

Chapter 7

Special considerations in configuration lay out

(Lecture 31)

Keywords

Considerations which influence airplane lay out – aerodynamic, structural, crash worthiness, manufacturing, maintainability and environmental considerations

Topics

7.1 Introduction

7.2 Aerodynamic considerations

7.3 Structural considerations

7.4 Crashworthiness

7.5 Producibility or manufacturing considerations

7.6 Maintainability

7.7 Environmental considerations

7.7.1 Airplane noise

7.7.2 Emissions

7.8 Additional considerations for military airplanes

7.8.1 Radar detectability

7.8.2 Infrared detectability

7.8.3 Visual detectability

7.8.4 Vulnerability

Reference

Exercises

Chapter 7

Special consideration in configuration lay out

Lecture 31

Topics

7.1 Introduction

7.2 Aerodynamic considerations

7.3 Structural considerations

7.4 Crashworthiness

7.5 Producibility or manufacturing considerations

7.6 Maintainability

7.7 Environmental considerations

7.7.1 Airplane noise

7.7.2 Emmissions

7.8 Additional considerations for military airplanes

7.8.1 Radar detectability

7.8.2 Infrared detectability

7.8.3 Visual detectability

7.8.4 Vulnerability

7.1. Introduction

After dimensions of the major components have been obtained the subsequent steps in the design process are as follows.

- i) Development of a smooth, producible and aerodynamically efficient external geometry. The methods to obtain smooth external geometry are called lofting.
- ii) Installation of internal features such as crew station, payload, landing gear and various systems.
- lii) Integration of propulsion system.
- iv) Working out details such as wetted area, cross sectional areas, volume etc.

The final layout is a compromise between aerodynamic, structural, and functional requirements. Producibility, maintainability, and environmental considerations also affect the layout.

These considerations are briefly discussed in this chapter. The material is based on chapter 8 of Ref.1.18; chapter 4 of Ref.1.14.; chapter 5 of Ref.3.4 and various chapters of Ref.7.1. In addition, various aspects of lofting and ways to obtain areas and volumes of airplane components, are also discussed in chapter 7 of Ref.1.18.

7.2. Aerodynamic considerations

A poorly designed external shape of the airplane could result in undesirable flow separation resulting in low $C_{L_{max}}$, low lift to drag ratio and, large transonic and supersonic wave drag. Section 8.2 of Ref.1.18, leads to the following remarks.

- (i) Minimization of wetted area is an important consideration as it directly affects skin friction drag and in turn parasite drag. One way to achieve this is to have smallest fuselage diameter and low fineness ratio (between 3 and 4 , Ref.1.9, chapter 3). However, proper space for payload, ease of maintenance and tail arm also needs to be considered.
- (ii) To prevent flow separation, the deviation of fuselage shape from free stream direction should not exceed $10^\circ - 12^\circ$.
- (iii) Proper fillets should be used at junctions between
 - (a) wing and fuselage, (b) fuselage and tails and (c) wing and pylons.
- (iv) Base area (unfaired, rearward facing blunt surface) should be minimum.
- (v) Canard, if used, should be located such that its wake does not enter the engine inlet as it may cause engine stalling.
- (vi) Area ruling

The plan view of supersonic airplanes indicates that the area of cross section of fuselage is decreased in the region where wing is located. This is called area ruling. A brief note on this topic is presented below.

It was observed that the transonic wave drag of an airplane is reduced when the distribution of the area of cross section of the airplane, in planes perpendicular to

the flow direction, has a smooth variation. In this context, it may be added that the area of cross section of the fuselage generally varies smoothly. However, when the wing is encountered there is an abrupt change in the cross sectional area. This abrupt change is alleviated by reduction in the area of cross section of fuselage in the region where the wing is located. Such a fuselage shape is called 'Coke-bottle shape'. Figure 7.1 illustrates such a modification of fuselage shape.

