

Chapter 6

Fuselage and tail sizing - 7

Lecture 29

Topics

6.4 Engine location

- 6.4.1 Location of engines on different airplanes
- 6.4.2 Spanwise locations of wing mounted engines
- 6.4.3 Location of nacelle relative to wing leading edge

6.4 Engine location

The engine output required is already known from the performance requirements like V_{\max} , $(R/C)_{\max}$, H_{\max} and take-off distance (section.4.10.6). The number of engines and their location need to be chosen. Airplanes have been designed with one, two, three, four and eight engines. The following considerations decide the number of engines used in the airplane.

- (a) The ratings of the available engines.
- (b) Cost of the engine.
- (c) Ease of maintenance
- (d) Performance and stability of the airplane with one engine being inoperative.

The low speed general aviation aircraft usually have a single engine. Similarly, military airplanes in light weight and medium weight category also have a single engine.

The transport airplanes have two or more engines from the considerations of safety in the event of failure of one engine. Early jet transport airplanes (Boeing 707,747) had four engines as the reliability of the engines was not as high as the latest engines and large size engines were not available. Subsequently, twin engine configuration became popular for airplanes with medium range and 100 to 200 passenger seating capacity (Boeing 727,737; Airbus 320,340). Economic

considerations and reliability of the engines reinforced this choice. However, the available thrust would reduce to half with one engine inoperative and hence, these airplanes generally have higher thrust to weight ratio and a large vertical tail. As a compromise between two and four engines some airplanes have three engines (e.g. McDonnell Douglas DC-10, Lockheed Tristar).

6.4.1 Location of engines on different airplanes

The locations of engines in case of one, two, three and four engines are briefly dealt with in this subsection. The airplanes with engine-propeller combination and jet engines are considered.

A) Single engine-propeller combination

In this case, three arrangements are mainly used. These are :

- (a) tractor propeller ahead of engine located in nose of fuselage
- (b) pusher propeller behind the engine located at the rear end of the fuselage
- and (c) pod mounted engine with tractor or pusher propeller.

In a tractor configuration the propeller is in front of the engine and is driven by a shaft in tension.(Ref.1.2). Figure 6.6 shows such a configuration.

In a pusher configuration the propeller is mounted behind the engine so that the drive shaft is in compression (Ref.1.2). Fig.6.11 shows an example of a pusher airplane.



Fig.6.11 Image of a pusher airplane

(Adapted from Prescott pusher, 1000aircraftphotos.com)

An amphibian airplane can land and take-off both on land and on water. In such airplanes the propeller should be away from the surface of water. In some amphibian airplanes the propeller is mounted on a pod above the fuselage. Figure 6.12 shows the image of an amphibian airplane.



Fig.6.12 Image of an amphibian airplane with pod mounted engine and pusher propeller

(Adapted from 1000aircraftphotos.com)

Remarks:

(i) Reference 1.18, chapter 10 suggests other possible locations for single engine with propeller. Like engine nacelle mounted on top of vertical tail with either tractor or pusher configuration.

(ii) The relative advantages and disadvantages of tractor and pusher propeller configurations are as follows.

For obvious reasons a tractor installation moves the c.g. of the airplane forward and a pusher installations moves the c.g. rearwards.

(a) The contribution of a tractor propeller is destabilizing to longitudinal, directional and lateral stability. Whereas, the contribution of a pusher propeller is stabilizing (sections 2.6, 5.5 and 6.8 of Ref.3.1 discuss these aspects.)

(b) A pusher propeller is in the wake of the wing and fuselage. Consequently, it is slightly less efficient than a tractor propeller (Ref.1.24, chapter 8)

(iii) Many military airplanes have a single jet engine. In these cases the engine is located in the rear part of the fuselage. The air intakes are generally located on the sides of fuselage (Figs.1.2 c and d). The images of single engined military airplanes like Mirage 2000, ADA Light Combat Aircraft (LCA) and SAAB Gripen, can be viewed on internet (www.google.com).

The location of engine, in military airplanes, inside the fuselage has two advantages. (a) The engine is less vulnerable to enemy attack.(b) The fuselage is elongated which results in slender fuselage and provides longer tail arms for horizontal and vertical tails.

(B) Twin engine configuration

Twin engine configurations with propellers may be driven by piston engines or turboprop engines. The engines are commonly mounted on the wings with tractor propellers as in the case ATR-72-200 (Fig.6.7a). The configuration with pusher propellers mounted on rear fuselage has also been used (Fig.1.1a).

In the twin engine passenger airplanes with jet engines, the engines are located on pylons on the wings or mounted on rear fuselage. Figure 1.2f shows a typical configuration with wing mounted engines. The pictures of Airbus 318, 319, 320

and 321 in Appendix 1.1 and those of Boeing 737 and 777 in Appendix 1.2, are examples of airplanes of this type. Figure 6.13 shows the image of an airplane with two engines mounted near rear end of fuselage.



Fig.6.13 Image of a jet airplane with engines mounted on pylons near the rear end of fuselage
(Adapted from aacjet.com)

Remark :

Some military airplanes have two jet engines in fuselage. Examples of such airplanes are Tornado (Fig.1.7) and F-22 Raptor.

(C)Configurations with three engines

Some jet airplanes have 3 engines. In this case two engines are located with pylons on the wing. The third engine is located at the rear end of fuselage.

