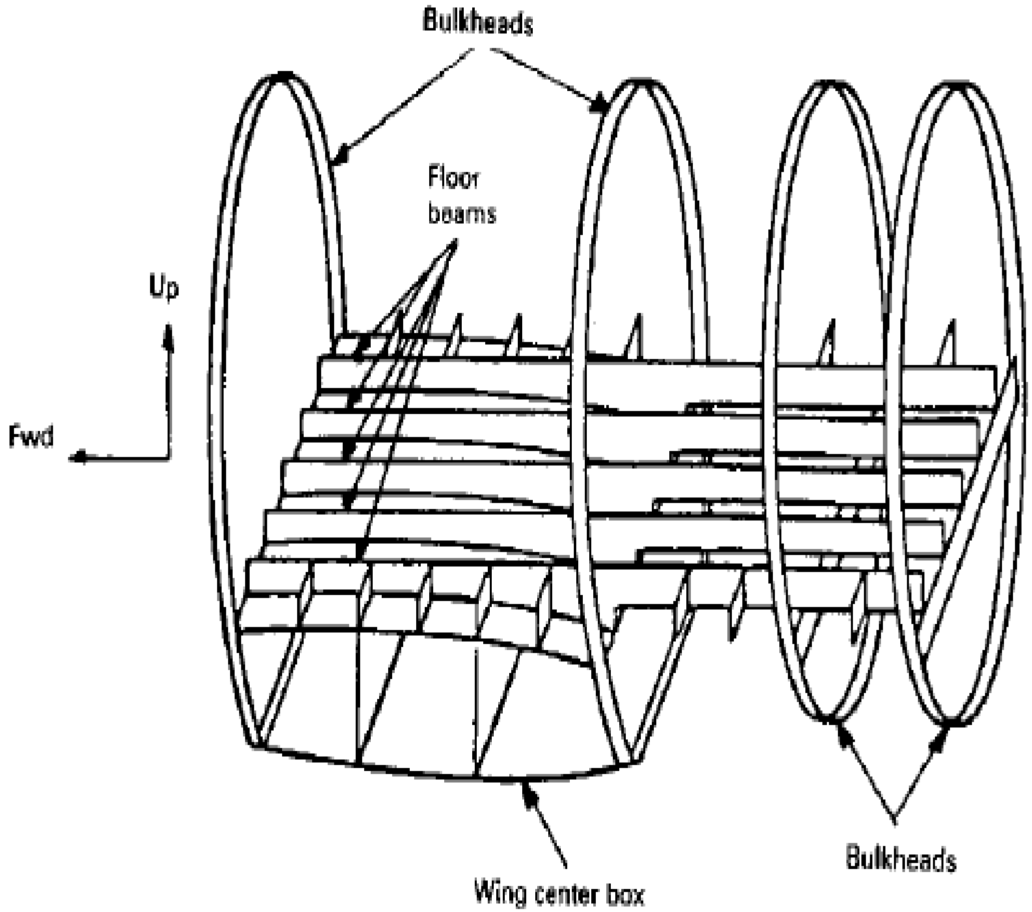






A common process of forming fuselage frame.


Seat track
Seat track
Frame
Floor beam
Floor panels
Fuselage
Floor beam
Seat track
Floor panel
Seat track
Floor beam
Seat track



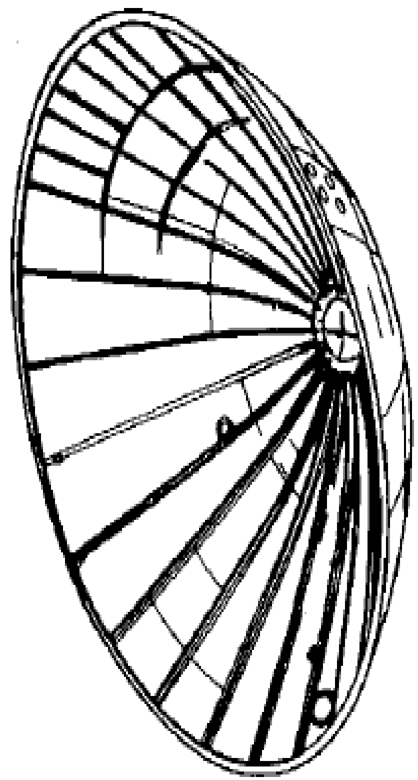
Typical transport fuselage center section floor beams arrangement.

Pressure Bulkhead

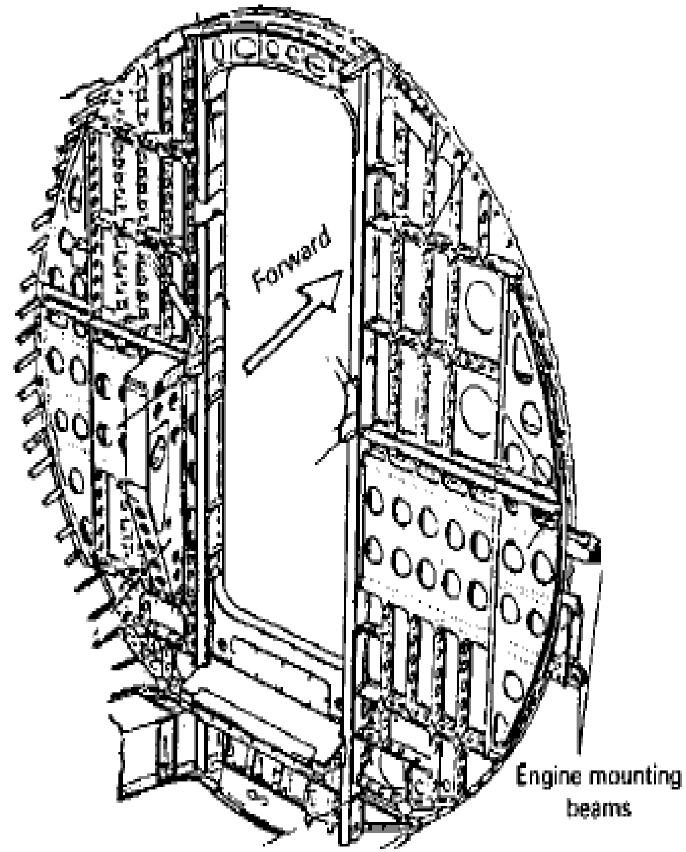
- The cylindrical shell of a pressure-cabin is closed at the rear by some kind of dome in preference to a flat bulkhead, except for supporting rear fuselage engine mount as shown in Figure. which would have to be heavily braced to withstand the pressure.
- From a structural point of view, a hemi-spherical shell provides an ideal rear dome because the membrane stresses for a given amount of material are the least.
- On the basis of this argument, the best shape for the rear dome of a pressure cabin is the hemisphere.

This design is guided by two basic considerations:

1. Owing to the comparatively heavy membrane force involved, it is desirable to avoid any radial offset between the shell and the dome skins.
2. There must not, in the neighborhood of the joint, be any reduction in the longitudinal bending stiffness of the fuselage wall, the maintenance of which the elastic stability of the wall depends on.



(a) Dome



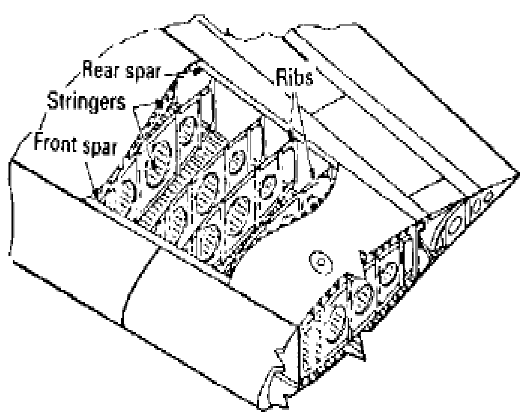
(b) Flat bulkhead

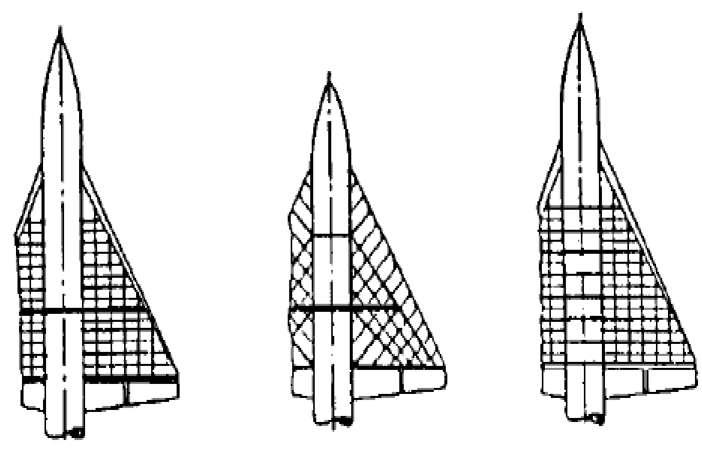
Typical pressure bulkheads.

