SCHOOL OF AERONAUTICS (NEEMRANA)

UNIT-1 NOTES

FACULTY NAME: D.SUKUMAR. **CLASS: B.Tech AERONAUTICAL**

SUBJECT CODE: 6AN5 **SEMESTER: VI**

SUBJECT NAME: AIRCRAFT DESIGN

Preliminaries:
Aircraft Design Requirements, specifications, role of users. Aerodynamic and Structural Consideration, Importance of weight. Airworthiness requirements and standards. Classifications of airplanes. Special features of modern airplane.
Air Loads in Flight: Symmetrical measuring loads in flight, Basic flight loading conditions, Load factor, Velocity - Load factor diagram, gust load and its estimation, Structural limits.

INTRODUCTION:

The process of design of a device or a vehicle, in general involves the use of knowledge in diverse fields to arrive at a product that will satisfy requirements regarding functional aspects, operational safety and cost. The design of an airplane, which is being dealt in this course, involves synthesizing knowledge in areas like aerodynamics, structures, propulsion, systems and manufacturing techniques. The aim is to arrive at the configuration of an airplane, which will satisfy aforesaid requirements.
The design of an airplane is a complex engineering task. It generally involves the following.
a) Obtaining the specifications of the airplane, selecting the type and determining the geometric parameters.
b) Selection of the power plant.
c) Structural design and working out details of construction.
d) Fabrication of prototype.
e) Determination of airplane performance, stability, and structural integrity from flight tests.

STAGES IN AIRPLANE DESIGN:
The design process can be divided into the following three stages.
a) Project feasibility study.
b) Preliminary design.
c) Design project

Project Feasibility Studies:
The aim of this study is to evolve a complete set of specifications for the airplane. It involves the following steps.
1) Comprehensive market survey to assess the number of airplanes needed.

2) Study of the operating conditions for the proposed airplane. These conditions include (a) landing field length, (b) type of landing field, (c) weather conditions in flight and near landing sites and (d) visibility.
3) Study of the relevant design requirements as laid down by the civil and military regulating agencies. Some of the regulating agency for civil airplanes are : FAA (Federal Aviation Admination) in USA; EASA (European Aviation Safety Agency) in Europe; DGCA (Director General of Civil Aviation) in India.
The military airplanes are governed by more stringent regulations called MIL specifications in USA.
4) Evaluation of existing designs of similar airplanes and possibility of incorporating new concepts.
5) Collection of data on relevant power plants.
6) Laying down preliminary specifications which may consist of the following.
a) Performance: Maximum speed, maximum rate of climb, range, endurance, rate of turn, radius of turn, take-off and landing field lengths.
b) Payload.
c) Operating conditions at the destinations.
d) Maneuverability.

Preliminary design
This stage of design process aims at producing a brochure containing preliminary drawings and stating the estimated operational capabilities of the airplane. This is used for seeking approval of the manufacturer or the customer. This stage includes the following steps.
(i) Preliminary weight estimate.
(ii) Selection of geometrical parameters of main components based on design criteria.
(iii) Selection of power plant.
(iv) Arrangement of equipment, and control systems.
(iv) Aerodynamic and stability calculations.
(vi) Preliminary structural design of main components.
(vii) Revised weight estimation and c.g. travel.
(viii) Preparation of 3-view drawing.
(ix) Performance estimation.
(x) Preparation of brochure. Section 10.3 deals with the items included in the brochure. It is also called aircraft type specification.

Design project
After the preliminary design has been approved by the manufacturer / customer. The detailed design studies are carried out. These include the following stages.
1) Wind tunnel and structural testing on models of airplane configuration arrived after preliminary design stage. These tests serve as a check on the correctness of the estimated characteristics and assessment of the new concepts proposed in the design.
2) Mock-up: This is a full scale model of the airplane or its important sections. This helps in (a) efficient lay-out of structural components and equipments, (b) checking the clearances, firing angles of guns, visibility etc.

Currently this stage is avoided by the use of CAD(Computer Aided Design) packages which provide detailed drawings of various components and subassemblies.

3) Complete wind tunnel testing of the approved configuration. Currently CFD (Computational Fluid Dynamics) plays an important role in reducing the number of tests to be carried-out. In CFD, the equations governing the fluid flow are solved numerically. The results provide flow patterns, drag coefficient, lift coefficient, moment coefficient, pressure distribution etc. Through the results may not be very accurate at high angles of attack, they are generally accurate near the design point. Further, they provide information on the effects of small changes in the geometric parameters, on the flow field and permit parametric studies.

4) Preparation of detailed drawings.

5) Final selection of power plant.

6) Calculations of (a) c.g. shift (b) performance and (c) stability.

7) Fabrication of prototypes. These are the first batch of full scale airplane. Generally six prototypes are constructed. Some of them are used for verifying structural integrity and functioning of various systems. Others are used for flight testing to evaluate performance and stability.

Classification of airplanes

At this stage, it is helpful, to know about the different types of airplanes.

The classification is generally based on

(a) The purpose of the airplane,

(b) The configuration and

(c) Design Mach number (e.g. subsonic, supersonic and hypersonic).

Classification of airplanes according to function

There are two main types of airplanes viz.

i) Civil aircraft and

ii) Military aircraft.

The civil airplanes are categorised as

a) Passenger,
b) Cargo,
c) Agricultural,
d) Sports and
e) Ambulance.

The military airplanes are categorised as

a) Fighter,
b) Bomber,
c) Interceptor,
d) Reconnaissance, and
e) Airplanes for logistic support like troop-carriers and rescue airplane.

The military aircraft are often designed to cater to more than one role e.g. fighter-bomber or interceptor-fighter.

Influence of the function of airplane on specifications/design requirements

The specifications or design requirements of an airplane are decided by its function. It can be mentioned that a passenger airplane should have:

(a) High level of safety in operation,
(b) Adequate payload carrying capacity,
(c) Economy in operation,
(d) Comfort level depending on range and cruising altitude,
(e) Ability to fly in weather conditions normally encountered on chosen routes and
(f) Ability to use airfields of intended destinations.

A bomber airplane should have:

(a) Range corresponding to the mission,
(b) Capacity to carry and deploy intended bomb load,
(c) High values of speed, endurance, and ceiling
(d) Adequate protection against accidental fire.

An interceptor airplane should have:

(a) Adequate thrust to give high
    (i) Rate of climb,
    (ii) Maximum flight speed and
    (iii) Maneuverability
(b) Ceiling 3 to 4 km above that of contemporary bombers
(c) Ability to fly in adverse weather conditions and
(d) Appropriate armament.

Civil & Fighter Aircraft

Classification by Configuration

Airplanes can be classified in accordance with their shape and structural layout, which in turn will contribute to their aerodynamic, tactical and operational characteristics. It can be done by classification of the following:

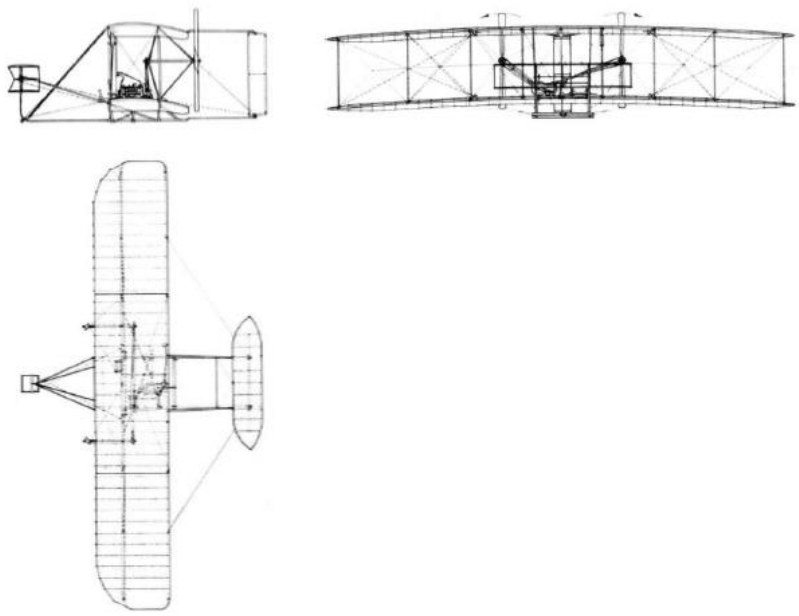
(a) Shape and position of the wing
(b) Type of fuselage
(c) Location of horizontal tail surfaces
(d) Type of landing gear
(e) Location and number of engines.

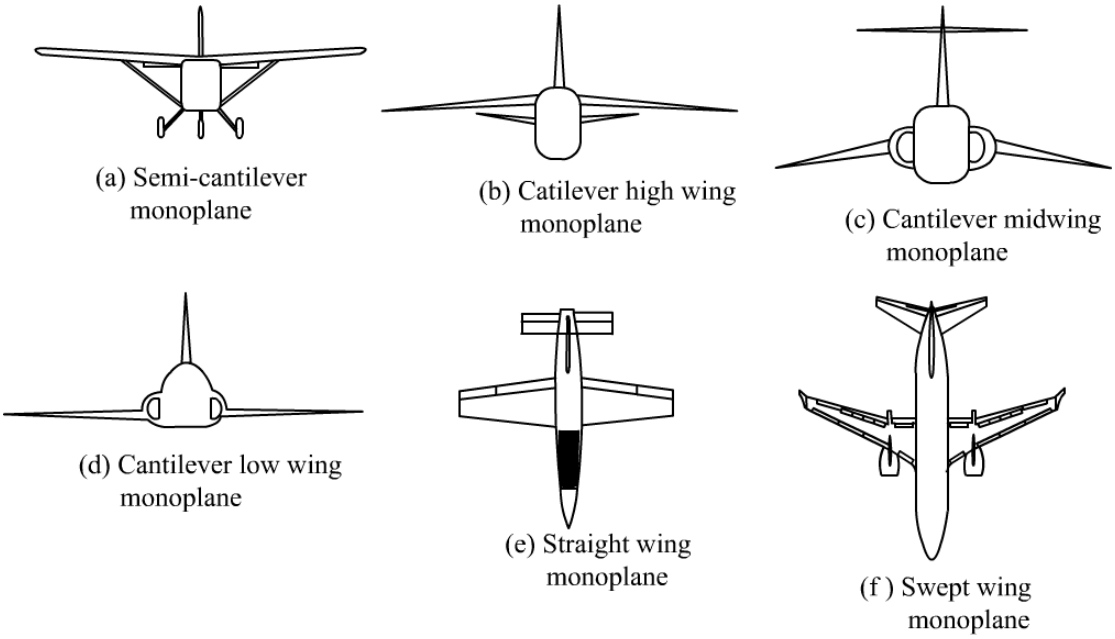
Classification of airplanes based on wing configuration

Early airplanes had two or more wings e.g. the Wright airplane had two wings braced with wires. Presently only single wing is used. These airplanes are called monoplanes. When the wing is supported by struts the airplane is called semi cantilever monoplane. Depending on the location of the wing on the fuselage, the airplane is called high wing, mid-wing and low wing configuration. Further, if the wing has no sweep the configuration is called straight wing monoplane. The swept wing and delta wing configurations are shown in Figs.

