Chapter 1

Lecture 2

Introduction - 2

Topics

1.5 Classification of airplanes according to configuration

This classification is based on the following features of the configuration.

a) Shape, number and position of wing.

b) Type of fuselage.

c) Location of horizontal tail.

d) Location and number of engines.

The different types of configurations are shown in Fig.1.2.

As an exercise the student is advised to study, at this stage, various types of airplanes from Jane's all the world aircraft (Ref.1.21).

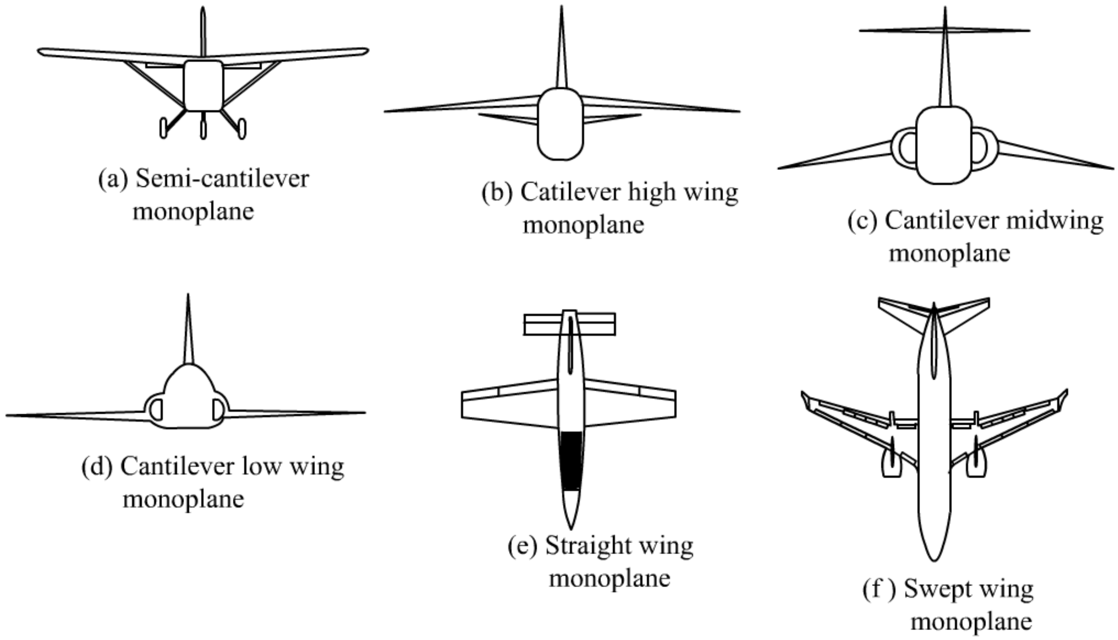

Fig.1.2 Types of airplanes(cont.)