DESIGN OF WING

WING BOX STRUCTURE

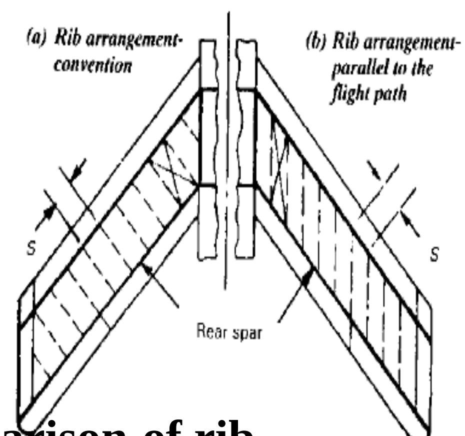
- A wing requires longitudinal (lengthwise with the wing) members to withstand the bending moment which are greatest during flight and upon landing.
- There are several types of wing structure for modem high speed airplanes; thick box beam struc-ture



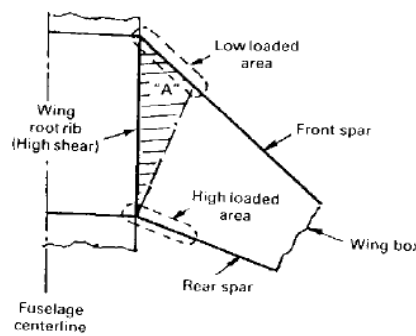


Wing Box Design

- The primary structural design problem is one of general structural layout –
  - First, a large percentage of the wing bending shall be carried by the spars,
  - Second, in which direction should be primary wing ribs run.



Comparison of rib direction (rectangular box)



Wing root load distribution problem of swept wing

Wing Layout

The wing design has to allow for so many factors -planform, spar and stringer location, landing-gear attachment & retraction, power plant, ailerons and flaps.

- Draw planform of wing with the necessary dimen-sions, to scale, to satisfy aspect ratio, area, and sweepback.
- Determine the mean geometric chord
- Locate the front spar at a constant percentage of the chord, from root to tip.
- Locate the rear spar similarly.
- Mark out the aileron. The leading edge of the aileron may be parallel to the rear spar.

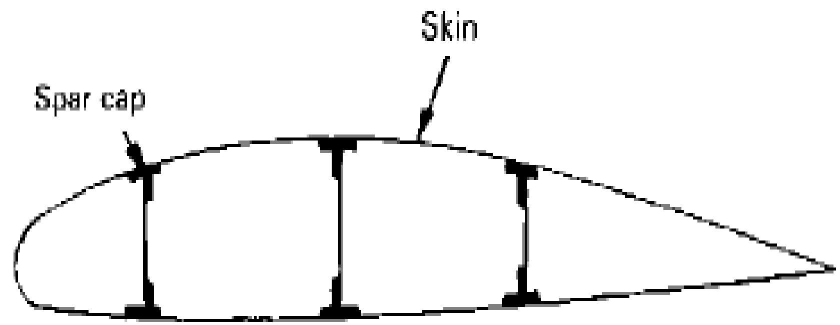
Wing Covers

The disposition of the bending-load resistant material wing structure according to

a) All bending material is concentrated in the spar caps;

b) The bending material is distributed around the periphery of the profile;

c) skin is primarily bending material. Typical wing cross-section in which the bending material is concentrated in the spar caps.



Three spar wing - all bending materials concentrated at the spar caps

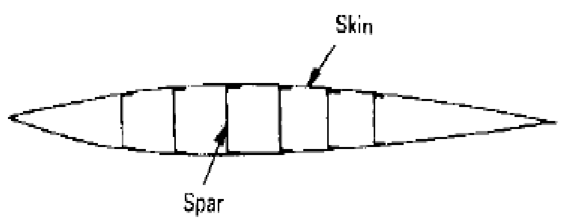
Advantages of the concentrated spar cap type

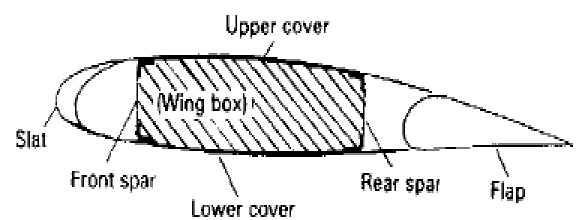
- Simplicity of construction (mostly used on general aviation aircraft).
- Because of the concentration of material, the spar caps can be so designed that buckling occurs near the ultimate stress of the material; this allows the use of higher allowable stresses.

Disadvantages of the concentrated spar cap type

- 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.

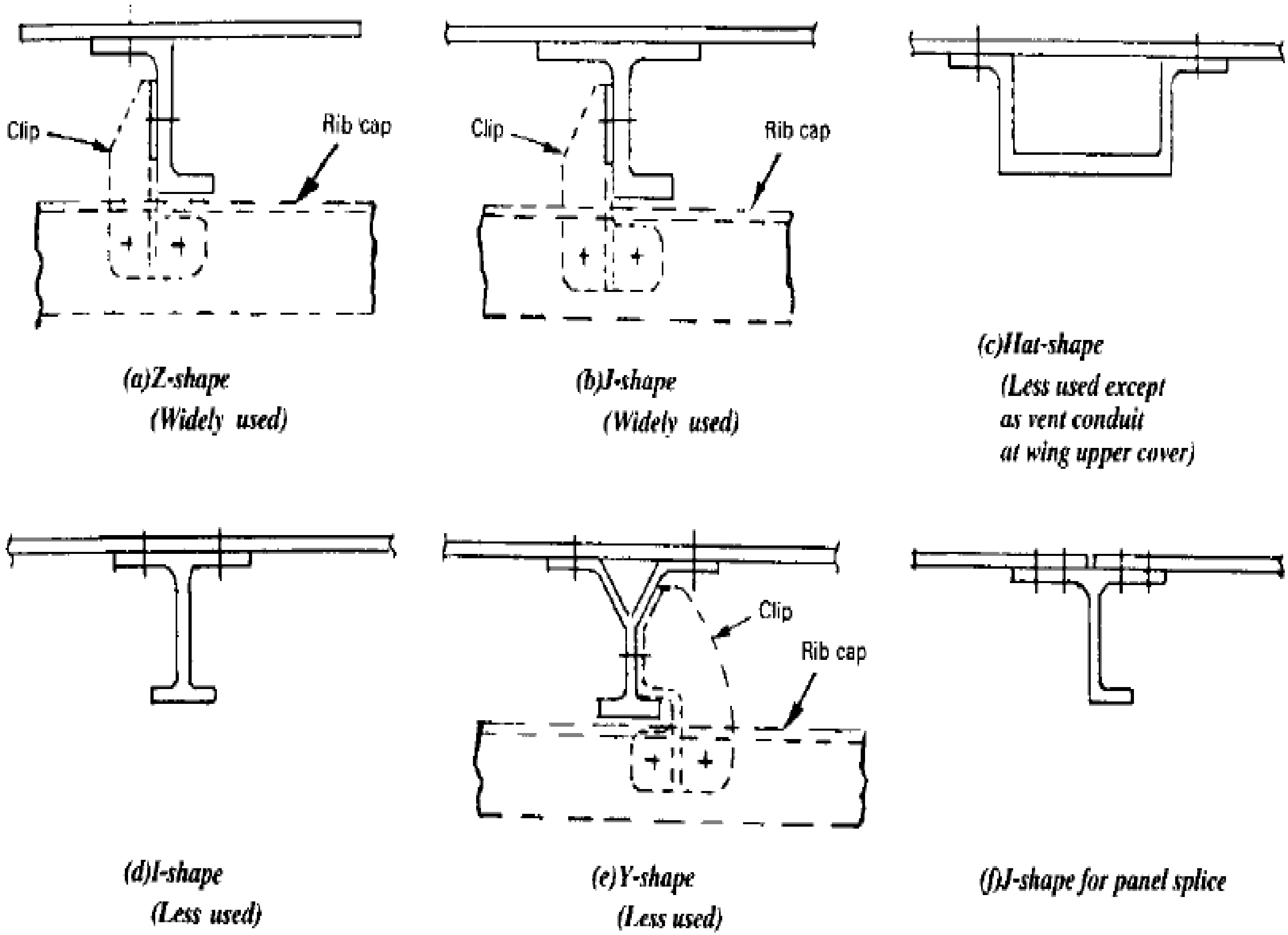
- Typical wing cross sections in which the bending material is distributed around the periphery of the profile..
- In high speed airplanes, the wing structure is usually made of multiple spars which are primarily shear material and carry vertical shear
- The torsional moments are primarily resisted by the skin and the front and rear spars.