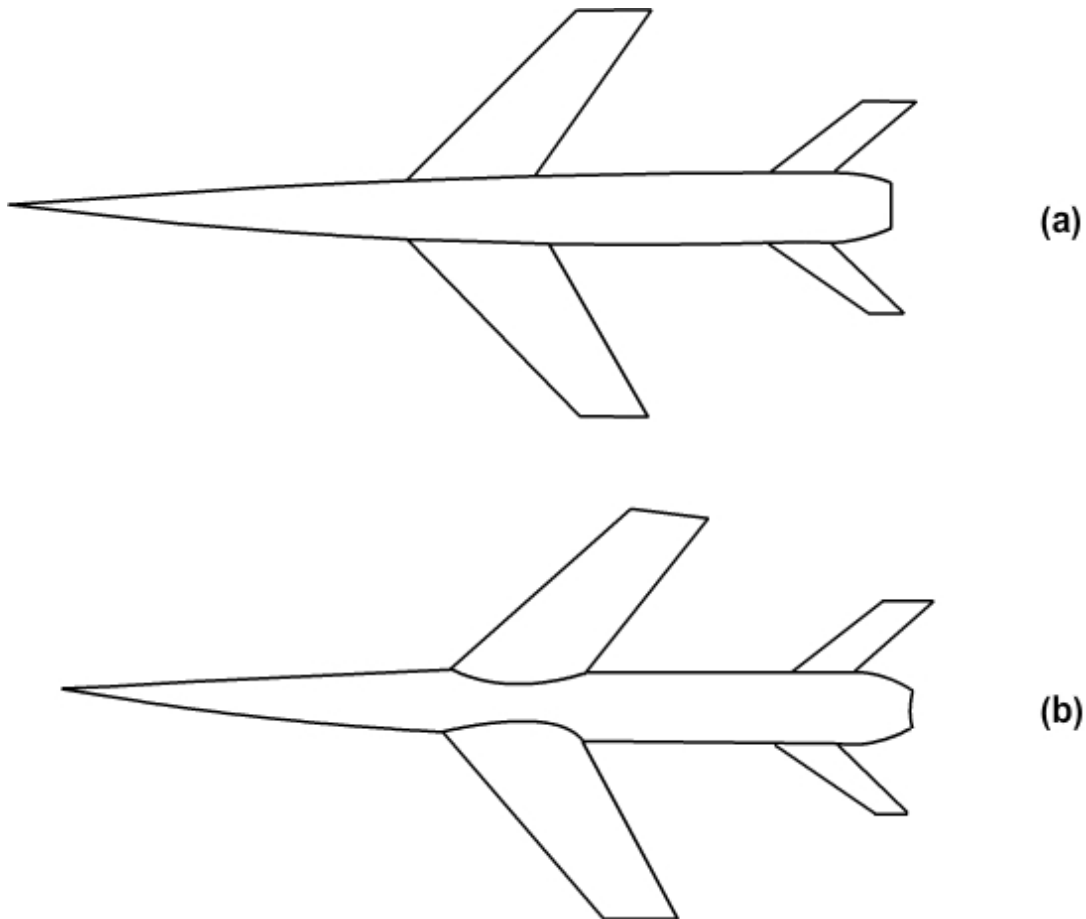


Fig.7.1 Design for low transonic wave drag

- (a) Abrupt change in cross sectional area at wing fuselage junction
- (b) Coke-bottle shape

Figure 7.2, based on data in Ref.3.4 , chapter 5, indicates the maximum wave drag coefficient, in transonic range, for three configurations viz (i) a body of

revolution (ii) a wing-body combination without area ruling and (iii) a wing-body combination with area ruling. Reference 3.4, chapter 5 may be referred to for further details. Substantial decrease in wave drag coefficient is observed as a result of area ruling. Figure 7.3. presents a practical application of this principle.