(a) Shape and Position of the Wing

(1) Braced airplane – D.H. Tigermoth
(2) Braced sesquiplane – An- 2
(3)Semi-Cantilever monoplane, Pushpak, Piper Cub,
(4)Semi-cantilever parasol monoplanes…Baby Ace
(5) Cantilever low-wing monoplaneDC-3, HJT-16, IL-18, DH Comet
(6) Cantilever mid-wing monoplane …Hawker Hunter, Canberra
(7)Cantilever high-wing monoplane…An-22, Breguet 941, Fokker friendship
(8)Straight wing monoplane… F-104 A….
(9)Swept-wing monoplane… F-24, MIG-21, Lightning ……
(10)Delta-monoplane with small ARAvro-707, B-58 Hustler, Avro Vulcan.





Types of Wings

Straight Wing

Swept Wing

Forward Swept Wing

Oblique Wing

Types of Wings

Variable Sweep Wing

Delta Wing

Biplane

Triplane

Classification of airplanes based on fuselage

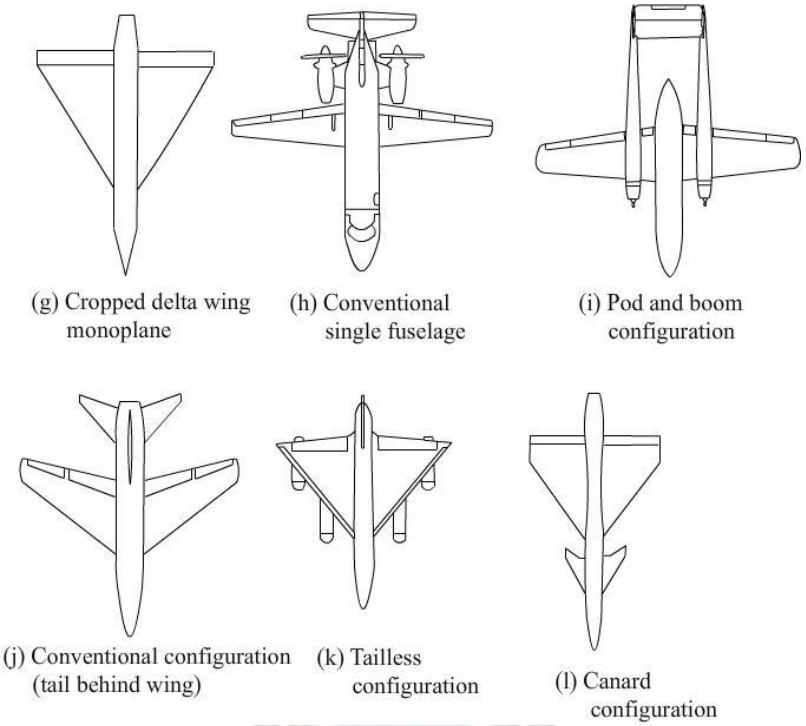
Generally airplanes have a single fuselage with wing and tail surfaces mounted on the fuselage. In some cases the fuselage is in the form of a pod. In such a case, the horizontal tail is placed between two booms emanating from the wings. These airplanes generally have two vertical tails located on the booms. The booms provide required tail arm for the tail surfaces. Some airplanes with twin fuselage had been designed in the past. However, these configurations are not currently favoured.

(b) Type of fuselage

(1) Conventional single-fuselageHT-2, Boeing 707,

(2) Twin-fuselage design

(3) Pod and Boom construction. Fairchild Packet, Vampire



Classification of airplanes based on horizontal stabilizer

In a conventional configuration, the horizontal stabilizer is located behind the wing. In some airplanes there is no horizontal stabilizer and the configuration is called tailless design. In these airplanes, the functions of elevator and aileron are performed by ailevons located near the wing tips.

When both ailerons (on left and right wings) move in the same direction, they function as elevators and when the two ailerons move in opposite direction, they function as ailerons. In some airplanes, the control in pitch is obtained by a surface located ahead of the wing. This configuration is called canard configuration

Types of Tails

T Tail

Twin Fin

Horizontal Tailless

Vertical Tailless

(c) Location of horizontal tail surface

(1)Conventional design with horizontal tail located behind the wing Krishak, Avro-748,
(2) Tail-less design with no horizontal tail …Mirage IV, B-58 Hustier, Concorde
(3)Canard design with horizontal tail located ahead of the wing… (XB-70-A …)

(d) Type of landing gear

(1)Retractable landing gear… DC-9, TU-114, SAAB-35
(2)Non-retractable landing gear…Pushpak, An-14, Fuji KM-2

Fixed type of landing gear

Retractable type of landing gear

Classification of airplanes based on number of engines and their location

Airplanes with one, two, three or four engines have been designed. In rare cases, higher number of engines are also used. The engine, when located in the fuselage, could be in the nose or in the rear portion of the fuselage. When located outside the fuselage the engines are enclosed in nacelles, which could be located on the wings or on the rear fuselage. In case of airplanes with engine-propeller combination, there are two configurations – tractor propeller and pusher propeller. In pusher configuration the propeller is behind the engine. In tractor configuration the propeller is ahead of the engine.

(e)Classification by Power Plants

a. Types of engines

Piston engines – Krishak, Dakota, Super Constellation, etc. Turboprop engines – Viscount, Fokker Friendship, An-12, etc.
Turbo-jet engines – Turbo-fan, By-pass engines –HJT-16 (Kiran), Boeing 707 MIG-21, etc.
Ram-jet engines
Rocket engines – Liquid propellant – Solid propellant – X-15A

b.Number of engines

Single-engine – HJT-16, DH Chipmunk, Hawker Hunter, etc.
Twin-engine – HF-24, DC-3, Canberra, etc.
Multi-engine – An-22, Boeing 707, Belfastetc.

c.Engine Located

Propeller single engine located in fuselage nose (HT-2, YAK-9, BEAGLE A-109).

“Pusher”-engine located in the rear fuselage (Bede x BD-2)

Engines (jet) submerged in the wing

(a) At the root – DH-Comet, TU-104, Tu-16

(b) Along the span – Canberra, U-2, YF-12A

Jet engines in nacelles suspended under the wing by “POD” mountings - Boeing 747, Airbus, Boeing 707, DC-8, Convair 880,

Boom and Pod construction - Fairchild Packet, Vampire Engines (jet) located on the rear fuselage – Trident, VC-10, IL-62, Caravelle

Jet engines located within the rear fuselage – HF-24 (Marut),
Lightning, MIG-19,…

Engine Arrangement

Factors affecting the configuration

The configuration of an airplane is finalized after giving consideration to the following factors.

(I) Aerodynamics

(II) Low structural weight

(III) Lay-out peculiarities

(IV) Manufacturing procedures

(V) Cost and operational economics

(VI) Interaction between various features

(I) Aerodynamic considerations – drag, lift and interference effects

The aerodynamic considerations in the design process involve the following.

(A) Drag

The drag of the entire configuration must be as small as possible. This requires (a) thin wings, (b) slender fuselage, (c) smooth surface conditions, and (d) proper values of aspect ratio (A) and sweep (Λ).

(B) Lift

The airplane must be able to develop sufficient lift under various flight conditions including maneuvers. The maximum lift coefficient also decides the landing speed. These considerations require proper choice of (a) aerofoil, (b) means to prevent flow separation and (c) high lift devices.

(C) Interference effects

In aerodynamics the flows past various components like the wing, the fuselage and the tail are usually studied individually. However, in an airplane these components are in proximity of each other and the flow past one component affects the flow past the others(components). The changes in aerodynamic forces and moments due to this proximity are called interference effects. The lay-out of the airplane should be such that increase in drag and decrease in lift due to interference effects are minimized. These can be achieved in subsonic airplanes by proper fillets at the joints between

(a) Wing and fuselage,

(b) Tail and fuselage and

(c) Wing and engine pods.

(II) Low structural weight

The weight of the aircraft must be as low as possible.

This implies use of

(a) High strength to weight ratio material,

(b) Aerofoil with high thickness ratio

(c) Wing with low aspect ratio

(d) Relieving loads (e.g. wing mounted engines) etc..

The airplane structure must be strong enough, to take all permissible flight loads and stiff enough to avoid instabilities like, divergence, aileron reversal and flutter.

(III) Layout peculiarities

The specific function of the airplane often decides its shape e.g. the fuselage of a cargo airplane generally has a rectangular cross section and a large cargo door. The height of fuselage floor should be appropriate for quick loading and unloading

(Source:www.flickr.com)
(a) General view

(Source:www.img525.imageshack.uscom)
(b) Cargo being loaded

(IV) Manufacturing processes

During the detail design stage, attention must be paid to the manufacturing processes. The cost of manufacture and quality control also must be kept in mind.