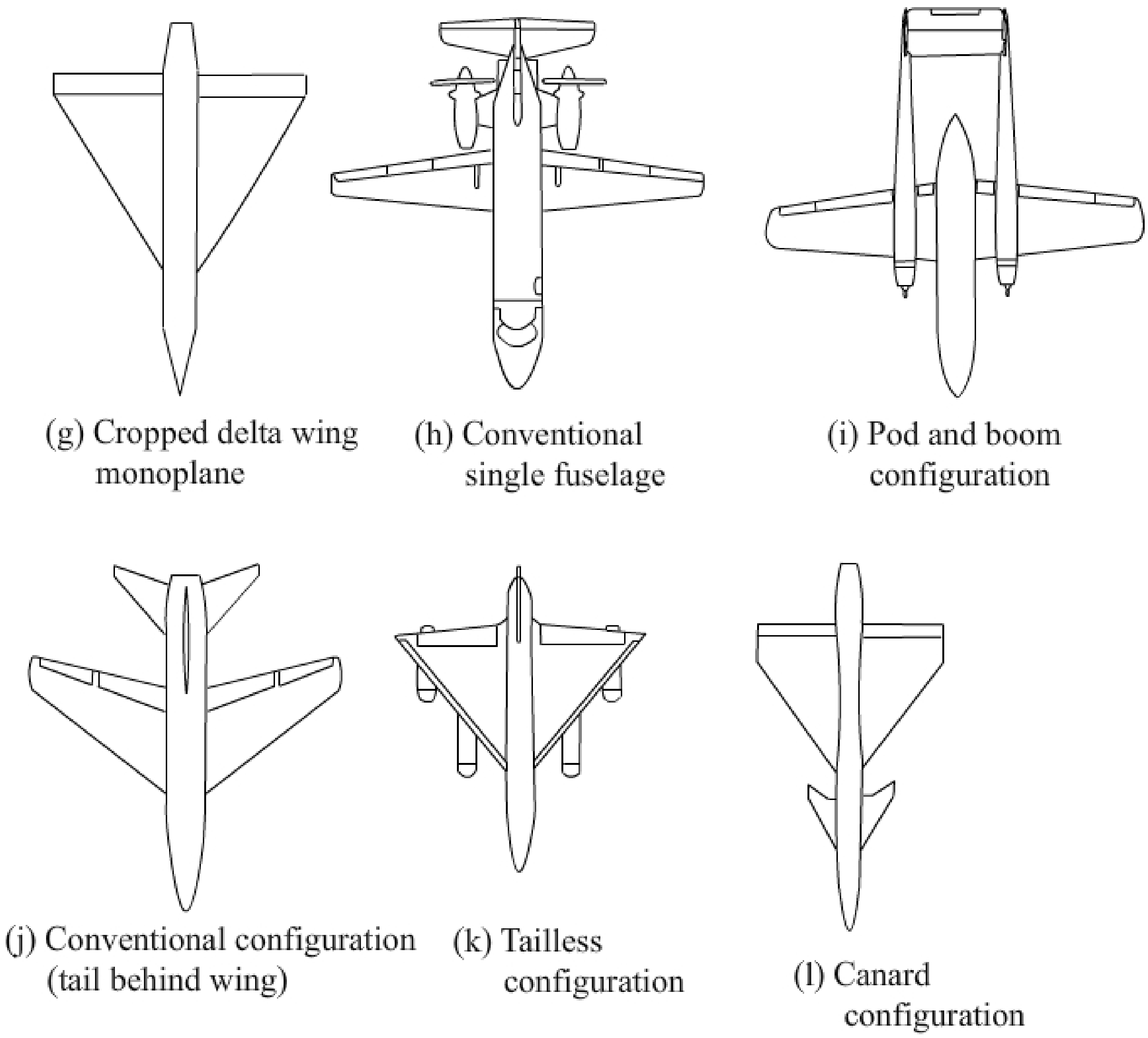

Fig.1.2 Types of airplanes

1.5.1 Classification of airplanes based on wing configuration

Early airplanes had two or more wings e.g. the Wright airplane (Fig.1.3) 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 semicantilever monoplane (Fig.1.2a). Depending on the location of the wing on the fuselage, the airplane is called high wing, mid-wing and low wing configuration (Fig.1.2b, c and d). Further, if the wing has no sweep the configuration is called straight wing monoplane (Fig.1.2e). The swept wing and delta wing configurations are shown in Figs.1.2f and g.

