

Chapter 1 Introduction (Lectures 1,2 and 3)

Keywords : Purpose and scope of airplane design; stages in airplane design; classification of airplanes based on purpose, design requirements and configuration; factors affecting airplane configuration; historical background; course outline.

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1.2.2 Preliminary design

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Chapter 1

Lecture 1

Introduction - 1

Topics

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1.1 Purpose and scope of airplane design

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.

Remark:

Figure 1.1a shows the three-view drawing of a turboprop airplane and illustrates the large variety of parts in an airplane. The parts of fuselage seen in the figure are the nose, the cockpit, the central fuselage (or passenger cabin) and the rear fuselage (or tail cone). The wing has flaps and ailerons. Also seen are the power plants (in the present case the turboprop engines with propeller), the nacelle, the pylon, the landing gears, the horizontal tail, the vertical tail, elevator, rudder and tab. The airplane also has control systems, the electrical systems, the fuel systems etc..

Figure 1.1b shows the three view sketch of a military airplane. This figure again brings out the fact that an airplane consists of a large variety of components. The cutaway drawing of Airbus 380 in Appendix 1.1 shows the internal features of large transport airplane.

The completion of the design of an airplane in a reasonable period of time requires a large body of competent engineers specialized in various areas. Help is also needed from research laboratories to try out and give new ideas and for testing of different components. For example, Laboratories of NASA (National Aeronautics and Space Administration) in USA; ARC(Aeronautical Research Council) in UK; ONERA (Office National d'Etudes et de Recherches Aerospatiales) in France; DFVLR (Deutsche Forschungs and Versuchsanstalt fur Luft-und Raumfahrt, now DLR) in Germany; NAL (National Aerospace Laboratories) in India, are some of the agencies carrying out Aerospace research. However, the work of all these must be coordinated by the design bureau. The final design is a compromise between conflicting requirements so that optimum results are obtained from the point of view of design criteria.

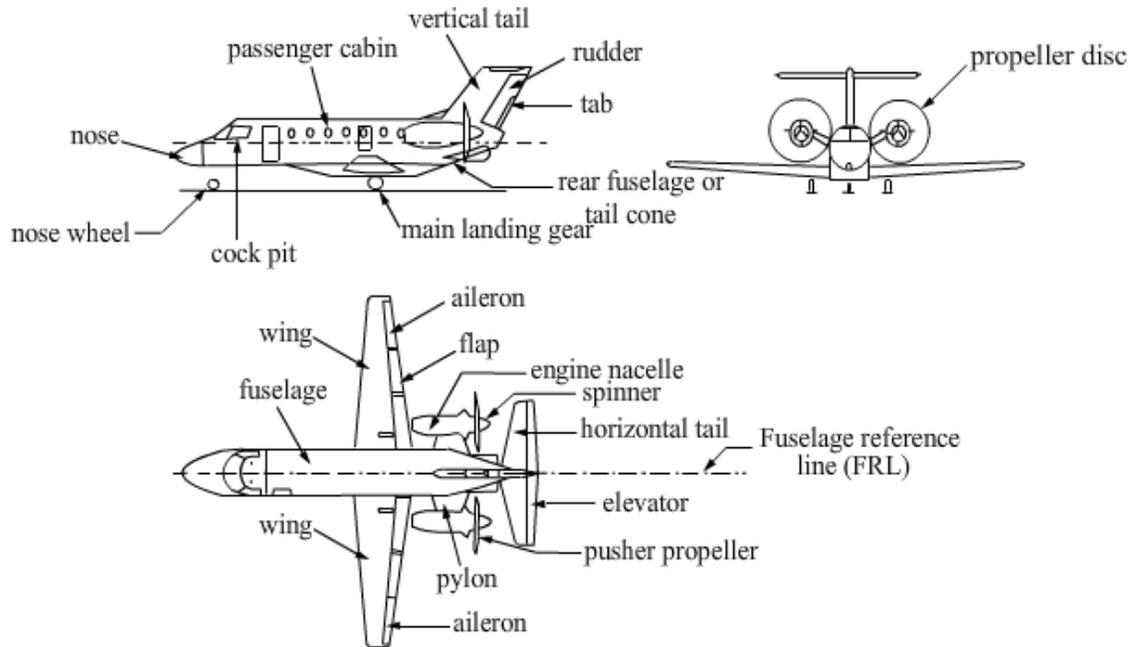


Fig 1.1a Three-view drawing of an airplane with turboprop engine
(Based on drawing of SARAS airplane supplied by National Aerospace
Laboratories, Bangalore, India)