Skin-Stringer Panels

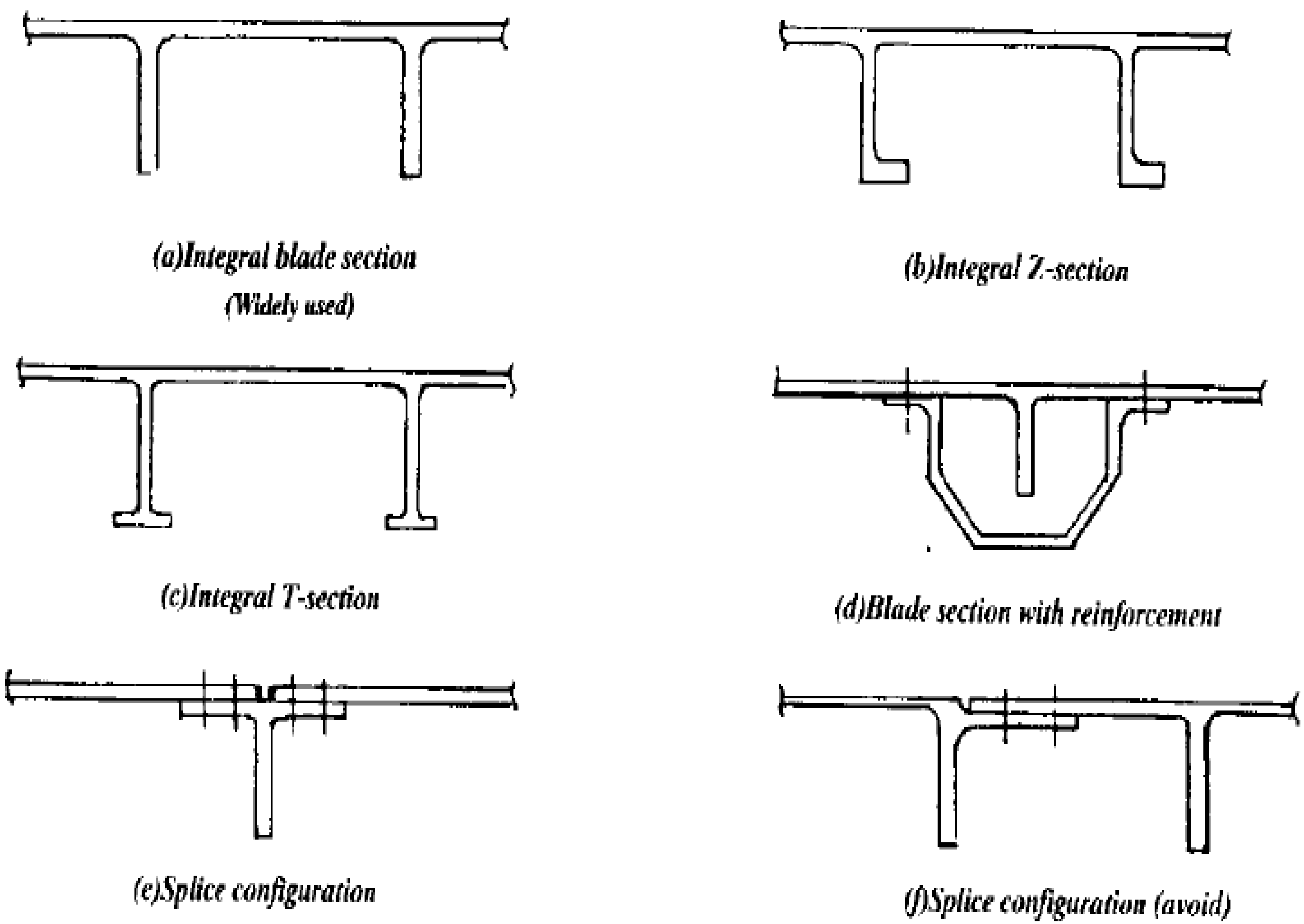
- The most common wing covers of transports are skin-stringer panels as shown in Figure.
- Wing skins are mostly machined from a thick plate to obtain the required thickness at different locations and then required pads can be integral; otherwise the pads or doublers have to he riveted or bonded on the basic skin around cut-outs.
- The machined skins combining with machined stringers arc the most efficient structures to save weight.



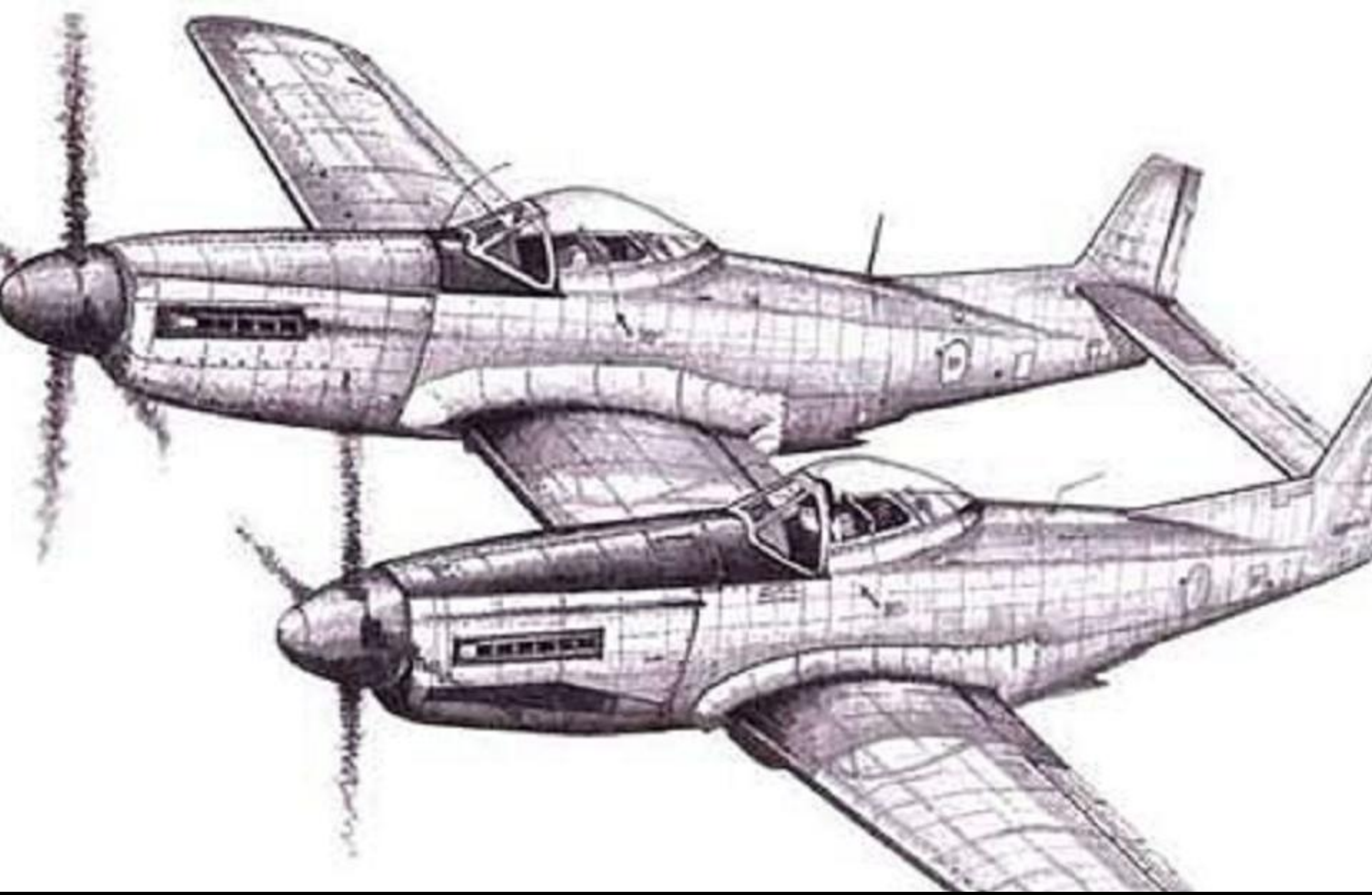
Typical wing skin-stringer panels

Integrally Stiffened Panels

- In aircraft where weight always a critical problem, 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.
- Integrally stiffened structures have their greatest advantage in highly loaded applications because of their minimum section size.
- Investigations have indi-cated that an integrally stiffened section can attain an exceptionally high degree of structural efficiency.