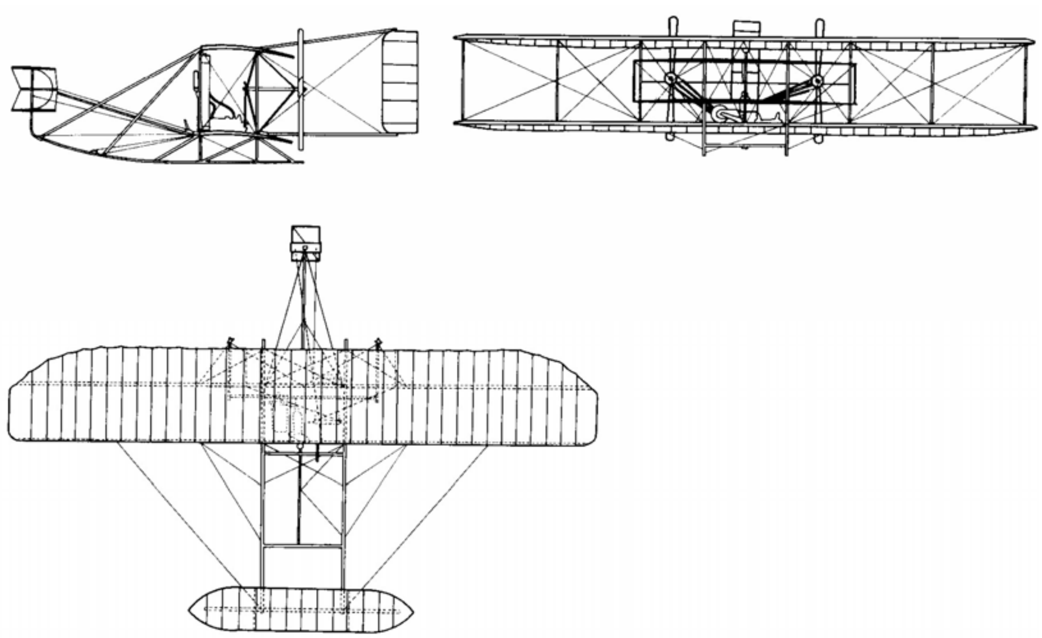

Fig.1.3 Wright flyer

(Adapted from : http://www.wrightbrothers.orgs/1905%20Flyer%203V.jpg)

1.5.2 Classification of airplanes based on fuselage

Generally airplanes have a single fuselage with wing and tail surfaces mounted on the fuselage (Fig.1.2 h). 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 (Fig.1.2i). 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.

1.5.3 Classification of airplanes based on horizontal stabilizer

In a conventional configuration, the horizontal stabilizer is located behind the wing (Fig.1.2j). In some airplanes there is no horizontal stabilizer and the configuration is called tailless design (Fig.1.2k). In these airplanes, the functions of elevator and aileron are performed by ailevons located near the wing tips. When both ailevons (on left and right wings) move in the same direction, they function as elevators and when the two ailevons 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 (Fig.1.2l). In conventional configuration the horizontal tail has a negative lift and the total lift produced by the wing is more than the weight of the airplane. In canard configuration, the lift on the canard is in the upward direction and lift produced by the wing is less than the weight of the aircraft. However, the canard has destabilizing contribution to the longitudinal stability.

1.5.4 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 (see section 6.6 for further details). 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 (Fig.1.2h). In tractor configuration the propeller is ahead of the engine(Fig.1.4).

Remark:

The features of the airplane like wing configuration, fuselage configuration, tail configuration, engine location mentioned in subsections 1.5.1 to 1.5.4, have certain advantages and disadvantages. These are dealt with in chapters 5, 6, 7 and 9, after adequate background material is covered. Students interested in obtaining some information at this stage, may refer to Chapter II of Ref. 1.6, chapters 3 and 4 of Ref.1.13 and chapter 3 of Ref. 1.14.

1.6 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

Chapter 7 gives the details of these considerations. Here, a brief outline is given to provide an overall perspective.

1.6.1 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 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 by proper fillets at the joints between (a) wing and fuselage, (b) tail and fuselage and (c) wing and engine pods.

1.6.2 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.

1.6.3 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 (Fig.1.4).

(Source:www.flickr.com) (Source:www.img525.imageshack.uscom)
(a) General view (b) Cargo being loaded
Fig.1.4 A cargo airplane-C130 Hercules

1.6.4 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.

1.6.5 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.

1.6.6 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.

1.7 Brief historical background of airplane development

1.7.1 Early developments

Important developments which led to successful flight by Wright brothers are briefly mentioned in this subsection.

(a) By the beginning of the eighteenth century, it was realised that human muscle power was not adequate to sustain a man in air by the flapping of wings like the birds.

(b)It was known that a flat plate at an angle of attack produces lift. Further, for a single wing to be stable the centre of gravity (c.g.) should be ahead of the aerodynamic centre. Sir George Cayley (1774–1857) showed that (a) a cambered plate would produce higher lift at the same angle of attack and (b) a combination of two wings - one behind the other would produce a stable configuration. Figure 1.5 shows this concept and a brief explanation of it is as follows.