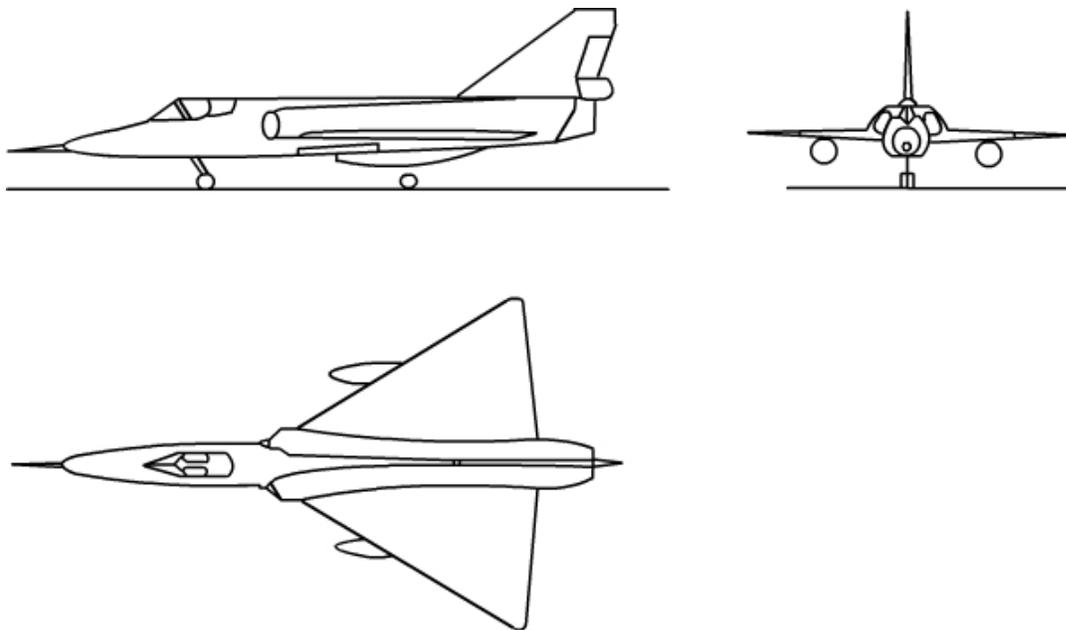


Fig 1.1b Three view sketch of a military airplane
(Adapted from Ref.1.1)

1.2 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

1.2.1 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 Administration) 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 distances.
 - b) Payload.
 - c) Operating conditions at the destinations.
 - d) Maneuverability.

1.2.2 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 by the manufacturer or the customer. This stage includes the following steps.

- i) Selection of geometrical parameters of main components based on design criteria.
- ii) Arrangement of equipment, and control systems.
- iii) Selection of power plant.
- iv) Aerodynamic and stability calculations.
- v) Preliminary structural design of main components.
- vi) Weight estimation and c.g. travel.
- vii) Preparation of 3-view drawing.
- viii) Performance estimation.
- ix) Preparation of brochure. Section 10.3 deals with the items included in the brochure. It is also called aircraft type specification.

1.2.3 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.

Remark:

In military airplanes, there may be a “demonstrator program”. According to Ref.1.2, a demonstrator program is an agreed schedule of tests of new hardware including complete airplane, before the military customer. This is in advance of the decision on procurement and often to establish what is possible. According to Ref.1.3, a demonstrator is a new aircraft, engine or system constructed to prove its novel features prior to embarking on full development of the same product.

- 8) Series production and flight testing to meet specified operational and airworthiness requirements
- 9) Obtaining type certificate: According to Ref.1.2, it is a legal document, issued by a regulating agency like Federal Aviation Agency (FAA) in USA, allowing the manufacturer to offer the item (e.g. airplane) for sale.

Remarks:

i) References 1.4 to 1.20 present a partial list of books on airplane design. They, (especially Ref.1.18 and 1.19,) contain additional information on various stages of airplane design process.

- ii) Brief information about Airbus Industry and Boeing Aircraft company is contained in Appendices 1.1 and 1.2. This would illustrate the complex and multidisciplinary nature of aircraft design.
- iii) In the remaining part of this introductory chapter, the following topics are dealt with.
 - 1.2 Classification of airplanes.
 - 1.3 Factors affecting the configuration.
 - 1.4 Stages in preliminary design as part of this course and
 - 1.5 Brief Historical Background.

1.3 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 and (b) the configuration.

1.4 Classification of airplanes according to function

There are two main types of airplanes viz. civil and military.

The civil airplanes are categorised as passenger, cargo, agricultural, sports and ambulance.

The military airplanes are categorised as fighter, bomber, interceptor, reconnaissance, and 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.

1.4.1 Influence of the function of airplane on specifications/design requirements

The specifications or design requirements of an airplane are decided by its function. Following Ref. 1.6 Chapter I, 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.

For further details see Ref.1.6, chapter I. Reference 1.19, chapter 2 gives a comparison between design requirements of civil & military airplanes.

Remark:

The airplanes can also be classified depending on the requirements they must satisfy from the regulating agencies (Ref.1.24, Chapter 1). According to the regulations specified in USA the airplanes can be classified as follows.

- A) Civil airplanes which are further classified as (a) general aviation aircraft and (b) transport.
- B) Military airplanes.

The general aviation (GA) aircraft are governed by the Federal Aviation Regulation FAR 23 of Federal Aviation Agency (FAA). These (GA) aircraft are categorised as (a) normal (b) utility (c) aerobatic and (d) agriculture.

As the name suggests, the aerobatic aircraft are intended to perform manoeuvres. These aircraft are also referred to as acrobatic aircraft. These

aircraft are designed to withstand load factors more than those for the normal category aircraft.

The agricultural aircraft are intended for agriculture related operations like crop praying, seeding etc. They mostly fly at very low levels above the ground.

The utility aircraft are intended for various missions of transportation. They are also used for special purposes like photography.

The general aviation aircraft in the category of normal, acrobatic and agricultural aircraft weigh not more than 12500 lbs (5670 kgf). Whereas the utility aircraft weigh not more than 19000 lb (8618 kgf) and can carry upto 19 passangers.

The transport aircraft are non-military aircraft. These are governed by FAR 25.

They weigh more than 19000 lb (8618 kgf) and carry more than 19 passangers.

The FAR requirements cover various aspects of design and the student is advised to refer to FAA website. Brief information can be obtained from Appendix F of Ref.1.18.

The home-built or garage-built aircraft are not certified by government agencies.

They are designed and built by enthusiastic individuals. They are not permitted to be sold in USA.

The military aircraft are governed by military standard, 'MIL-STD' or "MIL-SPEC".

Students may consult internet for additional details.

Note: "general aviation aircraft" is a technical term. This term is used, in this course, whenever airplanes governed by FAR 23 are being referred to.