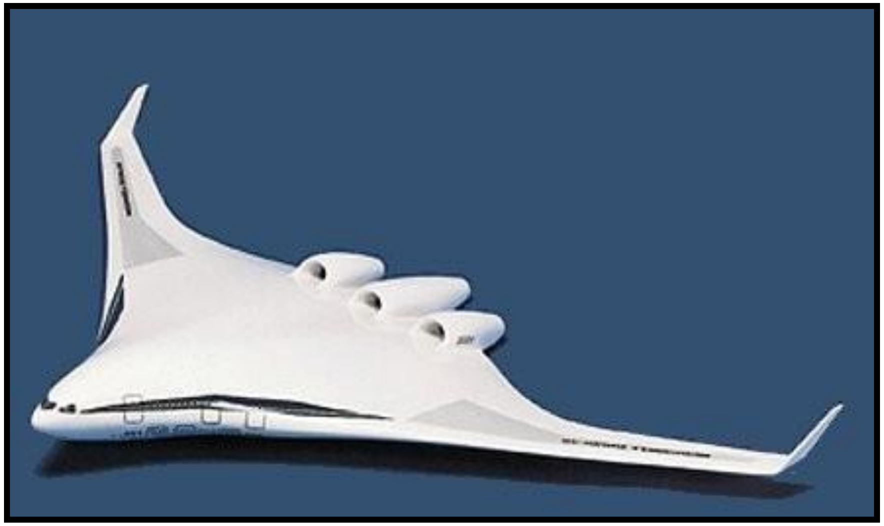
Typical Integral Stiffened Panels

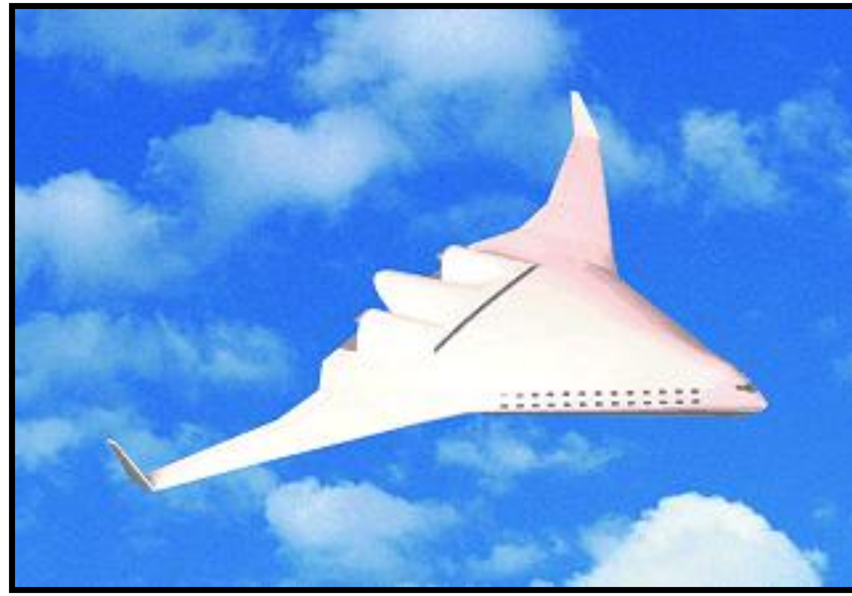


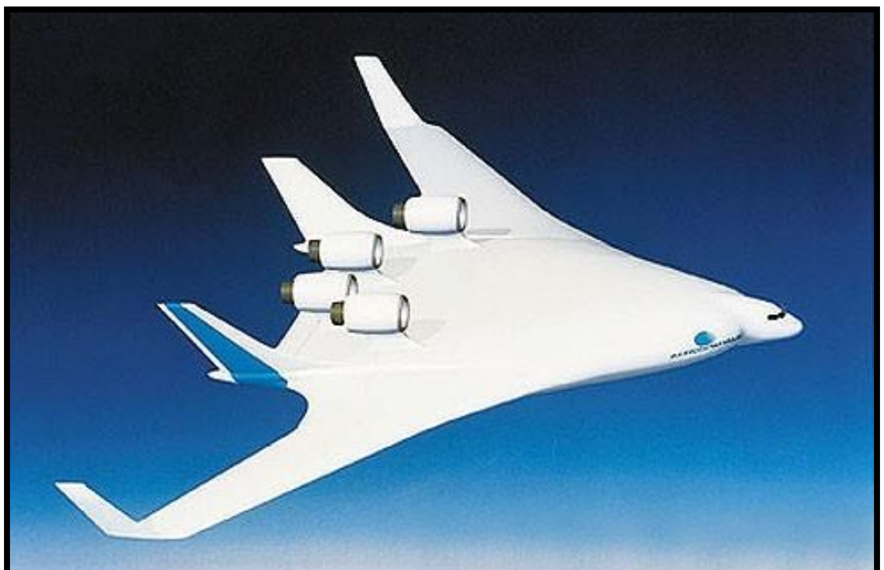
Fuselage Design

Some unconventional ideas ...

More unconventional ideas ...







Layout Procedure

Primary Decisions

•Pressurization requirements or not?

Affects fuselage section

•Powerplant system internally mounted or not?

If yes then dominant effect

•Does payload occupy most of the fuselage volume?

If yes then use payload as starting point for fuselage layout.

•Are there any special considerations?

twin boom, flying boat, V/STOL, etc.

Layout Procedure

Layout Modules (Cont.)

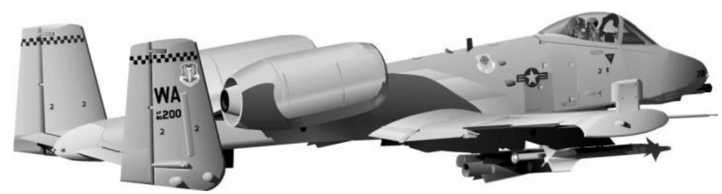
Modules include:

- Payload
- Powerplant installation
- Crew compartment
- Wing carry-through box structure
- Avionics volume, APU & air conditioning
- Landing gear stowage & mounting
- Tail section

Primary Considerations

Common practice is to modularize layout:

crew compartment, powerplant system, payload configuration, fuel volume, landing gear stowage, wing carry-through structure, empennage, etc. or simply into front, center and rear fuselage section designs.



Primary Considerations

E-170 Fuselage Sections

Primary Considerations

Normal (High) Differential Pressurization

Usual requirement is for effective altitude to be no more than 2.44 km (8000 ft) ISA for passenger transports.

Implied pressure differentials are:

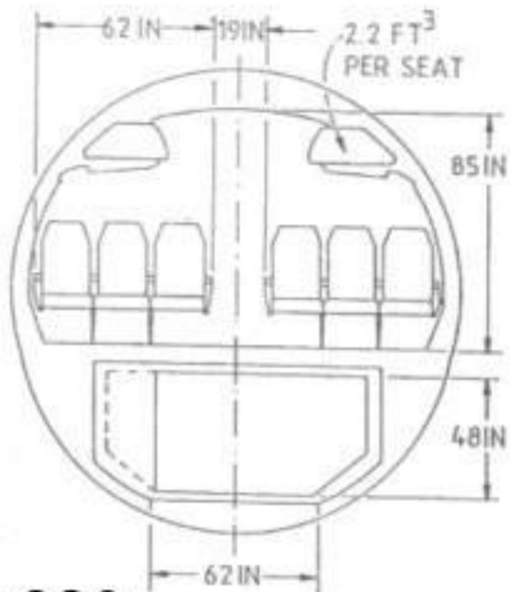
0.37 bar (5.5 psi) for a/c at 7.6 km (25,000 ft).

0.58 bar (8.5 psi) for a/c at 13.1 km (43,000 ft).

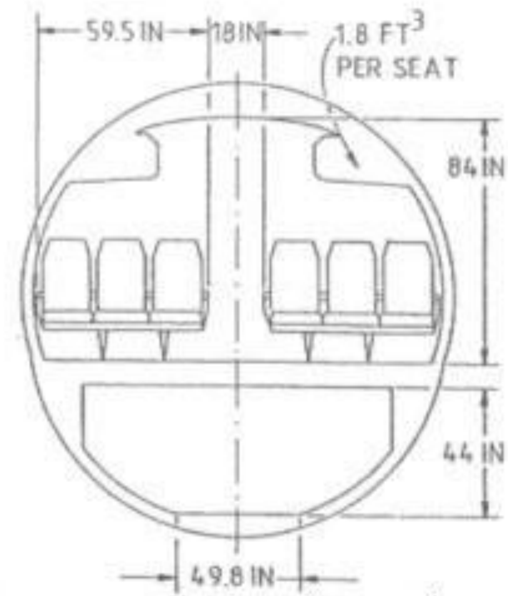
0.65 bar (9.4 psi) for a/c at 19.8 km (65,000 ft).

High pressure differential required across most of fuselage for passenger transports so often over-riding fuselage structural design requirement.