(V) Cost and operational economics – Direct operating cost (DOC) and Indirect operating cost (IOC)

The total operating cost of an airplane is the sum of the direct operating cost (DOC) and the indirect operating cost (IOC). The DOC relates to the cost of hourly operation of the airplane viz. cost of fuel, lubricants, maintenance, overhaul, replacement of parts for airframe and engine. IOC relates to crew cost, insurance cost, depreciation of airplane and ground equipment, hangar rental, landing charges and overheads. Thus, for a personal plane lower initial cost of the airplane may be more important whereas, for a long range passenger airplane lower cost of fuel may be the primary consideration.

(VI) Interaction of various factors

Some of the considerations mentioned above may lead to conflicting requirements. For example, a wing with an airfoil of relatively higher thickness ratio, has lower structural weight but, at the same time has higher drag. In such situations, optimization techniques are employed to arrive at the best compromise.

Primary requirements for Civil Aircraft

Passenger Aircraft

- High Safety level
- High payload carrying capacity
- Economy in operation
- Comforts
- Ability to fly in any Weather (All-weather flying) aerodromes
- Ability to use aerodromes of respective classes

Cargo Aircraft

- High payload carrying capacity
- Economy in operation
- Ability to fly in any Weather
- Suitable for civil aerodromes

Primary requirements for Military Aircraft

Strategic

- Long range (over 6000 km)
- High load carrying capacity - (2000-4000 kg)
- High speed
- High endurance
- High ceiling
- Adequate fire protection

Tactical

- Long range 3000-5000 km)
- High load carrying capacity (above 6000 kg)
- High speed
- High ceiling

- High endurance
- All-weather flying
- Ability to use field aerodromes

Primary requirements for Military Aircraft – FIGHTERS-Tactical

- High speed (300-400 kmph- more than contemporary bomber speeds)
- High ceiling (2-4 km than bomber more than contemporary bomber ceilings)
- Maneuverability
- Sufficient endurance
- High rate of climb
- Ability to launch repeat- ed attacks
- All-weather flying
- Ability to use field aerodromes
- Ease of dismantling and assembling

Primary requirements for Military Aircraft – FIGHTERS- Interceptor

- High rate of climb
- High ceiling (3-4 km contemporary ceilings)
- High speed (500-600 kmph more than contemporary bomber speeds
- High Maneuverability
- All-weather flying
- Ability to fire powerful single volley at target
- Ease of dismantling and assembling

Primary requirements of bomber

- Long range,
- High load carrying capacity,
- High speed ,
- High endurance,
- High ceiling and
- Adequate fire protection.

Primary requirements of interceptor

- High rate of climb,
- High ceiling (3 to 4 km above contemporary bombers),
- High speed ,
- High Maneuverability,
- Ability to fly in any weather and
- Appropriate armament.

Tailless and Flying Wing Design

A flying wing is a tailless fixed-wing aircraft which has no definite fuselage, with most of the crew, payload and equipment being housed inside the main wing structure.

Advantages of tailless and flying wing design

- Small drag-reduction of the number of non lifting surfaces and minimizing the interference effects lead to much lower CD.

- Smaller structural weight. In this design the horizontal tail and that part of the fuselage carrying the tail is eliminated. The bending moment is less
- Large thickness at the root of the wing .The structure can therefore be made lighter due to the increased rigidity of the wing section

Disadvantages

- Restricted c.g travel due to the absence of horizontal stabilizer
- The wing tips are wash-out. This causes a negative lift at wing tips and hence a larger wing area is required to develop the same overall lift.
- Poor directional stability
- Use of high lift devices results in large diving moments.
- Reversal of panel stresses at wing tips-Due to the negative lift at the tips of flying wing some of the wing panels have to be designed for both tensile and compressive loads

Canard design

In this special type of design the horizontal tail surfaces are located ahead of the main plane. In the major part of the flight the canard tail assists the wing in sharing the weight. The horizontal tail is effective as it is not in the downwash of the wing surface.

Advantages

- The forces acting on the horizontal tail is upwards and supplements the lift developed by the wing. Hence for the same CL the wing area is reduced, and there is a decrease in drag.
- The wing weight is lesser than the conventional aircraft wing
- At low speeds the horizontal tail stalls first, and automatically sets the airplane to a smaller angle of attack. Wing stall is difficult.
- After reaching the critical mach number the lifting stabilizer permits compensation of the growing wing diving moment
- When the Mach number increases, the static stability of the canard also increases.

Disadvantages

- Shock stall may occur on the horizontal stabilizer before occurs in the wing
- At supersonic speeds the longitudinal stability is more difficult in the canard the canard type than conventional airplane.
- The elevator power required for landing is very high.
- The landing characteristics are very poor.

The advantages of high wing design

- Increased lateral stability
- The possibility of engine failure due to suction of hard particles from the ground is 4 times less than in a low wing design.
- In passenger aircraft there is passenger comfort. The down view of the passenger is undisturbed by the wing
- In cargo aircraft, loading and unloading are easier, on account of the lower position of fuselage.

- The interference drag is lower as compared to low wing airplane.

Disadvantages of high wing design

- The area of the vertical stabilizer is 20-22% of the wing area as compared to 10-12 % in low wing design. This increases weight and drag.
- The weight of the fuselage is increased as lower fuselage is to be reinforced for protection in emergency landing.
- The weight of the fuselage structure is increased by the heavy frames needed for the attachment of the landing gear to the fuselage. Landing gear weight also very high.
- If the bogies are attached to the fuselage the treads are narrow, which leads to poor stability on the ground.
- Maintenance and inspection of engines are difficult

Location of engines

- Engine under pylons
- Inside the root portion of the wing
- Outside the rear fuselage
- Advantages in engine under pylon
- The weight of wing structure decreases by 15-20 %as the wing is relieved by the weight of the engines
- The space inside the wing is utilized for fuel storage, maintenance, inspection and replacements are facilitated
- The wing structure is free from the heat from the engines, and better fire safty can be achieved.

Disadvantages

- Failure of outboard engine create a large yawing moment. This moment has to be counted by rudder deflection which results in higher drag.
- Smaller ground clearance increases the possibility of foreign particles entering the engines.
- The noise level in the cabin is 5 db higher as compared to airplanes having engines on the rear fuselage.

Engines located in the wing root

Advantages

- There is very little increase in frontal area due to installation of power plants.
- Almost the entire wing span can be used for ailerons and high lift devices

Disadvantages.

- The weight of the wing is high due to the cut portion in the wing spars to accommodate engine
- The weight of the power plant is high due to the long air ducts.
- The intake is located at a place where the air flow is not clear.
- The space in the root cannot be used for fuel accommodation

Engine located on the rear fuselage

Advantages

- There is less noise in the cabin and the fuselage
- The entire wing can be used for fuel storage
- The whole wing space can be used for high lift devices and ailerons
- Fire hazard is minimum.
- The actual wing does not deviate from the design profile and the wing is clean.

Disadvantages

- The fuel is located far from the engines, therefore the length of the pipe line is increased and special fuel pumps should be provided.
- Due to power plant weight at the tail, longer fuselage is provided ahead of the wing which requires larger vertical and horizontal stabilizers.

AIRCRAFT LOADS

A general understanding of the various types of airframe loads, their generation and application during the design process, the transfer processes from "external loads" into "structural loads", loads qualification during ground and flight testing is therefore of equal importance to the process of usage monitoring and derivation of usage factors from the different fatigue tests or the set-up of structural inspection programs.

When life of aircrafts are discussed, often the flight hours or number of flights are still considered the governing factor, sometimes adapted with factors on "damage hours" or "usage", while from a structural engineering viewpoint the operational stress spectrum and therefore the life on the different aircraft components are not only a matter of flight hours and spectrum ratio but also driven by modification status, structural weight status and role equipment.

This paper describes loads- analysis and verification activities during the major phases of the life of an airframe, where structural loads and their influences on the airframe condition are vital to the structural integrity and the economic usage of the weapon system:

- The structural loads during design and Qualification of A/C structures
- Loads monitoring during usage
- Impacts due to aircraft modification and role changes.

Trends with respect to the increased usage of theoretical modelling are also discussed.

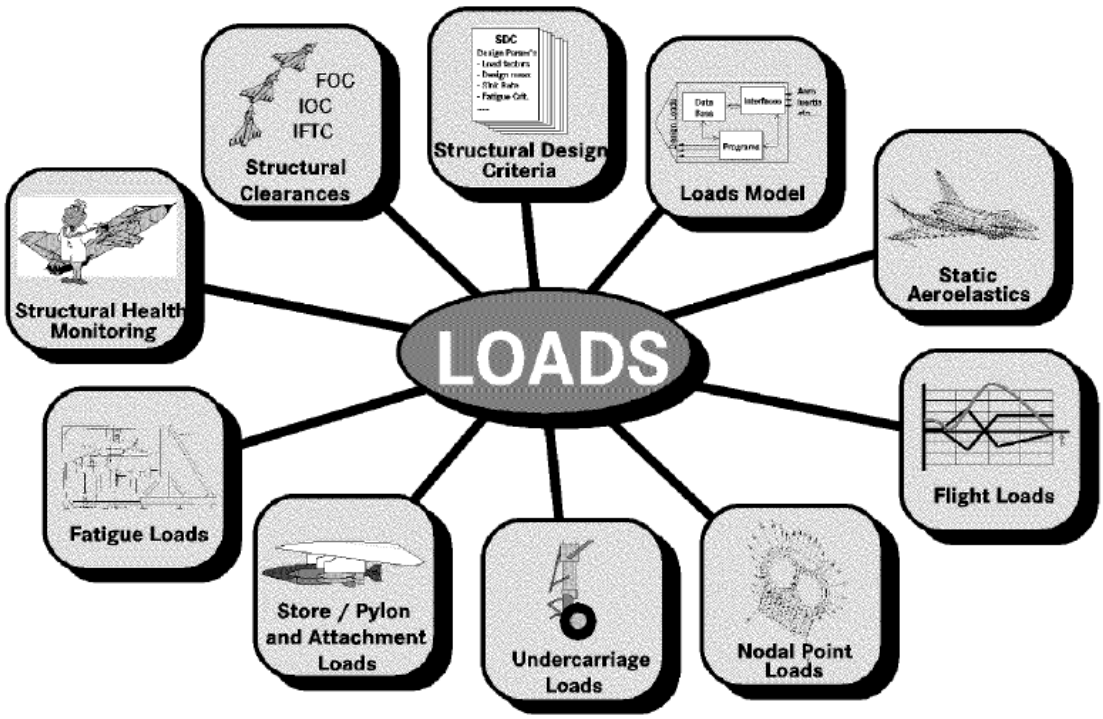
1. STRUCTURAL LOADS DURING THE DESIGN AND QUALIFICATION OF AIRCRAFT STRUCTURES

Loads are accompanying an aircraft's life from "the cradle to the grave". Although the overall type and magnitude of major load sets remain the same, there is no "fixed" loadset that is be applied to one aircraft model throughout the life and often identical airframes serving different roles within a fleet over time will be subjected to very different loads.