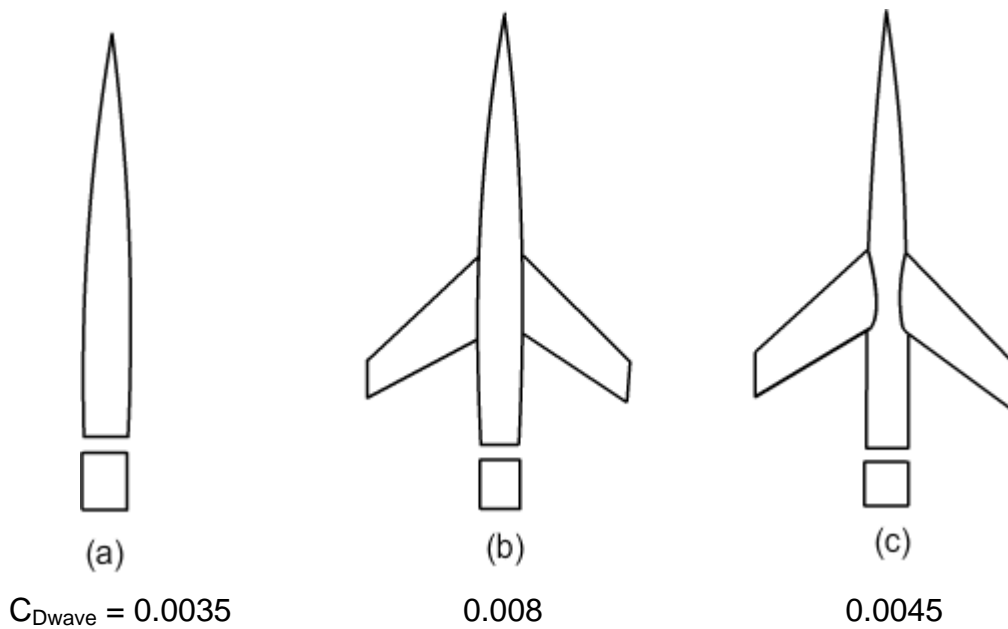


Fig.7.2 Maximum transonic wave drag coefficient of three different shapes
(a) body of revolution (b) wing-body combination without area ruling (c) wing-body combination with area ruling

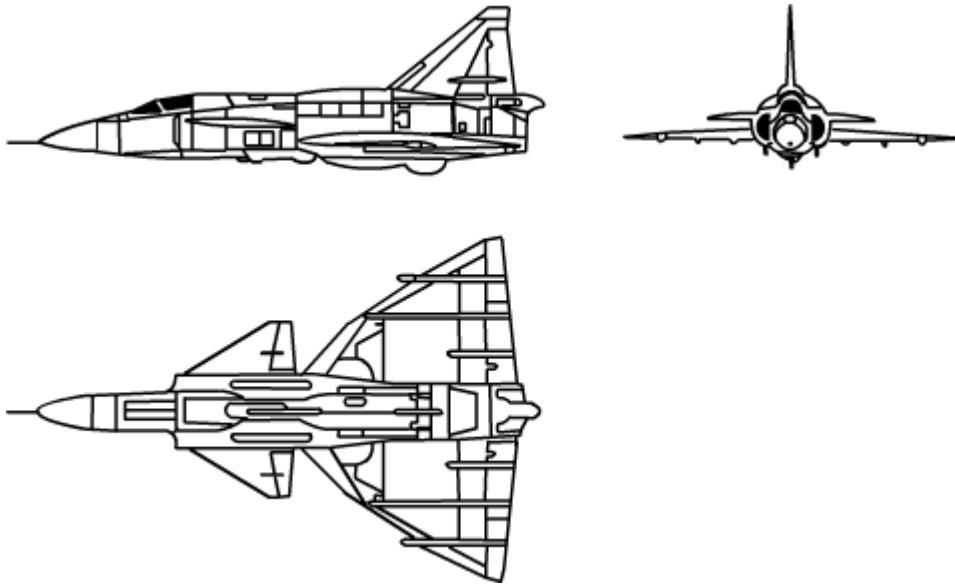


Fig.7.3 An example of area ruling - SAAB VIGGEN
(Adapted from <http://upload.wikimedia.org>)

7.3. Structural considerations

Primary concern in the design process is to obtain an airplane with low structural weight. This is achieved by provision of efficient load path i.e. structural elements by which the opposing forces are connected.