Fuselage Layout Considerations - Transports

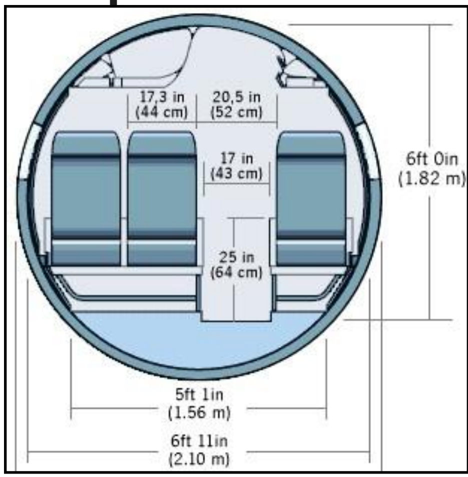


A320

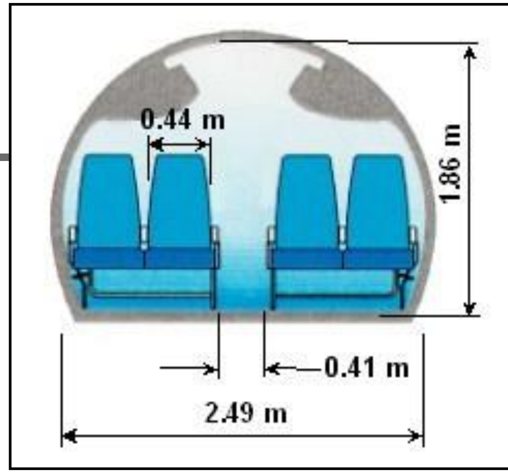


Boeing 707/727/737/757

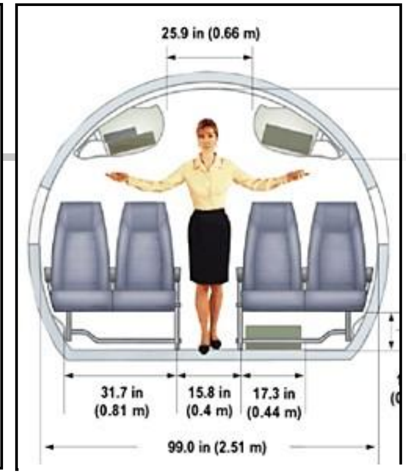
CrossSection



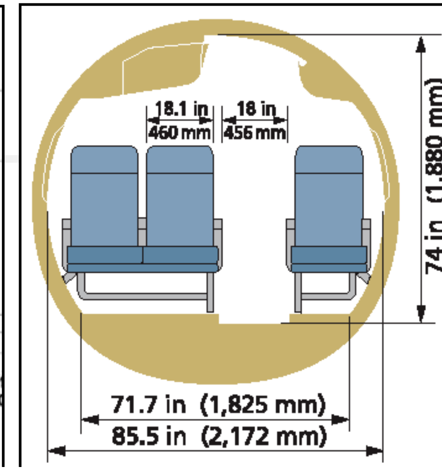
ERJ 145



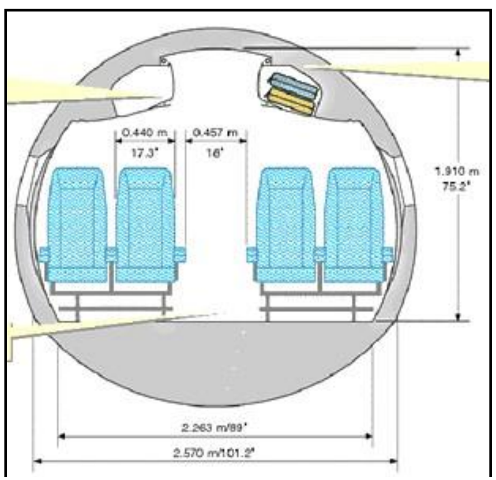
CRJ 200



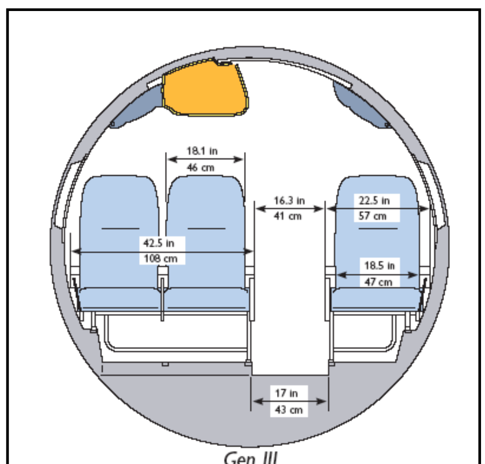
DHC 8



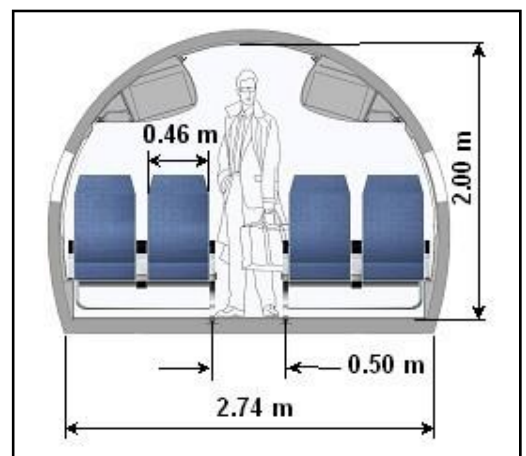
Dornier 328



ATR 42 / 72



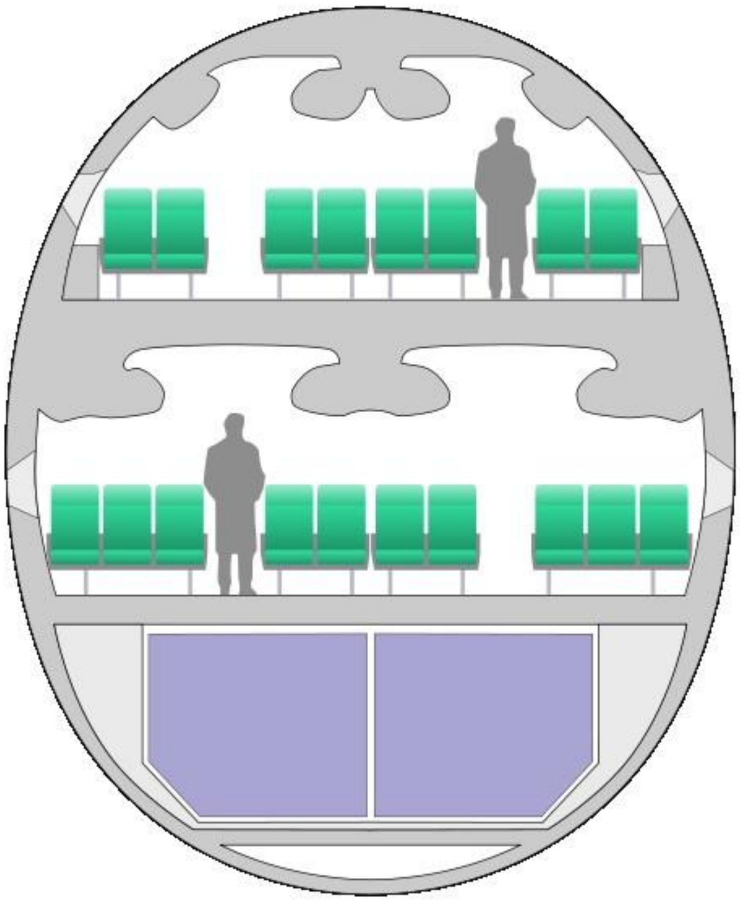
Saab 340 / 2000



EMBRAER 170/190

Cabin Width & Cross-Section

Double-Deck Airbus A380



Powerplant Location

Powerplant Location

If powerplant is located within fuselage, this is a primary consideration for fuselage layout.

Three main powerplant arrangements affecting fuselage layout.

Nose-mounted.

Central or central/rear location.

Rear fuselage location.

Powerplant Location

Nose-Mounted Engine

Either piston or turbine-driven propeller.

Powerplant Location

Rear Fuselage Location

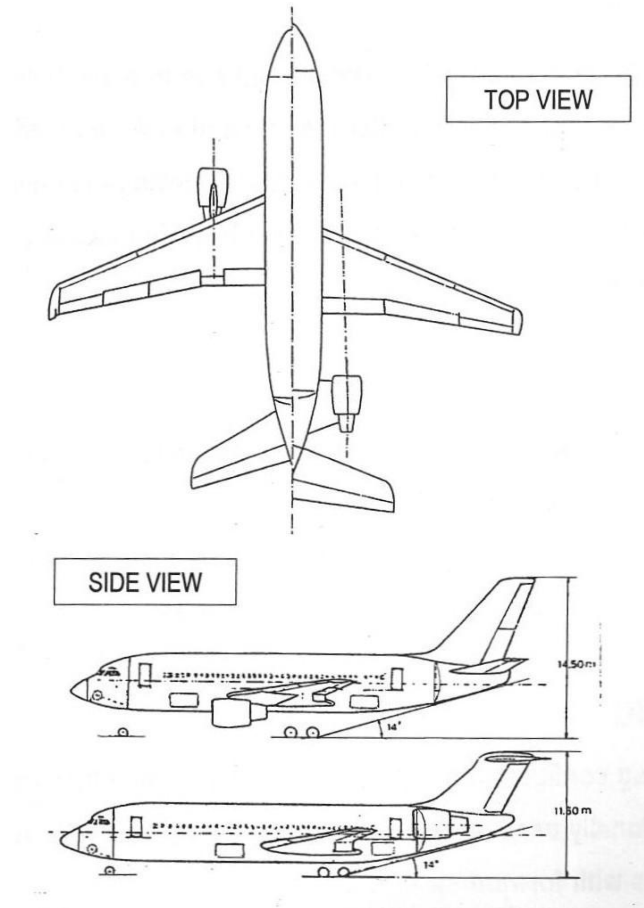
Common for supersonic combat aircraft with low aspect ratio wings.

Major advantage is reduced length of exhaust tail pipe.