To include as much as possible (or specified) of these loading scenarios in the early process of designing a new type of aircraft is the responsibility of the loads engineering department, while ensuring that these loads can be safely endured throughout the specified life is the task of the design and stress engineers. "New" load sets, developed later during usage of the

aircraft are common tasks and handled similar as the "initial design loads" by the design authority with the constriction, that now the airframe is already build and deployed and the focus is on minimising changes though structural modifications to qualify the structure for its new environment either through analysis and / or test.

In short, every major change in the aircraft's role, payloads or usage in principle influences the loads acting on the airframe or at least some components. Figure below gives an idea how loads are initially generated and how they are used throughout the design-, qualification- and usage process.



Loads and Fatigue

The determination of loads together with the qualification for static strength and fatigue by calculation and test for all important structural components is a main prerequisite for successful design and safe operation of any aircraft.

Whereas for transport aircraft with their rather limited range of operational manoeuvres and high number of flight hours / cycles fatigue is the main design driver for the airframe, fighter aircraft are predominantly designed to (static) limit load cases for the "corners" of the envisaged flight envelope, which in general cover a lot of strength required for fatigue of their comparatively short life.

But this is only true as long as fighter life does not exceed the originally planned lifetime and the roles, missions etc. Are compatible with the design criteria at the beginning.

Aging aircraft in both cases does not only mean that an aircraft is getting older in terms of flight hours and flight cycles, it also means that some of the reference data for the basic design criteria have changed during time, i.e.:

- airframe and equipment mass growth
- enhancement of systems performance, especially engine thrust
- new configurations (stores)

- update of flight control systems (FCS) (electronically or hardware changes like added slats or enlarged ailerons)
- mission profiles and additional/changed roles
- actual usage spectrum

Most of these changes have an immediate impact on aircraft load scenarios, others will not change load levels but may change underlying statistic, e.g. fatigue spectra. Assessment of external loads is therefore a basic task throughout the life of a fleet.

Admittedly in many cases there is no simple one to one relationship between "external" loads and local internal stresses, which after all are the basis for the assessment of "life consumption" or "remaining life" of structural components. But providing loads are known for a special structural interface or component, reliable conclusions can be drawn regarding local stresses relating the manifold of load cases from experience, measurement and detailed FE analysis during design, qualification and test phases in many cases.

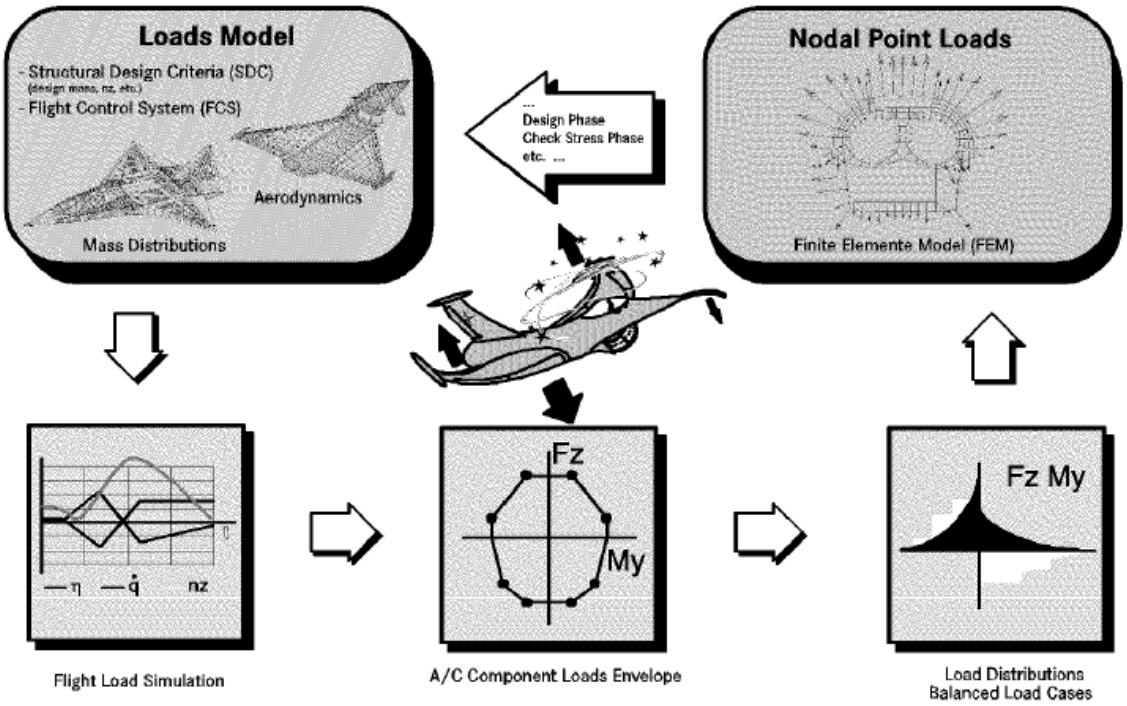
In addition the comparison of load spectra alone may already be suitable for drawing conclusions without recourse to detail stress calculations of specific locations for components with limited load case variations i.e. landing gears.

The Determination of Design Loads

Design loads, better "Initial Design Loads" are the first step in the loads history of an airframe that influences the detail design of a component (i.e. wing or fuselage structure) or, at a later stage in the design process, a part (i.e. wing spar cap or fuselage skin panel) in many details. Since not every load is determining these design tasks, establishment and identification of the "design loadcases" is important. The following is a summary on the methods how design loadcases are determined, with special attention to points where an immediate context with fatigue calculations exists.

Fig. below shows a typical "loads loop" which usually is repeated several times in the different phases of the aircraft design.

First of all the Structural Design Criteria (SDC) are prepared as a basis for design, specifying the basic performance and flight parameters, then a Loads Model (LM) is built, based on the SDC's, the aerodynamic, flight mechanic and weight and balance data of the aircraft.



LOADS LOOP

The loads module ensures that load cases selected for design are analysed for an overall balanced aircraft (mass, inertia and aerodynamic forces) for all manoeuvres and the loads analysis is performed in a time history sequence, thus providing load information on structural interfaces for every time step of the chosen manoeuvre. Results of the loads module is either continues external load distribution for any component (i.e. bending, torque and shear force distribution along fuselage stations for all load cases or a) distribution of loads on the Finite Element (FE) grid nodal points for subsequent "global FEAnalysis".

Thus, starting with the SDC the load loop ends with the preparation of external loads for stress analysis of components.

Usually an improved or changed data basis results in an update of the LM and consequently in more accurate and more detailed design load cases. Typical improvements are a better aerodynamic data basis (i.e. via extensive wind tunnel testing) or a refined FE-model because of an advanced design status. Modifications in the mass and balance status, control laws etc. may also result in substantial changes of the loads model, especially in advanced computer controlled flight vehicles.

The importance of the link between knowledge of external loads and structural stress distributions for the assessment of fatigue life cannot be underestimated. Whereas in the past the available computer resource was rather poor and strong software tools were scarce goods, leading to a strong selection of load cases to be analysed in detail, today there are virtually no limits, from this side. Computers power do play an important part with respect to better and refined results in the assessment of loads, however the correct selection of the critical manoeuvres for the fatigue spectrum and their loads analysis still influences the fatigue performance of a structure during the design phase.

Most of today's ageing aircraft fleets of the NATO air forces were designed and flight tested by the end of the sixties or the beginning seventies, like the Tornado, Harrier, F-16, F-18,

Mirage 2000 etc. An aircraft like the F-4 Phantom even dates back to the fifties and is still in service in some air forces of the alliance.

When comparing design environments of the a.m. models it should be pointed out that in the meantime the circumstances and requirements for aircraft design and analysis have changed in many ways, in detail:

- much better tools, soft- and hardware, and with that a very intensive investigation to calculate and control limit and fatigue loads (including a substantial increase in the number of component load monitoring stations)

	Tornado IDS	Future Europ.Fighter
Basic Loads Cases (BLC) Flight and Ground Handling Loads	33	105
Unit Loads Cases (ULC) Hammershock, Engine Thrust, Airbrake etc.	12	16
Combined Load Cases Superposition of scaled ULCs to BLCs	~ 100	590

- More accurate loads databases in terms of
  - Advances in "Carefree Handling"- Flight Control Systems (FCS)
  - Aircraft mass distributions predictions
  - Aircraft aerodynamics calculated with mature CFD (Computational Fluid Dynamics) methods and verified earlier and more reliable in wind tunnel tests.
  - coupling of structural models and aerodynamic models for aeroelastic effects available
  - Finite Element modelling of the structure with interfaces to the Loads Model
- extensive flight testing, especially dedicated flight load surveys
- extensive structural ground tests

Basically this means that the static design of "old" aircraft usually is rather conservative and on the safe side.