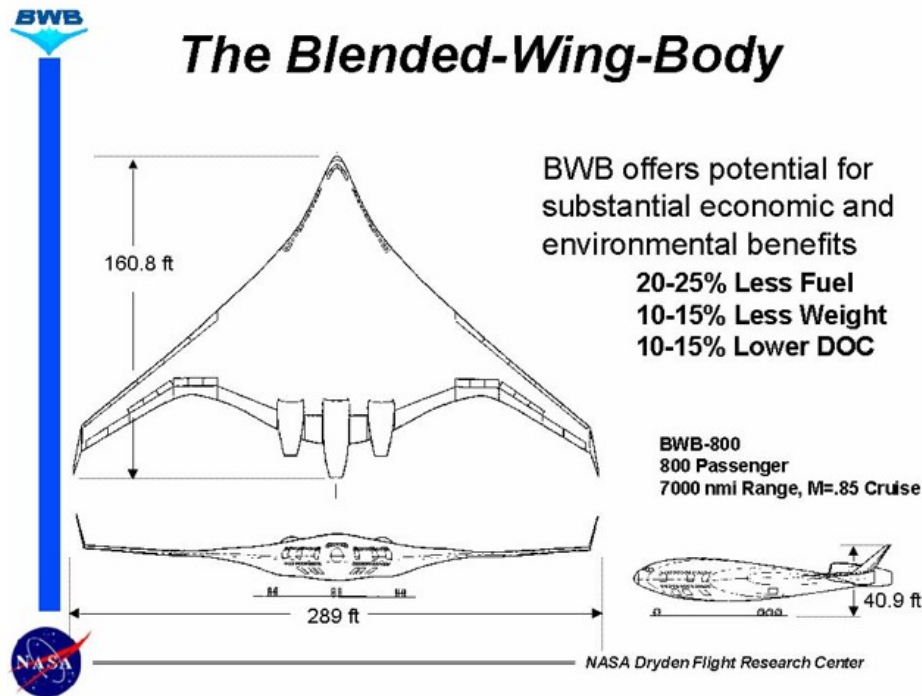
It may be recalled that the structural members are of the following types.

- a) Struts which take tension
- b) Columns which take compressive load
- c) Beams which transfer normal loads
- d) Shafts which transmit torsion
- e) Levers which transfer the load along with change of direction.

The most efficient way of transmitting the load is when the force is transmitted in an axial direction.

In the case of airplane the lift acts vertically upwards and the weights of various components and the payload act vertically downwards. In this situation, the sizes and weights of structural members are minimized or the structure is efficient if

opposing forces are aligned with each other. This has led to the flying wing or blended wing-body concept (Fig.7.4) in which the structural weight is minimized as the lift is produced by the wing and the entire weight of the airplane is also in the wing.



Note : 160.8 ft = 49.01 m ; 289 ft = 88.1 m ; 40.9 ft = 12.47 m and
7000 nmi = 12964 km

Fig.7.4 Blended-wing-body concept
(Source: NASA Website)

However, in a conventional airplane the payload and systems are in the fuselage. The wing produces the lift and as a structural member it behaves like a beam. Hence to reduce the structural weight, the fuel tanks, engines and landing gears are located on the wing, as they act as relieving load. Reduction in number of cutouts and access holes, consistent with maintenance requirements, also reduces structural weight.

Remark:

Equation 5.5 shows that the weight of the wing is reduced with high thickness ratio, low aspect ratio, no sweep and high taper ratio. Some of these requirements are in conflict with aerodynamic considerations.

This has led to different wing geometries for airplanes with different flight Mach number. For example, low speed airplanes have moderate aspect ratio, high thickness ratio, taper ratio between 0.3 to 0.5 and no sweep. High subsonic jet airplanes have moderate aspect ratio, moderate thickness ratio, moderate sweep and taper ratio around 0.2. Supersonic airplanes have highly swept or delta wings. For efficient performance at various flight Mach numbers, variable sweep has also been used.

7.4 Crashworthiness

During a crash, parts of airplane would break loose and fly forward. Hence heavy items should not be located behind and above the passengers. Landing gear and engine nacelles may get ripped away during a crash. Hence, they should be located such that they do not rip open fuel tanks. Lower portion of fuselage should be such that it does not dig into ground. Reference 1.18, section 8.9 and Ref.1.14, chapters 4 and 5 may also be referred to for additional information. In the case of passenger airplanes emergency exits and evacuation system need to be provided.