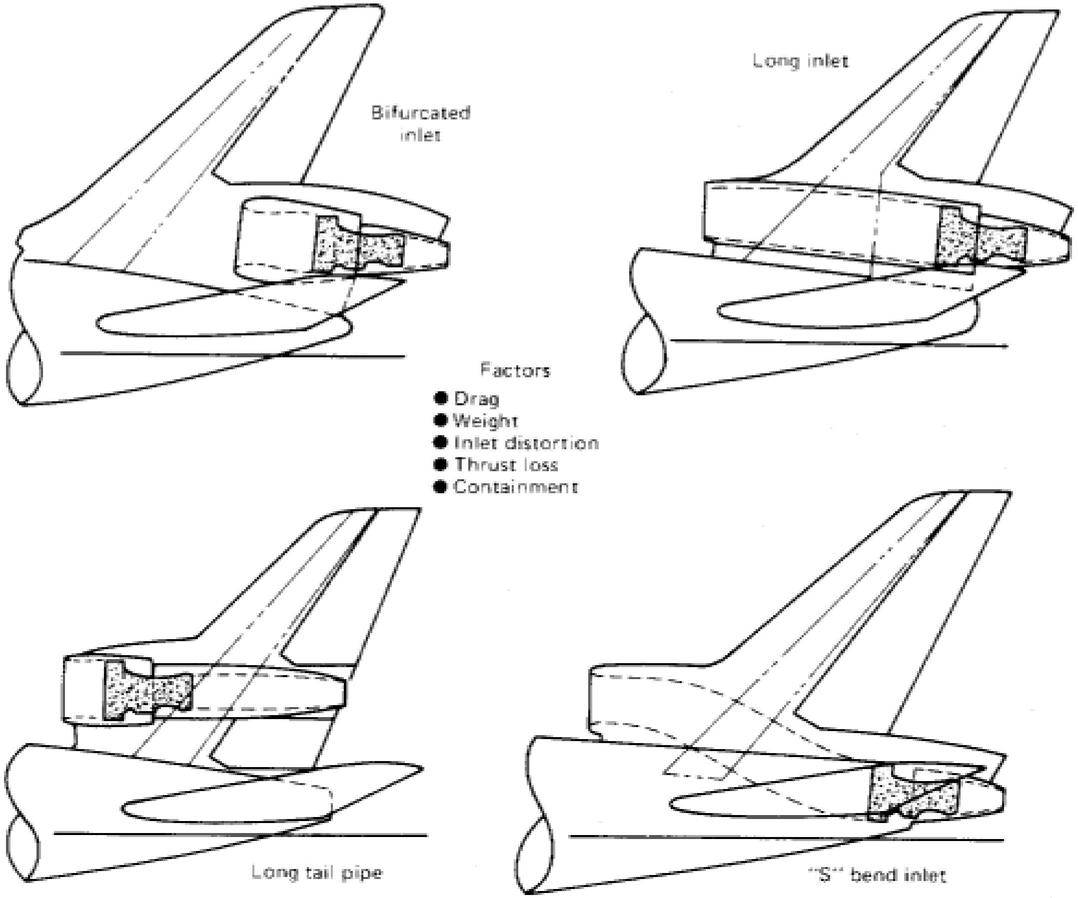
Wing carry-through structure passes ahead of powerplant, easing access and removal.

Complicates design of empennage attachment structure, though OK if a canard configuration.

Powerplant Location



Three-engine Arrangements



Local Layout Aspects

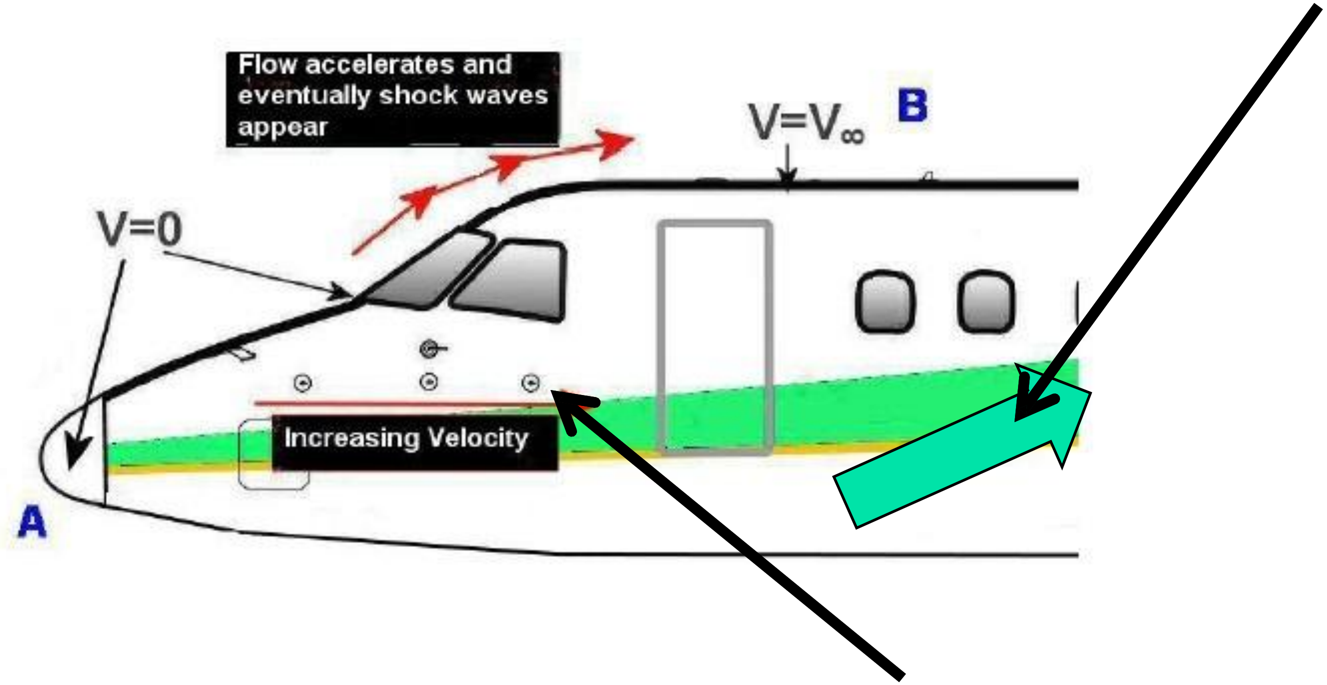
Wing Vertical Location – Structural Considerations

Primary wing structure should be continuous across fuselage – rules out use of mid-wing position when requirement for single payload volume to occupy most of fuselage.