With respect to fatigue the situation is often less satisfying, i.e. without powerful tools like a balanced Loads Model, one procedure was balancing loads over the aircraft artificially in those days, and design load cases therefore were generated for parts of the structure like aft or forward fuselage or tail plane only, the effect of these loads on other areas of the structure remained unknown and components, not immediately under survey were not analysed for this load case, therefore the effect of changes to these load cases later remained also unknown.

Structural Design Criteria (SDC)

Aircraft loads are determined according to requirements and regulations collected in a systems specification document called Structural Design Criteria, the major reference for loads and structural analysis engineers during the design phase.

Many of the SDC requirements come from the customer; others are prepared in co-operation between customer and original equipment manufacturer (OEM), usually the principal design contractor. The SDC are also subject to revisions during the design process.
Some of the more important items regarding loads and structures are:
Design masses are defined for different flight conditions to cover the whole mass and centre of gravity (C.G.) range, i.e.:

- Basic flight design mass
- Landing design mass
- Maximum take off mass

Total mass and mass distribution not only affect loads on wing as is sometimes believed but loads on most parts of the aircraft's structure. Design mass is one of the most important criteria for structural design. For example the basic flight design mass is coupled to the max/min allowed vertical load factor Nz, for increased masses through the rule: Nz.Weight - const. to avoid overloads or assessing the effects of over-g.

V-n DIAGRAM

A V-n diagram shows the flight load factors that are used for the structural design as a function of the air speed. These represent the maximum expected loads that the aircraft will experience. These load factors are called as limit load factors. These diagrams are used primarily in the determination of combinations of flight condition and load factors to which the airplane structure must be designed.
For purposes of structural sizing, analysis is performed at four extreme loading conditions on the V-n diagram. The Positive High Angle of Attack (PHAA) is the loading condition represented by the intersection between the positive operational load limit line and the positive maximum lift curve. The Positive Low Angle of Attack (PLAA) is at the intersection between the positive operational load limit line and the dive speed. The Negative High Angle of Attack (NHAA) and Negative Low Angle of Attack (NLAA) are defined similarly except are for the negative loads. Should the gust envelope extend beyond the manoeuvring envelope in any of these four locations, the load factor of the gust envelope is instead used for the extreme loading condition. The high angle of attack conditions are characterized by a high coefficient of lift and high drag. The low angle of attack conditions are characterized by a high lift force. Designing to accommodate these four extreme loading conditions will guarantee that the wing will not undergo structural damage so long as operational load limits are not exceeded.
The control of weight in aircraft design is of extreme importance. Increase in weight requires stronger structures to support them, which in turn lead to further increase in weight & so on. Excess of structural weight means lesser amounts of payload, affecting the economic viability of the aircraft. Therefore there is need to reduce aircraft's weight to the minimum compatible with safety. Thus to ensure general minimum standards of strength & safety, airworthiness regulations lay down several factors which the primary structures of the aircraft must satisfy. These are,

- **LIMIT LOAD**: the maximum load that the aircraft is expected toexperience in normal operation.

- **PROOF LOAD**: product of the limit load and proof factor
- **ULTIMATE LOAD** : product of limit load and ultimate factor

There are two types of V-n diagram:

- The V-n maneuver diagram
- The V-n gust diagram

STALL SPEED AND MINIMUM SPEEDS:

The so-called 1-g stall speed of an airplane is defined by:

$$V_S = \sqrt{\frac{2W}{\rho C_{L_{max_{trim}}} s}}$$

Where

$C_{Lmaxtrim}$ is the maximum trimmed lift coefficient of the airplane.

The minimum speed at which an airplane is controllable is defined by:

$$V_S = \sqrt{\frac{2W}{\rho C_{L_{max_{controllable}}} s}}$$

Where

$C_{Lmaxcontrollable}$ is the maximum trimmed lift coefficient at which the airplane is controllable.

The load factor encountered by an airplane in flight is defined by:

$$n = \frac{L}{W}$$

Clearly, in level flight, n=1. Most flight tests close to stall encounter a load factor of about n=0.9. Therefore, an effective stall lift coefficient may be computed from:

$$C_{L_{max_{controllable}}} = \frac{C_{L_{max}}(n=1)}{n}$$

The V-n diagram for the aircraft is drawn for the two cases namely:

- Intentional maneuver(pilot induced maneuver)
- Unintentional maneuver(gusts)

Maneuvering Envelope:

In accelerated flight, the lift becomes much more compared to the weight of the aircraft. This implies a net force contributing to the acceleration. This force causes stresses on the aircraft structure. The ratio of the lift experienced to the weight at any instant is defined as the Load Factor (n).

$$n = \frac{\frac{1}{2}\rho_\infty V_\infty{}^2 C_{L\,max}}{W/S}$$

Using the above formula, we infer that load factor has a quadratic variation with velocity. However, this is true only up to a certain velocity.This velocity is determined by simultaneously imposing limiting conditions aerodynamically ((CL)max) as well as structurally (nmax). Thisvelocity is called the Corner Velocity, and is determined using the following formula,

$$V_A = V_{Corner} = \sqrt{(2\frac{n_{max}}{C_{Lmax}}\frac{W}{S})}$$

V-n diagram is used primarily in the determination of combination of flight conditions and load factors to which the airplane structure must be designed. V-n diagram precisely gives the structural (maximum load factor) and aerodynamic (maximum CL) boundaries for a particular flight condition.

Calculation:

The main velocities that r plotted in the V-n diagram are:

- 1 – g Stall Velocity
- Design Manoeuvring Velocity
- Design Cruise Velocity
- Design Dive Velocity 1-g Stall Velocity, Vs:

$$V_S = \sqrt{\frac{2W_{FDWG}}{\varrho C_{N_{max(controllable)}} S}}$$

Where,

ρ = Density at the sea altitude (1.225kg/m3)

(W_{FDWG} / S) = Wing Loading

= 29770*9.81/44.3

=**6592.40kg/m2**

$$C_{N_{max(controllable)}} = \sqrt{\left(C_{L_{max(controllable)}}\right)^2 + \left(C_{D_{at\,C_{L_{max(controllable)}}}}\right)^2}$$

Where, C_{Lmax} = 2

$\therefore$ **C_N = 1.1*** C_{Lmax}

=2.2

1-g Stall Velocity, Vs= 69.94 m/s .

DESIGN LIMIT LOAD FACTORS n limpos and n limneg:

The positive design limit load factor, nlimpos, must be selected by the designer, but must meet the following condition

$$n_{lim_{pos}} \geq 2.1 + \frac{24,000}{W_{FDGW} + 10,000}$$

$\geq 2.1 + (24000 / (29770+10000)$

$\geq$**2.705**

Hence our design satisfied the above condition.

The negative design limit load factor n_{limneg}, must be selected by the designer, but must meet the following condition:

$n_{limneg} \geq 0.4 n_{limpos}$ for normal and for utility category airplanes. Therefore,

$n_{limneg} \geq 0.4 \times 2.705$

$\therefore 1.52 \geq 1.082$

Hence our design satisfied the above condition.

DESIGN MANEUVERING SPEED V_A :

The design manoeuvring speed VA, must be selected by the designer, but must satisfy the following relationship:

$$V_A \geq V_S \sqrt{(n_{lim_{pos}})}$$

VA$\geq$ 69.94$\sqrt{2.705}$

VA $\geq$ 114.986 ms^{-1}

DESIGN CRUISE SPEED V_C:

The design cruise speed VC, must be selected by the designer, but must satisfy the following relationship:

$$V_C \geq k_c \sqrt{(W_{FDGW})/S}$$

k_c= 36 for acrobatic aircraft

$V_C \geq 36 \times \sqrt{672.00}$

$V_C \geq$ 933.23 ms^{-1}

DESIGN DIVING SPEED V_D

The design diving speed must satisfy the following relationship:

VD≥ 1.25 VC

VD ≥ 1.25 * 933.23

VD = 1166.541ms-1

Construction of V-n Diagram

Maximum Load Factor,

$$n_{max} = \left(\frac{L}{D}\right)_{max} \times \left(\frac{T}{W}\right)_{max}$$

$$n_{max} = \frac{1}{2}\,\rho_\infty\, V_\infty^2\, \frac{C_{L_{max}}}{\left(\frac{W}{S}\right)}$$

Curve AC:

AC is a line limiting the maximum amount of load that can be withstood by the weakest structure of the aircraft.

$$V_C = \sqrt{\frac{\left[\frac{T}{W} \times \frac{W}{S}\right] - \sqrt{\left[\frac{W}{S} \times \left(\frac{T}{W}\right)^2_{max} - (4\,k\,C_{D,0}\right]}}{\rho\, C_{D,0}}}$$

Along CD:

The velocity at point D is given by,

A straight line is used to join the points C and D. This VD is the dive velocity or the maximum permissible EAS in which the aircraft is at the verge of structural damage due to high dynamic pressure.