7.5 Producibility or manufacturing considerations

The cost of an airplane is generally proportional to its weight. However, factors like material chosen, fabrication processes (machining, forging, molding, welding, finishing etc.), tooling required and assembly man - hours also influence the cost. Hence, ease of fabrication is an important consideration in design of an airplane.

Some of the suggestions for reducing the manufacturing cost are (Ref.1.18, chapter 8) :

(i) There should be commonality of parts e.g. left and right landing gear, left and right halves of tail, ailerons etc., should be identical.

- (ii) Forgings are expensive and should be reduced in number.
- (iii) Installations of internal components, hydraulic lines, electrical wiring, cooling ducts need careful layout to avoid excessive cost.
- (iv) For convenience in assembly of entire airplane, it (airplane) is built from sub-assemblies. This needs incorporation of suitable subdivisions and allocation of parts to different sub-assemblies. This requires an adequate knowledge of structural design, fabrication techniques and principles of operation of major subsystems.
- (v) Use of CAD / CAM techniques require standardization of drawings and processes.
- (vi) Components made of FRP materials are lighter but need altogether different manufacturing techniques than the metal components.

7.6 Maintainability

Airplane being a costly means of transport, the general policy is to carry out periodical maintenance and not wait for break down. Different parts of the airplane have different service life. Hence, inspection and maintenance are carried out after a specified number of hours of flight. To carry out these, proper access doors need to be provided. However, such cut outs increase structural weight and a proper compromise is required. Civil airplanes also require ground servicing. The lay out of the airplane should enable low turn-around time for items like re-fuelling, fresh water replenishment, re-supply of food, toilet servicing, cabin cleaning and cargo/baggage handling (Fig.7.5). The military airplanes also require ground servicing like refuelling and replenishment of armament.

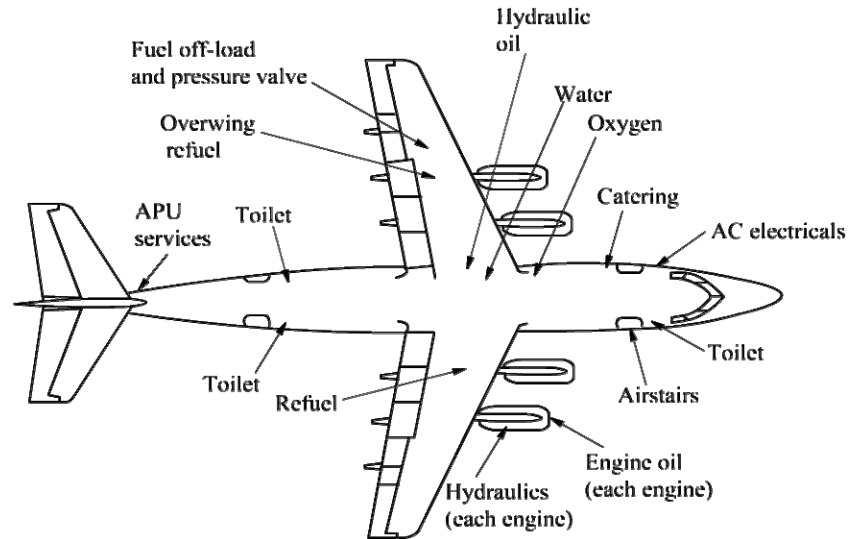


Fig.7.5 Ground service requirements

(Adapted from Ref.1.14, chapter 3 with permission from author)

7.7 Environmental consideration

In recent years factors like aircraft noise, emissions and ecological effects have acquired due importance and have begun to influence airplane lay out. Based on Ref.1.14, chapter 4 the following remarks are made.

7.7.1 Airplane Noise

Noise during the arrival and departure of the airplane affects the community around the airport. In 1994, ICAO (International Civil Aviation Organization) and later FAR (Federal Aviation Regulation) prescribed limits on noise level at three different points near the airport (Ref.1.14, chapter 4 be referred for details).