Old Fuselage for a New Airplane

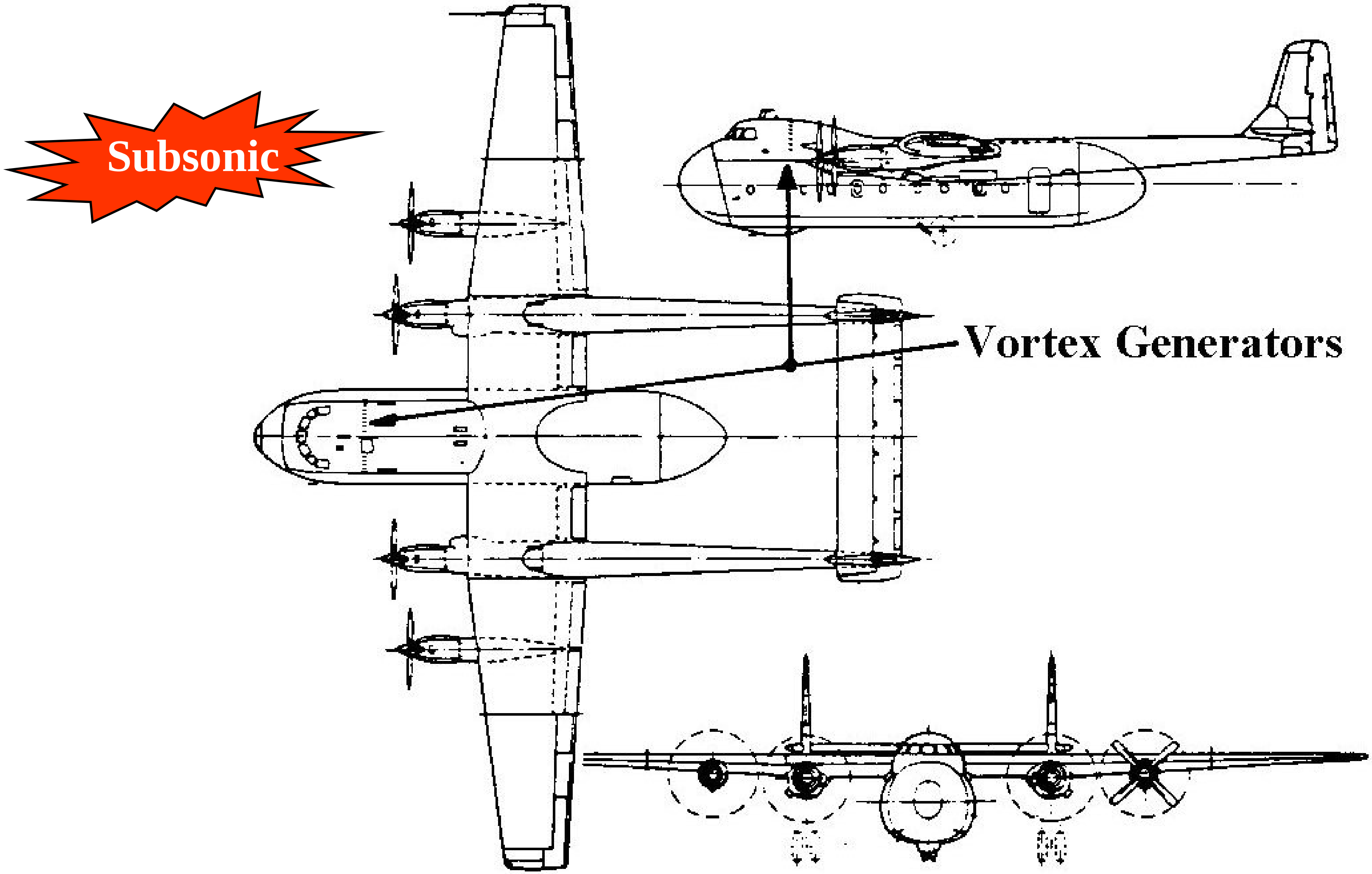
Typical Flow Pattern

Upwash caused by the wing



Here is not a good location for probes

Need for vortex generators due to flow separation

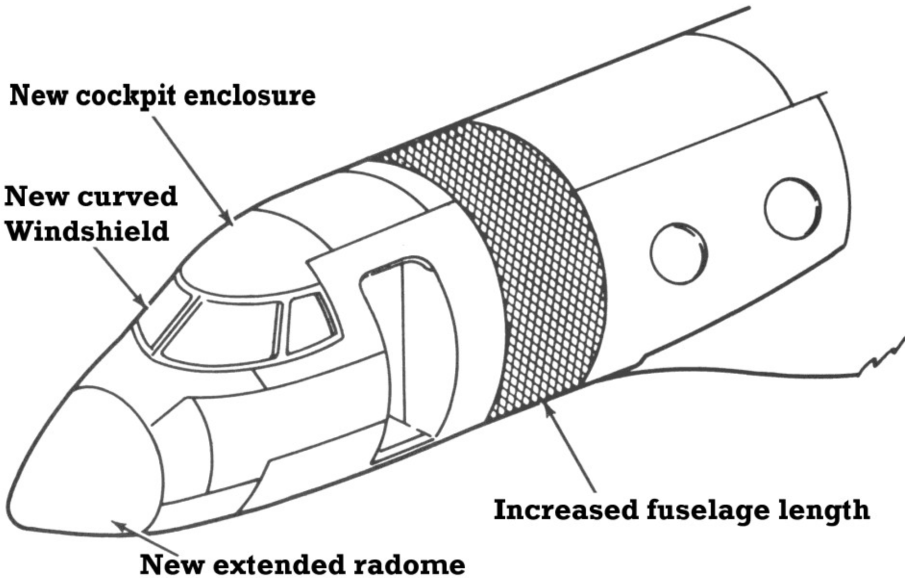


Example of Fuselage Design

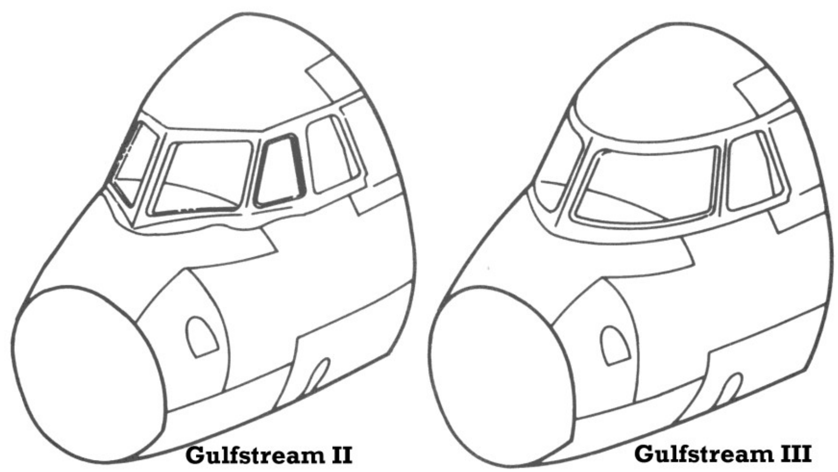
Vortex Generators to reattach the flow

Armstrong Whitworth 650 Argosy

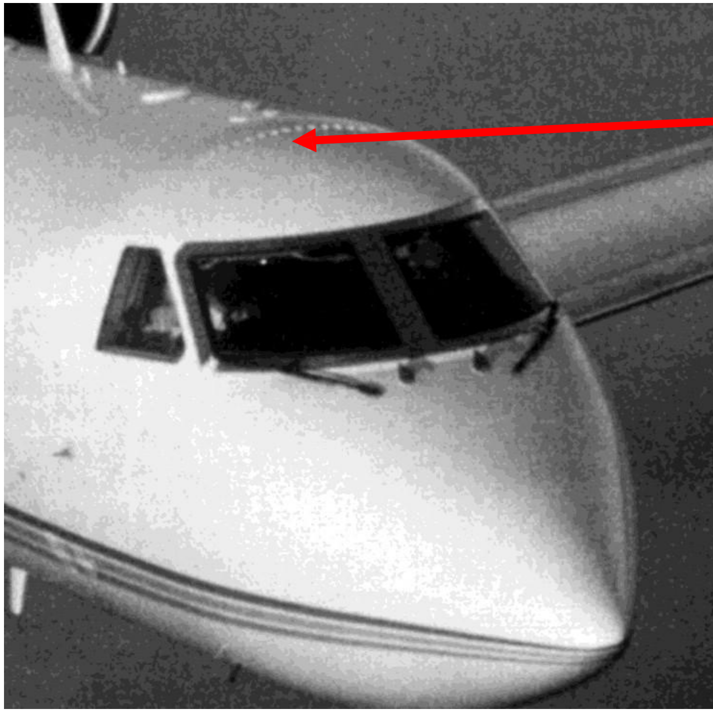
Improvements on the Gulfstream III ...



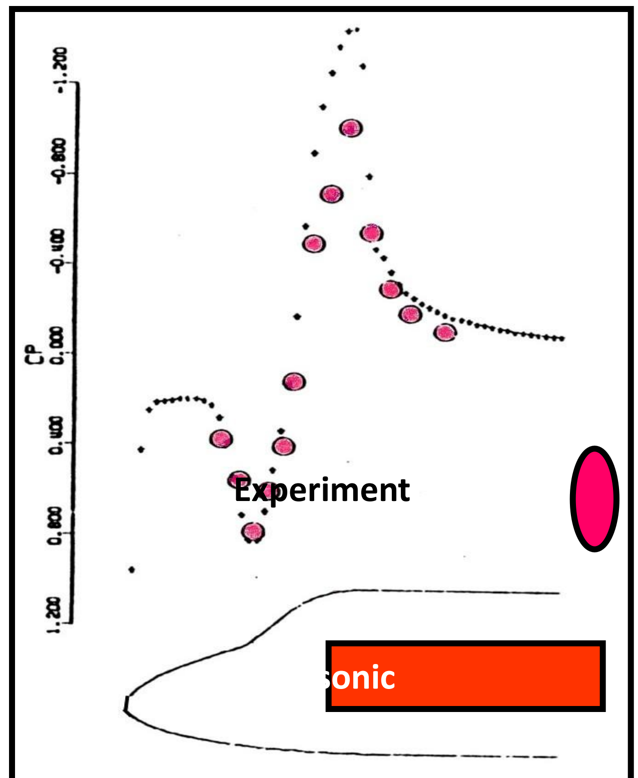
The aircraft flies in the transonic regime



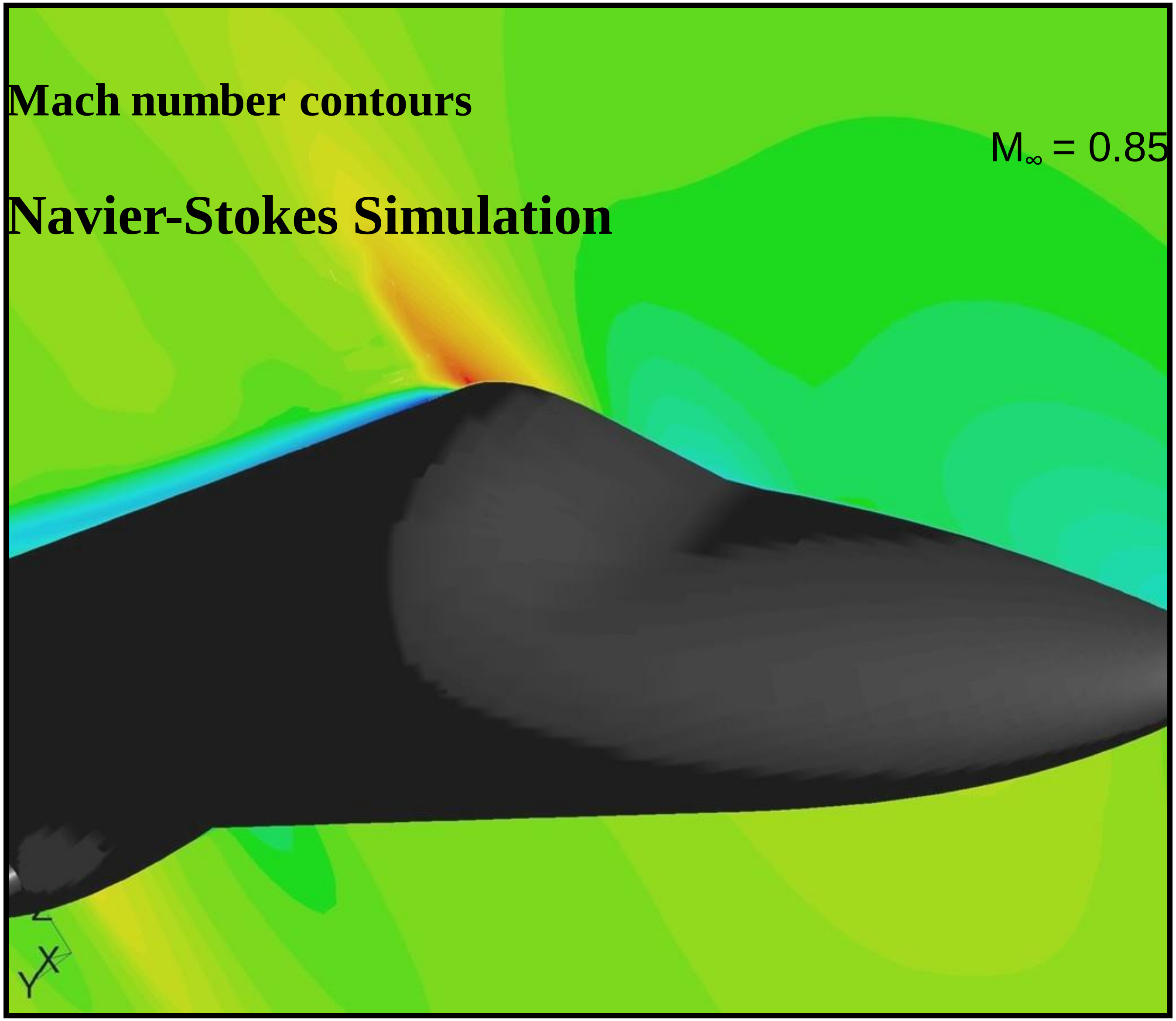
... however, shock wave over the cockpit persists