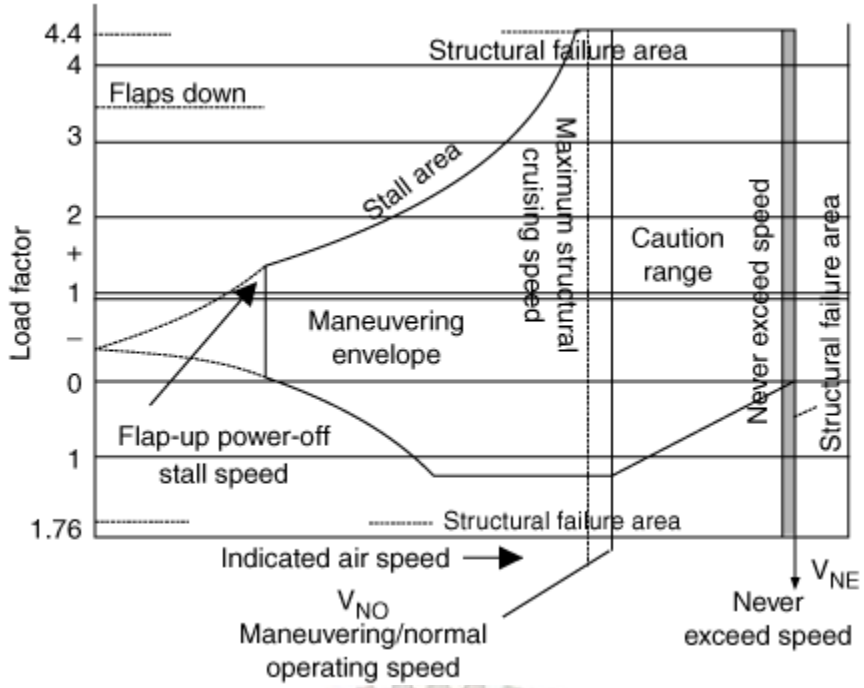
Along DE:

E corresponds to zero load factor point i.e. n = 0

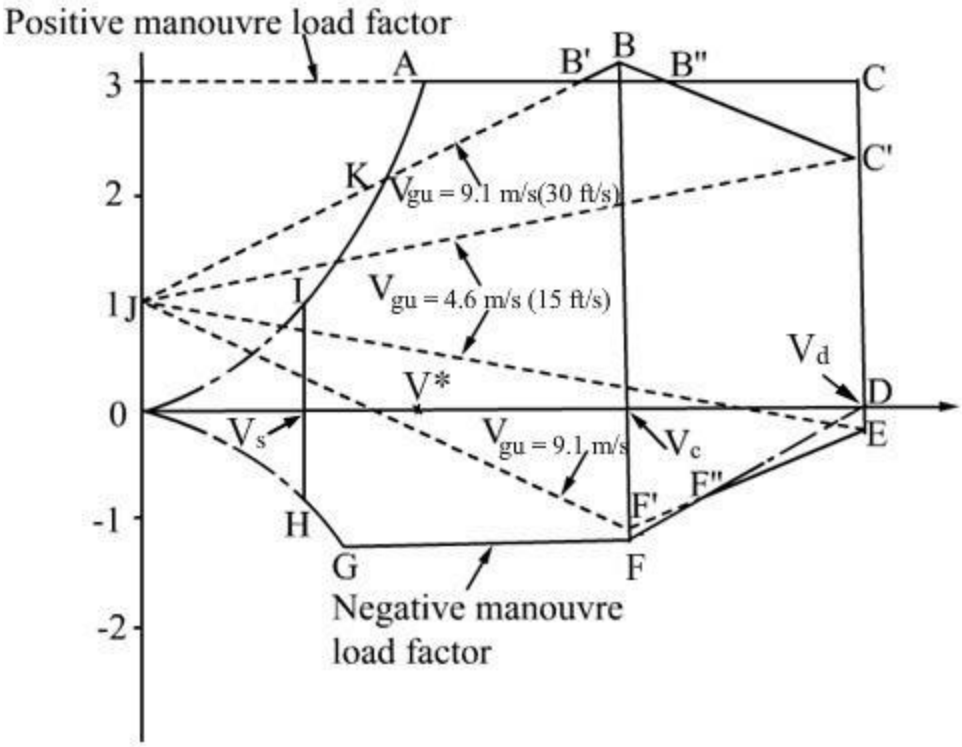
Curve OG:

Along GF:

Also $n_G = n_F$ Finally join GF by using a straight line



Sample V-n diagram



A typical V-n diagram

The load factor (n) has already been defined as the ratio of lift and weight i.e. n = L / W. In level flight n = 1. However, the value of 'n' during a manoeuver is greater than one. Hence, the structure of the airplane must be designed to withstand the permissible load factor. Further, when an airplane encounters a gust of velocity V_{gu} the angle of attack of the airplane

would increase by $\Delta\alpha = V_{gu}/V$. This increase in angle of attack, would increase the lift by ΔL, given by :

$$\Delta L = \tfrac{1}{2}\rho V^2 S C_{L\alpha} \Delta\alpha = \tfrac{1}{2}\rho V^2 S C_{L\alpha} V_{gu} / V$$

$$= \tfrac{1}{2}\rho V S C_{L\alpha} V_{gu}$$

$$\text{Hence, } \Delta n = \Delta L / W = \tfrac{1}{2}\rho V S C_{L\alpha} V_{gu} / W$$

From Eqs above, ΔL increases with V_{gu}. Further, for a given V_{gu}, the values of ΔL & Δn increase with flight velocity. An airplane must be designed to withstand the gust loads also.
In aeronautical engineering practice, the load factors due to manoeuvre and gust are indicated by a diagram called 'Velocity-load factor diagram or V-n diagram'. A typical V-n diagram is shown in Figure above. This diagram can be explained as follows.
(i) Curves OIA and OHG: The lift (L) produced by an airplane is given by
L = ½ ρV2S CL.
It should be noted that

(i) $C_L \leq C_{Lmax}$ and
(ii) at stalling speed(Vs),
L = W and n = 1.

However, if the airplane is flown with $C_L = C_{Lmax}$ at speeds higher than Vs, then
(a) L will be more than W and
(b) L or n would be proportional to V^2.
This variation is a parabola and is shown by curve OIA in
Figure above, In an inverted flight the load factor will be negative and the V vs n curve in such a flight is indicated by the curve OHG in Fig. It may be mentioned that an airplane can fly only at V ≥ Vs and hence the portions OI and OH in Fig are shown by chain lines.

(ii) Positive and negative manoeuver load factors:
An airplane is designed to withstand a certain permissible load factor. Higher the permissible load factor, heavier will be the weight of airplane structure. Hence, for actual airplanes the manoeuver load factor is limited depending on its intended use. Federal Aviation Administration (FAA) in USA and similar agencies in other countries, prescribe the values of permissible manoeuver limit load factors ($n_{positive}$ and $n_{negative}$) for different categories of airplanes.

Type of airplane	$n_{positive}$	$n_{negative}$
General aviation-non aerobatic	2.5 to 3.8	-1
Transport	3 to 4	-1
Fighter	6 to 9	-3

A limit load is obtained by multiplying the limit load factor with the weight (W). The airplane structure is designed such that it can withstand the limit load without yielding. The ultimate load factor, in aeronautical practice, is 1.5 times the limit load factor. The ultimate load is obtained by multiplying the ultimate load factor with the weight (W). The airplane structure is designed such that it can withstand the ultimate load without failing, though there may be permanent damage to the structure.

In Figure, $n_{positive}$ = 3 and $n_{negative}$ = -1.2 have been chosen; the actual values depend on the weight of the airplane and its category.

(iii) Lines AC, GF and FD: The positive manoeuver load factor is prescribed to be constant upto the design diving speed (V_d); line AC in Fig. The design diving speed could be 40 to 50% higher than the cruising speed (V_c) for subsonic airplanes. For supersonic airplanes, the Mach number corresponding to V_d could be 0.2 faster than the maximum level flight Mach number. The negative manoeuver load factor is prescribed to be constant upto design cruising speed (line GF in Fig) and then increases linearly to zero at V = V_d (line FD in Fig).

(iv) Manoeuvre load diagram: The diagram obtained by joining the points OACDFGO is called 'Manoeuvre load diagram'.

(v) Manoeuvre point and Corner speed: The point 'A' in Figure is called 'Manoeuvre point'. The flight speed at this point is denoted by V* and is called 'Corner speed'. At point 'A' the lift coefficient equals C_{Lmax} and the load factor equals $n_{positive}$. This combination would result in the maximum instantaneous turn rate at the speed V*. See subsection 9.3.6 for definition of instantaneous turn rate.

(vi) Positive and negative gust load factors: From Equation it is observed that the gust load factor varies linearly with velocity. The regulating agencies like FAA prescribe that an airplane should be able to withstand load factors corresponding to V_{gu} = 30 ft/s (9.1 m/s) upto cruising speed (V_c) and V_{gu} = 15 ft/s (4.6 m/s) upto design diving speed (V_d). Lines JB and JF' in Figure show the gust lines corresponding to V_{gu} = 30 ft/s (9.1 m/s) and Lines JC' and JE in the same figure show the gust lines corresponding to Vgu = 15 ft/s (4.6 m/s).

It may be pointed out that a gust in real situation is not a sharp edged gust and the velocity V_{gu} is attained in a gradual manner. This causes reduction in the gust load factor. To take care of this reduction the gust load factor is multiplied by a quantity called 'Gust alleviation factor'.

(vii) Gust load diagram: The diagram obtained by joining the points JBC'EF'J is called 'Gust load diagram'.

(vi) Final V-n diagram: For its safe operation, an airplane must be designed to withstand load factors occuring at all points of the gust and manouever load diagrams. Hence, the final V-n diagram is obtained by joining the parts of these two diagrams representing the higher of the manoeuver and gust load factors.

The final V-n diagram in the case presented in Figure, is given by the solid curve obtained by joining the points IAB'BB''CEF''FGHI.

It may be pointed out that the gust load line JB' is above the curve IA in the region IK. However, along the curve IK the airplane is already operating at C_{Lmax} and any increase in angle of attack due to gust cannot increase C_L beyond C_{Lmax}.

Hence, the portion JK of the line JB is not included in the final V-n diagram.

It may also be pointed out that the angles of attack of the airplane are different at various points of the V-n diagram. Consequently, the components of the resultant aerodynamic force along and perpendicular to the chord of the wing would be different at different angles of attack. The structural analysis needs to take this into account. For example, the angle of attack is positive and high at point A and it is positive and low at point C. At points G and E the angles of attack are negative. Books on Airplane structures may be consulted for details.

Developments of Aircraft upto 1960's

Important developments upto 1960's are summarized in this section.

(a) First successful flight in Europe was by Voisin on March 30, 1907.

(b) Louis Bleriot's airplane, flown in 1907, appears to be the first airplane to have ailerons.