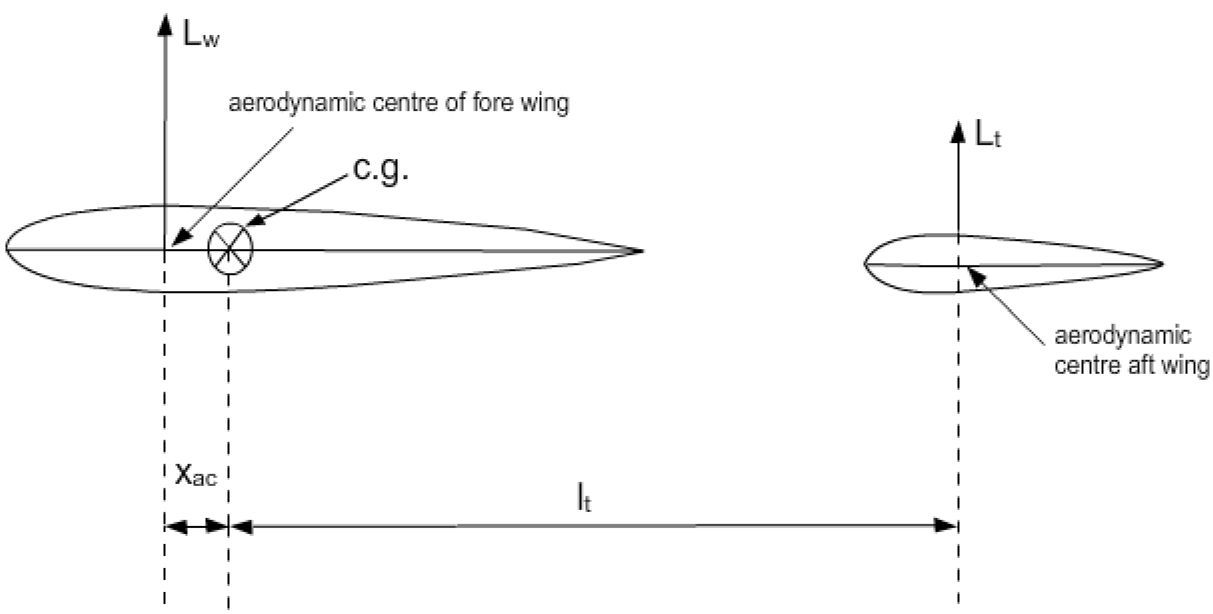

Fig.1.5 Stability of a configuration with two wings

For the configuration with two wings, shown in Fig.1.5, the conditions for equilibrium are :

$L = L_w + L_t$

$M_{cg} = L_w \times x_{ac} - L_t \times l_t = 0$

When this combination of the two lifting surfaces is disturbed (e.g. by gust of vertical velocity v_g), the angle of attack will change by $\Delta\alpha$ which is equal to

v_g / V_∞; V_∞ being the free stream velocity. For the combination to be stable, a negative moment (ΔM_{cg}) should be brought about so as to bring the combination back to the original equilibrium.

It is observed that due to $\Delta\alpha$, L_w changes to($L_w + \Delta L_w$)and L_t to($L_t + \Delta L_t$). This would produce a pitching moment $\left(\Delta M_{cg}\right)$ given by :

$$\Delta M_{cg} = \Delta L_w \; x_{ac} - \Delta L_t \, l_t$$

By a suitable choice of l_t the rear lifting surface could be small and yet result in the desired negative value for ΔM_{cg}**.** This important conclusion laid the foundation for the conventional configuration of a stable airplane in which a small horizontal tail is located behind the wing.

(c) The development of internal combustion engine in 1860's provided a power plant lighter than the earlier steam engines.

(d) Lilienthal (1848 – 1896) made several hang glider runs and tried to obtain a stable configuration.

(e) Orville Wright (1871 –1948) and Wilbur Wright (1867 – 1912) made trials between 1900 to 1903 and arrived at a suitable configuration and the successful flight took place on Dec.17, 1903.

Wright brothers' airplane (Fig.1.3) had the canard configuration and the vertical stabilizer was behind the wing. Instead of ailerons the control in roll was obtained by warping the wings. It may be pointed out that in the Wright flyer the engine is behind the wing i.e. a pusher configuration.