The noise is generated by:

- a) The engines,
- b) Parts of the airframe like control surfaces and high lift devices which significantly change the airflow direction.
- c) Projections in airflow like landing gear and spoilers.

Considerable research has been carried out to reduce the engine noise. High by-pass ratio engines with lobed nozzle have significantly lowered the noise level.

Noise level inside the cabin has to be minimal. This is achieved by suitable noise insulation. Further, the clearance between cabin and the propeller should not be less than the half of the radius of the propeller.

7.7.2 Emissions

Combustion of the fuel in an engine produces carbon dioxide, water vapor, various oxides of nitrogen (NO_x), carbon monoxide, unburnt hydrocarbons and sulphur dioxide (SO_2). The components other than carbon dioxide and water vapor are called pollutants. ICAO has prescribed acceptable limits of pollutants (grams of pollutant per kgf of fuel burnt). The thrust setting changes during the flight and hence the emission levels have to be controlled during landing, take-off and climb segment up to 3000 ft (1000 m). At high altitudes the NO_x components may deplete ozone layer. Hence, supersonic airplanes may not be allowed to fly above 50000 ft (15 km) altitude. It may be noted that cruising altitude for Concorde was 18 km. Improvements in engine design have significantly reduced the level of pollutants.

The amount of pollution caused by air transport is negligible as compared to that caused by road transport, energy generation and industry. However, the aircraft industry has always been responsive to the ecological concerns and newer technologies have emerged in the design of engine and airframe.

7.8. Additional considerations for military airplanes

These airplanes need special considerations like radar, infra-red and visual detectability and vulnerability.

7.8.1 Radar detectability

A radar installation consists of a transmitter antenna that sends a directed beam of electromagnetic wave and receiver antenna which picks up the faint radio waves that bounce off the object. The extent to which an object returns electromagnetic energy is a measure of its "Radar cross section (RCS)". Following remarks are made in this context.

- (i) Radar signal strength is inversely proportional to the 4th power of distance of the target.
- (ii) RCS depends on “look angle” i.e. the direction from threat radar.
- (iii) Following factors contribute to RCS.
 - (a) Flat surfaces perpendicular to incoming radar beams for example flat sides of fuselage.
 - (b) Leading edges.
 - (c) Inlet and exhaust cavities of engine.
 - (d) Discontinuities in surface.
- (iv) Stealth technology

The ways to reduce RCS are referred to as stealth technology. This requires proper shaping of the airplane - buried engines (no nacelles), flying wing, intakes on top of the airplane, exhaust with 2 – D nozzles. Use of radar beam absorbing materials like composites and special paints also reduces RCS (see Fig.1.10 for B-2 stealth bomber).

7.8.2 Infra-red detectability

Guidance of air-to-air and ground-to-air missiles is many times based on seeking source of infra-red (IR) radiation. Following are the sources of IR.

- (i) Engine exhaust
- (ii) Hot parts of airplane. Heating being caused by aerodynamic heating, at high speeds.
- (iii) Solar IR radiation reflected by skin and cockpit.

The Radiation from engine exhaust can be reduced in the following manner.

- (a) Having a bypass engine as power plant.
- (b) Increased mixing and lower temperature by using 2-D nozzle.

7.8.3 Visual detectability

Visual detection depends on the size of the airplane and color. Aircraft can also be detected in night by glow of engine exhaust. Camouflage schemes are used to avoid detection.

7.8.4 Vulnerability

Vulnerable area or component is that which when struck by a weapon will cause the aircraft to be lost. Following considerations reduce vulnerability.

- (i) Fuel should not be stored over or around engines and inlet ducts.
- (ii) Hydraulic lines and reservoirs should be away from engine.
- (iii) Engine bays, fuel bays and weapons bay should have fire suppressing systems.
- (iv) In twin-engined airplanes there should be enough separation between the two engines. This prevents the damaged engine affecting the other engine.
- (v) Critical components, crew and passengers should not be placed within 5 degrees arc of propeller disc.
- (vi) There could be redundancy in important systems like hydraulic, electrical, flight control and fuel systems.

Ref.7.1 be referred to for further details on combat survivability.