(c) A. Verdon Roe's airplane, flown in 1911, was a tractor airplane with engine ahead of wing and with horizontal stabilizer at rear.

(d) Prior to the First World War, the airplanes were developed for military use, namely reconnaissance and for guiding artillery fire and later for throwing grenades and bombs.

(e) During the First World War (1914 – 1918), the airplanes were developed as bombers and fighters. Passenger flights appeared later and by 1925 a variety of airplanes were being designed and used.

(f) By 1930's the following developments had been achieved.

(i) Streamlining of the airplane shape by features like retractable landing gear, engine cowling, fairing at wing-fuselage joints.

(ii) More powerful and reliable piston engines.

(iii) New aluminum alloys with higher strength to weight ratio and

(iv) Better instrumentation for control of airplane.

These developments brought about bigger airplanes, with improved performance namely higher speed, longer range and higher ceiling as compared to the earlier airplanes.

(g) The speed of the airplanes increased sharply with the availability of jet engines in 1940's.

(h) Supersonic flight was possible in 1950's due to the developments in aerodynamics. The problems associated with changes in lift & drag in the transonic range were tackled. Features like swept back wings, delta wing, fuselage with pointed nose were introduced.

For example, for the fighter airplanes the maximum speed increased from 150 kmph in 1914 to about 3500 kmph in 1970. The engine power increased from about 60 kW to a thrust of 30,000 kgf and the weight of the airplane increased from about 600 kgf to about 50,000 kgf.

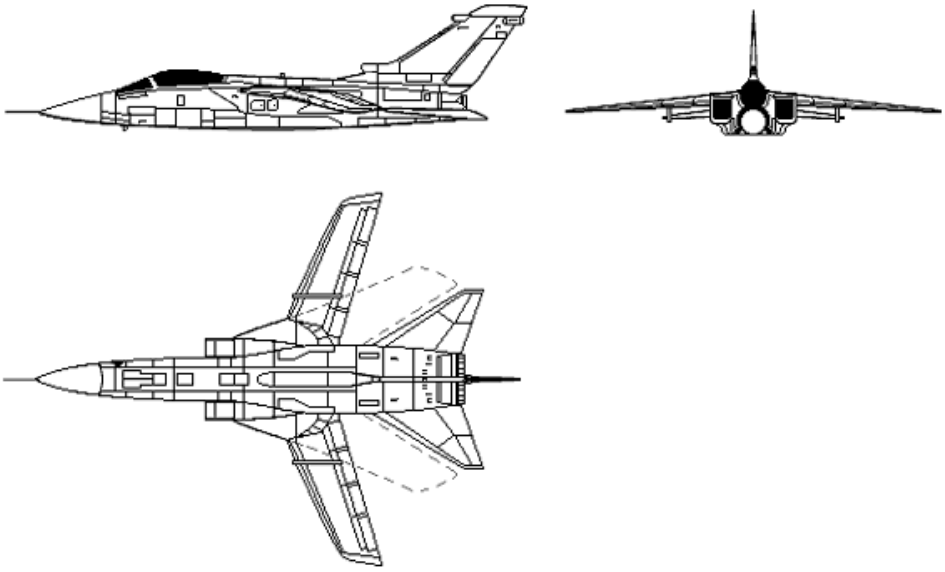
Some of the subsequent developments

Some of the important subsequent developments are as follows.

(a). Supersonic passenger airplane – Anglo-French Concorde in 1971 (Fig.1.6). Another example in this category is the Russian TU-144.

Concorde in flight

(b).Variable sweep military airplane - low sweep at low speed & high sweep at high speed



Variable sweep airplane – Tornado

(c). Passenger airplanes with upto 450 seats and range of 12000 km were available in early 1970's

Boeing 747

Currently the seating capacity of 650 passengers is available on Airbus A380

Airbus A380

(d). Supercritical airfoils with higher critical Mach number were available in 1970's.

(e). Automatic Landing system was introduced in 1960's.

(f). Fly - by -wire control was introduced in 1984. In this case, the movements of the control stick or pedals by the pilot are transmitted to a digital computer. The input to the computer is processed along with the characteristics of the airplane and the actuators of the controls are operated, so as to give optimum performance. Presently fibre optics is used for communication of signals and the system is called Fly-by-light (FBL).

(g). Bypass engine whose developments started in 1950's has become high bypass ratio engine; a bypass ratio of 17 has been achieved.

(h). Winglet at wing tips which were studied in 1970's are now found on most of the new jet airplanes and are also being retrofitted on older airplanes.

Airplane with winglets – Boeing 737-800

(i). The use of FRP (Fiber Reinforced Plastics) has increased and components like wings are also being made of FRP (for example LCA –Tejas made by HAL, Bangalore,India).

(j). Low Radar cross-section – stealth technology was introduced in late 1980's

B2 Stealth bomber

Features of some special airplanes:

1. **Largest Airplane:** Airbus A380-800F (Fig.1.8b)

Wing span - 79.75 m

4 engines each 355 kN thrust.

Maximum take-off Weight - 590 tons

2. Airplane with advanced technologies:

X-29A airplane (Fig.1.11) has, according to Ref.1.22:

Digital flight control

Negative longitudinal static stability (relaxed stability)

Closely coupled canard.

Forward swept wing

Aero- elastically tailored composite wing.

Thin supercritical wing with discrete variable camber.

X-29A

Modern fighter:

Lockheed YF-22 Advanced tactical fighter. Presently it is called F-22 Raptor.

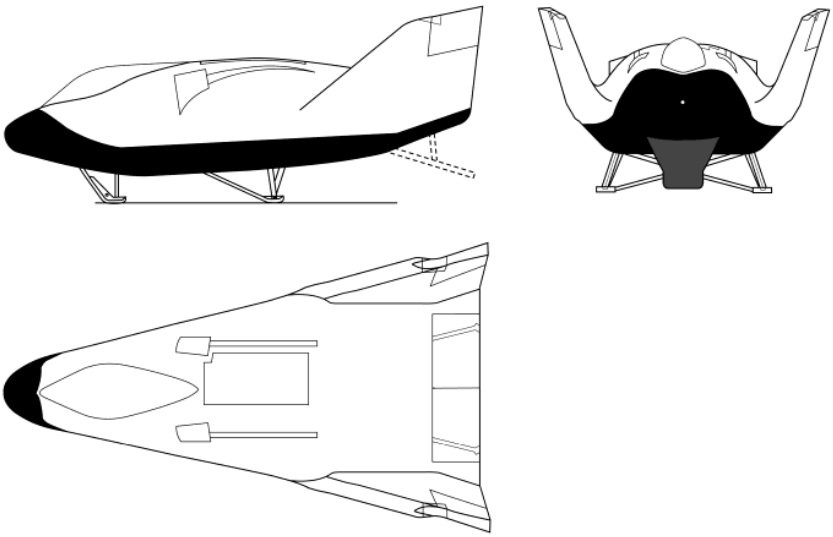
Span: 13.1 m;

Length: 19.6 m;

Height: 5.4 m;
Wing Area: 77.1 m^2;
Basic Empty weight: 15441 kgf.

Lockheed YF-22 Advanced tactical fighter

Reusable vehicle:
X-38 (Fig 1.13)
Length: 8.7 m
Wingspan: 4.4 m
Empty weight: 7260 kgf.
It may be added that the project was abandoned in 2002.



Reusable vehicle

AIRPLANE DATA SHEET

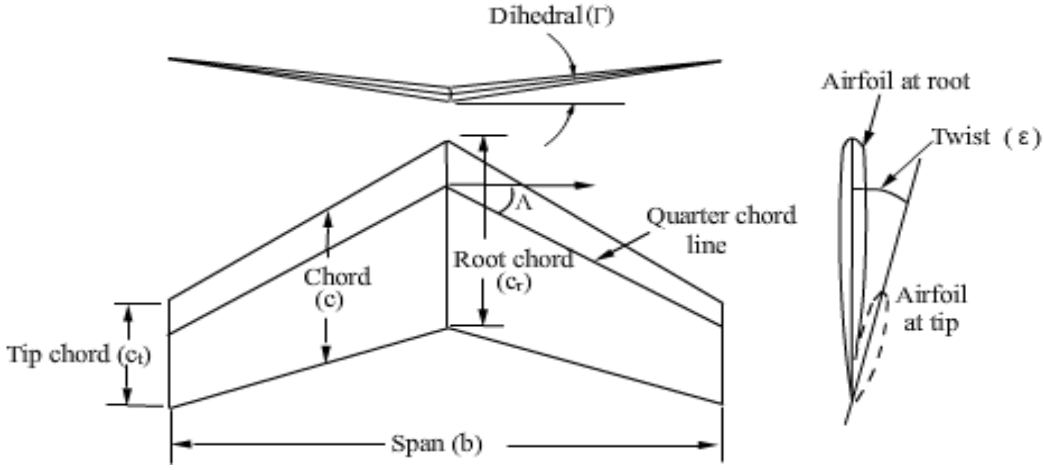
1. General description of airplane

i) Name of the airplane:
ii) Type of airplane *:
iii) Name of manufacturer and country of origin:

2. Power Plant

i) Type of power plant*:
ii) Name:
iii) Engine rating*:
iv) Specific fuel consumption:
v) Oil consumption :
vi) Weight of power plant:
vii) Overall dimensions of engine:
    a. Diameter (m):
    b. Length (m):
viii) Engine centre of gravity:
ix) Special accessories and controls:
x) No. of engines and their locations:
xi) Intake/propeller details

