AIRCRAFT STRUCTURAL DESIGN & ANALYSIS

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

Lilienthal
DAY 1
WHAT IS AN AIRCRAFT?

• An aircraft is a vehicle, which is capable of flying through the air (or through any other atmosphere)
KINDS OF FLYING MACHINES

• **Aerostat**: Flying machines (systems), which are lighter than air
  – Balloons
    (Unpowered aerostat)
  – Airships
    (Powered aerostat)

• **Aerodyne**: Flying machines (systems), which are heavier than air
  – Airplanes
  – Helicopter
WORKING PRINCIPLE

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

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

Nonrigid airship (blimp)

Semirigid airship
TYPES OF AIRSHIPS

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

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

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

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

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

Wright brothers (1903)
Aero A10 (1922)
Boeing 247 (1933)
Douglas DC9 (1965)
Airbus 380 (2007)
Boeing 787 (2008)
CLASSIFICATION BASED ON POWER

- Unpowered
- Propeller powered (20000 ft)
- Jet engine powered (40000 ft)
CLASSIFICATION OF CIVILIAN A/C

- **Airliner**
  - Boeing / Airbus / ATR / Bombardier / Douglas

- **Cargo**
  - Boeing / Airbus

- **Business aircraft**
  - Gulfstream / Bombardier / Dassault

- **Agricultural aircraft**
  - Grumman / Transavia / Pacific aerospace

- **General aviation**
CLASSIFICATION OF MILITARY AIRCRAFT

- Bombers
- Fighters
- Patrol
- Reconnaissance

- Transportation
- Air support / counter insurgency
- Military trainers
PARTS OF AN AIRCRAFT
MAJOR COMPONENTS OF AN AIRCRAFT

- Wings (to provide lift)
- Fuselage (to carry payload)
- Empennage (Directional stability)
- Landing gear (to land / takeoff / Taxiing)
- Flaps (High lifting devices)
- Ailerons (to control roll)
- Elevators (to control pitch)
- Rudders (to control yaw)
WINGS
WING is essentially a beam which gathers and transmits all the aerodynamic loads to the central fuselage attachment.
WING TYPES

• **Straight wing** :
  – If the leading edge of a wing is perpendicular to the airflow, it is called a straight wing

• **Swept wing** :
  – If the leading edge of a wing meets the airflow at an angle, it is called a swept wing
TYPICAL WING FORMS

Rectangle
(Wright brothers)
S=40’
C=6’

Triangle
(Concorde)
S=42.5’
C_r=90.75’

Trapezoid
(F18)
S=13’
C_r=15’
C_t=6’

Compound
(Space shuttle)
S=42.5’
C_r=90.75’

Trapezoid
(Boeing 747)
S=81.3’
C_r=54.3’
C_t=13.3’
PARTS OF A WING

• Wing box
• Fixed leading edge
• Fixed trailing edge
• Ailerons
• Spoilers
• Flaps
• Slats
WING TERMINOLOGY

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

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

• Wing structure should possess
  – Sufficient strength
  – Stiffness
  – Light weight
  – Minimum manufacturing problems
WING BOX DESIGN

PRIMARY ISSUES

• Rib direction
  – Perpendicular to rear spar
  – Parallel to flight path

• Bending load carrying members
  – Spar only
  – Spar and skin
WING BOX

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

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

a) Built up spar
b) Truss type
c) Bent up channel
d) Frame truss
e) Sine wave web
f) Integrally machined web
g) Integrally machined truss
SPARS

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

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

Typical spar caps
SPAR WEBS

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

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

• Ribs are used to define and produce the airfoil shape

• Carry inertial loads (fuel, equipment, missiles, rockets)

• Support skin-stringer panel in compression and tension

• Prevents wing skin buckling

• Transfers primary loads from the control surfaces and undercarriage to the spars
WING RIB DIRECTIONS

Perpendicular to rear spar

(a) Rib arrangement-convention

Parallel to flight path

(b) Rib arrangement-parallel to the flight path

S

Rear spar
WING RIB DIRECTIONS

Advantages

• Perpendicular to rear spar
  – Rib length is less
  – Connection is easy

• Parallel to flight path
  – Provides better aerodynamic shape

Disadvantages

• Parallel to flight path
  – Rib length is more (nearly 28%)
  – Maintaining 90° at joints
  – Skin gauge is more
TYPE OF RIBS

• Shear type rib
  – Web acts as fuel slosh inhibitor
  – Eliminates stress concentration by having a gradual cross section change from rib cab to shear web
  – Continuous support for the wing panels

• Truss type rib
  – Heavier
RIB SPACING

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

- Air loads
- Inertial load due to fuel, equipment, structure
- Crushing loads due to wing bending
- Concentrated loads (nacelle, landing gear)
- Diagonal tension loads from skin
• Stringers are stiffening members in the wing which run from root to the tip
• Stringers are made from forming or extrusion
SPAN WISE BEAMS

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

• Gives the wing it’s shape
• Carries loads
  – Bending and shear loads
  – Torsional loads caused by control surfaces and other features attached to the wing
• Creates walls for the wing mounted fuel tanks
WING SKIN STRINGERS

Z- Type

J- Type

Hat Type

I- Type

Y- Type

J- Splice
LEADING EDGE

• Leading edge :
  – The portion of the wing front of the spar is called as leading edge
LEADING EDGE COMPONENTS

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

- Slats are aerodynamic surfaces on the leading edge of the wings, which, when deployed, allow the wing to operate at a higher angle of attack.

- A higher coefficient of lift is produced as a product of angle of attack and speed.

- Used while landing or performing maneuvers which take the aircraft close to the stall.

- Retracted in normal flight to minimize drag.
TRAILING EDGE

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

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

• Plain Flap
  – rotates on a simple hinge

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

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

• Slotted flap
  – A slot (or gap) between the flap and the wing enables high pressure air from below the wing to re-energize the boundary layer over the flap
COMPARISON OF FLAPS
AILERONS

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

(b) Outboard aileron structure
SPOILERS

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

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

(a) Inboard spoiler

(c) Spoiler link assembly (typical both spoilers)

(b) Outboard spoiler
WING ROOT JOINT

- Spliced plate
- Tension bolts
- Lug
- Splice plate & tension bolt
TYPES OF LUG ARRANGEMENTS

Configuration “a”

Configuration “b”

Configuration “c”

\[ V_1 + V_2 \]

\[ R_2 \]

\[ h \]
WING GROUP CENTRE OF GRAVITY

Centreline

Fuselage skin

Wing group CG at 0.7 \((X_{rs} - X_{fs})\)

Mean Aerodynamic Chord (MAC)

Front Spar at 0.25 C

Rear Spar at 0.55 C to 0.6 C

0.35b/2

\(Y_{MAC}\)

b/2
WING LOADS

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