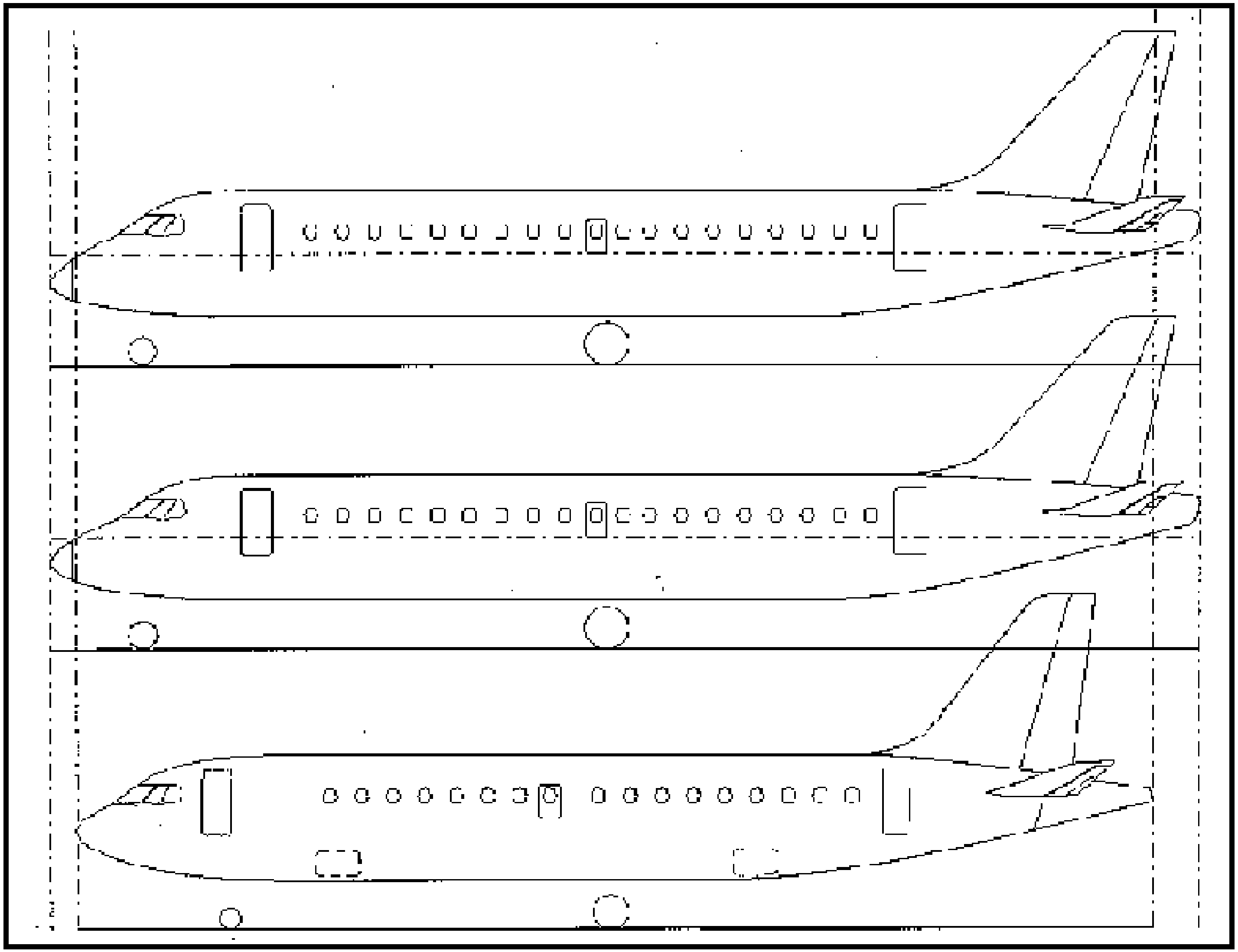
Shock wave causes flow separation in this region. Vortex generators fix problem. However, shock wave remains causing drag and considerable.



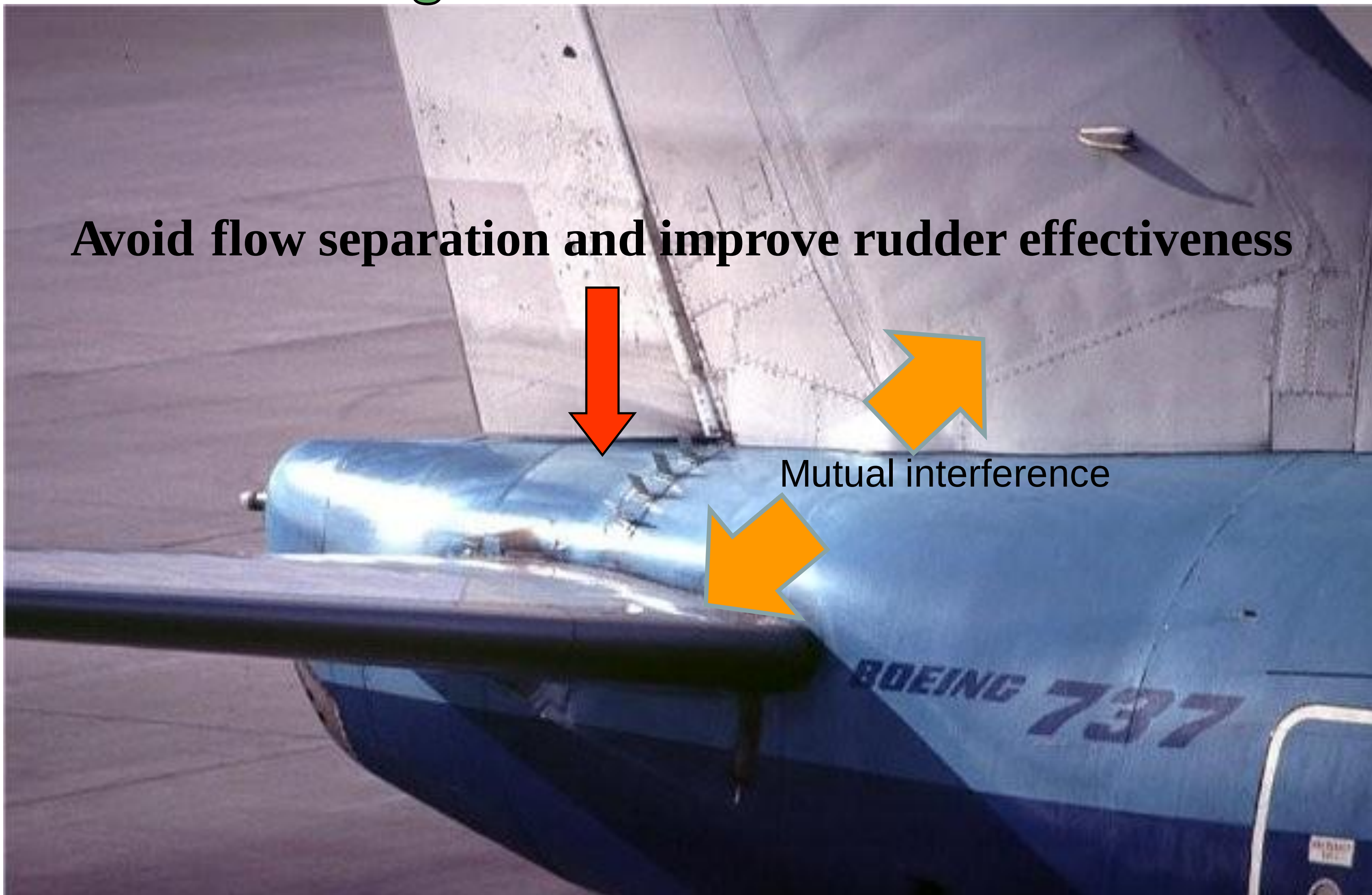
Shock Wave over the Cockpit



Embraer - Conceptual studies for the ERJ 170 aircraft



Vortex generators at tailcone



Fuselage – Local Layout Aspects