3. Wing: Planform shape



i) Airfoil section:
ii) Span (m):
iii) Root chord (m):
iv) Tip chord (m):
v) Area (S) (m^2):
vi) Mean chord* (m):
vii) Mean aerodynamic chord* (m):
viii) Sweep (Λ):
ix) Dihedral. (Γ):
x) Twist (ε)*:
xi) Incidence (i)*:
xii) Flap area (m^2):

xiii) Aileron area (m^2):
xiv) Type of high-lift devices:
xv) Location of spars:
xvi) Taper ratio (λ)*:
xvii) Aspect ratio (A)*:
xviii) Flap area/wing area:or S_{flap}/S
xix) Aileron area/wing area or $S_{aileron}/S$:
xx) Flap chord/ wing chord or C_{flap}/C_{wing}:
xxi) Aileron chord/wing chord or $C_{aileron}/C_{wing}$:
xxii) Location of wing on fuselage (high wing/mid wing/low wing):
xxiii) Construction and other details:

4. Horizontal tail surface

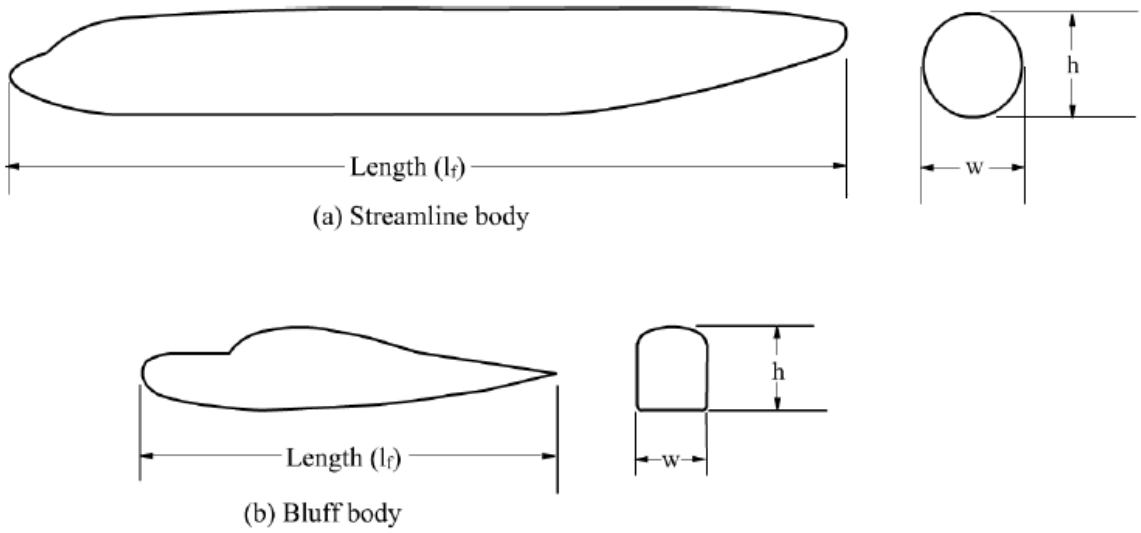
i) Type of horizontal tail *:
ii) Platform shape:
iii) Airfoil:
iv) Span (m):
v) Root chord (m) :
vi) Tip chord (m):
vii) Area (m^2):
viii) Sweep:
ix) Incidence (i)*:
x) Elevator area (m^2):
xi) Tab area (m^2):
xii) Aspect ratio:
xiii) Taper ratio:
xiv) Elevator area / Tail area:
xv) Tab area / elevator area:
xvi) Tail area(Sht) / wing area(S):
xvii) Elevator chord / tail chord:
xviii) Location of H.tail:
xix) Type of control and aerodynamic balancing*:
xx) Construction and other details:

5. Vertical tail surface

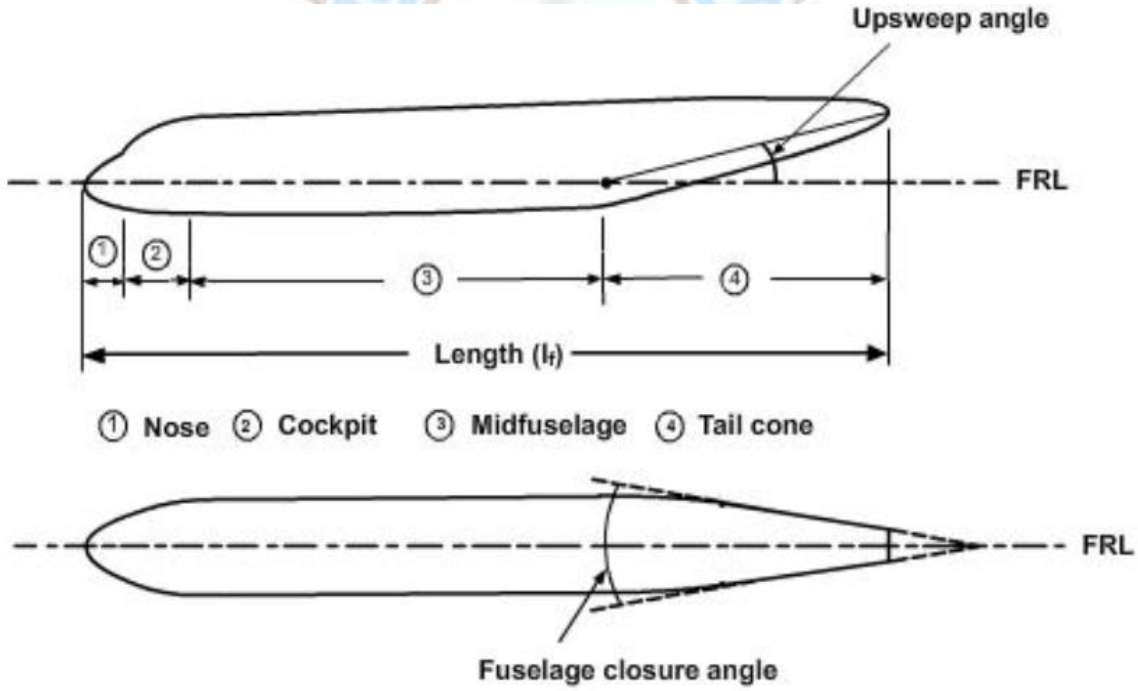
i) Type of vertical tail *
ii) Airfoil:
iii) Height (m):
iv) Root chord (m):
v) Tip chord (m):
vi) Area (m^2):
vii) Sweep:
viii) Off-set angle*:
ix) Rudder area (m^2):
x) Tab area (m^2):

xi) Aspect ratio (Av)*:
xii) Taper ratio:
xiii) Rudder area/tail area:
xiv) Tab area / rudder area:

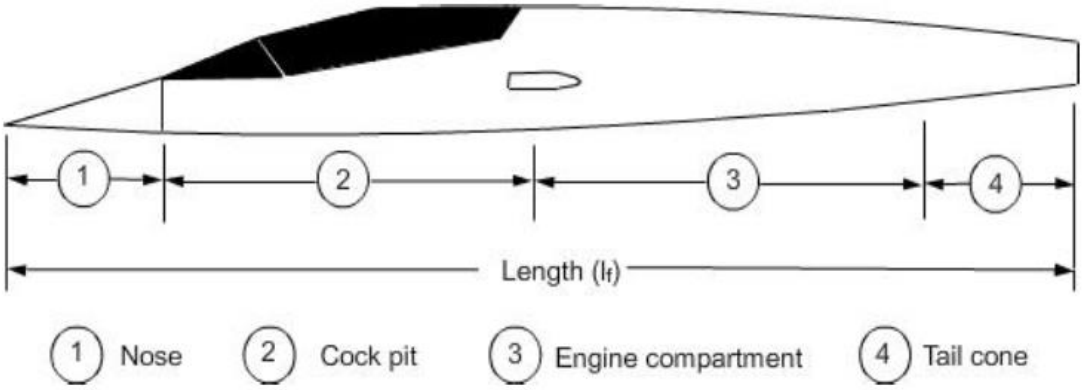
6. Fuselage



Fuselage parameters



Typical segments of a passenger airplane fuselage



Typical segments of a military airplane fuselage

i) Length (m):
ii) Length of nose (l_{nose}):
iii) Length of cockpit ($l_{cockpit}$):
iv) Length of tail cone ($l_{tailcone}$):
v) Length of payload compartment:
vi) Length of midfuselage:
vii) Upsweep angle
viii) Fuselage closure angle
ix) Shape and size of cabin:
x) Arrangement of payload and auxiliary equipment:
xi) Cockpit:
xii) Number and arrangement of seats:
xiii) Cockpit instruments:
xiv) Vision (angle):
xv) Construction and other details:
xvi) Length(l_f)/wingspan(b):
xvii) l_{nose}/l_f :
xviii) $l_{cockpit}/l_f$:
xix) $l_{tailcone}/l_f$:

7. Landing gear

i) Type of landing gear*:
ii) Number and size of wheels:
iii) Tyre pressure:
iv) Wheel base* (m):
v) Wheel tread* (m):
vi) Location of landing gears:
vii) Means to reduce landing run and other details:

8. Overall dimensions of airplane:

i) Length (m):
ii) Wing span (m):
iii) Height (m):
iv) Landing gear wheel tread (m):

v) Landing gear wheel base(m):
vi) Length/span:
vii) Height/span:
viii) Tread/span:

9. Weights

i) Pay load* (kgf):
ii) Empty weight* (kgf):
iii) Fuel weight (kgf):
iv) Structural weight (kgf):
v) Disposable load* (kgf):
vi) Landing weight (kgf):
vii) Normal gross weight (kgf):
viii) Maximum gross weight (kgf):
ix) Payload/gross weight:
x) Empty weight/gross weight:
xi) Fuel weight/gross weight:
xii) Structural weight/gross weight:
xiii) Wing loading*:
xiv) Power (or thrust) loading*:

10. Performance

i) Maximum speed (kmph) at sea level:
ii) Maximum speed (kmph) at altitude :
iii) Landing speed (kmph):
iv) Cruise speed (kmph) and altitude (km):
v) Maximum sea level rate of climb (m/min):
vi) Service ceiling (km):
vii) Range* or radius of action* (km):
viii) Endurance* (hours):
ix) Take-off run* (m):
x) Landing run* (m):