Figure 6.14 shows image of DC-10 airplane. Lockheed Tristar is another airplane in this category.



Fig.6.14 Image of a jet airplane with three engines

(Adapted from widebodyaircraft.nl)

(D) Four engined airplanes

There have been four engined airplanes with piston engines. Presently, the four engined airplanes are either with turboprop engines or jet engines. As mentioned in the beginning of example 2.1, the turboprop engines are more economical than the turbofan engines. Hence, the turboprop engines are utilised on airplanes flying at Mach numbers from 0.5 to 0.7. Figure 1.4 shows the Lockheed C-130 Hercules airplane with four turboprop engines mounted in nacelles attached to the wing.

In the case of jet transport airplanes the engines are mounted in nacelles attached through pylons to the wings (Fig.1.8a and b) or near the rear end of fuselage. In a few cases like HS Nimrod the engines are buried in the wing root. Figure 6.15 shows an image of this airplane.



Fig.6.15 Image of a jet airplane with engines buried in wing root
(Adapted from 1000aircraftphotos.com)

An example of four engines at rear is Ilyushin IL-62 (Fig.6.16)



Fig.6.16 Image of a jet airplane with four engines mounted on pylons near the rear end of fuselage

(Adapted from 1000aircraftphotos.com)

The configuration with engines under the wing seems to be the most preferred one. Following Ref.1.6 chapter II, the advantages and disadvantages of the above three configurations are pointed out below.

a) Engines held by pylons on wing :

The Advantages are as follows.

- I) The engines act as a relieving load on the wing and the weight of the wing structure could be decreased by about 15 percent.
- II) The space inside the wing can be fully utilized for fuel.
- III) Easy access for maintenance, inspection and replacement of engines.

The disadvantages are as follows.

- I) Smaller ground clearance increases the possibility of foreign objects being ingested in the engines.
- II) Failure of outboard engine creates a large yawing moment. To counteract this moment requires larger vertical tail area and rudder deflection as compared to other locations of engines. These result in higher structural weight and drag.

III) Noise level in the cabin is higher as compared to airplanes with engines mounted on rear fuselage.

b) Engines located in the wing root

The Advantages are as follows.

I) There is very little increase in frontal area of the airplane due to installation of power plants.

II) Almost the entire wing span can be utilized for ailerons and high lift devices.

The disadvantages are as follows.

I) The space in the root section of the wing cannot be used for accommodating fuel.

II) The intake is located at a place where the boundary layer on the fuselage affects the flow in it (intake).

III) The weight of the wing structure is increased due to presence of the cuts in wing spars.

c) Engines located on the rear fuselage

The advantages are as follows.

I) There is less engine noise in the cabin.

II) The entire wing space can be used for storing fuel and for high lift devices.

III) The flow over the wing is clean due to absence of pylons.

The disadvantages are as follows.

I) The fuel is located far from the engines, therefore the length of the pipeline is increased and special fuel pumps are needed.

II) Due to engines being located at rear, the c.g. of the airplane moves aft.

Consequently, the tail arms of the horizontal and vertical tails are reduced.

Remark:

The supersonic passenger airplanes like Concorde (Fig.1.6) have four jet engines attached to the wing. The design of the intakes of these engines is an involved task. The intake is of variable area type so that the total pressure loss is low at various flight speeds. Reference 1.18, chapter 10 be referred for intakes of jet engines operating at various flight Mach numbers.

6.4.2 Spanwise locations of wing mounted engines

As mentioned earlier, a wing mounted engine acts as a relieving load. The reason for this is as follows.

The structural design of wing is carried out considering mainly the load due to lift produced. In normal configuration the lift acts upwards. The weights of (a) fuel in the wing, (b) the engines attached to wing, (c) bombs attached to wing, act downwards. Thus, the bending moment produced due to the lift is reduced due to weights of fuel, engines etc. Hence, the weights of these items are called relieving weights. This also indicates that an engine located near the wing tip would cause maximum reduction in bending moment. However, there is another consideration for the spanwise location of the engine. This is due to effect on directional control when one engine fails. When all the engines (2 or 4) are operating, they do not produce any yawing moment. When one of the engines fails, the operating engine on the other wing half produces a yawing moment. This moment is balanced by a suitable deflection of rudder. In this situation, an engine located far outboard would require a large vertical tail and rudder deflection. This would increase overall weight and drag of the airplane. Hence, there is an optimum spanwise location for the engines which will minimise the overall weight and drag.

From the data on twin engined turboprop airplanes in Table 6.2, it is observed that the wing has constant chord upto 25% to 35% of the semispan. The engine nacelle is located such that it either starts or ends at this location.

For the 60 seater airplane under design, the spanwise location of the engines is chosen based on ATR-72-200. The constant chord portion of the wing extends upto 35% of the wing semispan. The engine nacelle is located such that its spanwise extent ends at this location (35% of wing semispan) .

In the case of airplanes with four engines (i.e. two engines on each wing half), the inboard engine is located around 30% semispan and outboard engine around 55% of semispan (Ref.1.15, chapter 2)

6.4.3 Location of nacelle relative to wing leading edge

It is observed that nacelle of the wing mounted engine projects beyond the leading edge of the wing. The following considerations need to be taken into account.

- (a) The interference between wing and nacelle should minimise loss of lift of wing and increase of drag of airplane as a whole.
- (b) In case of engines with propellers the slipstream of the propeller passes over the wing. The slip stream has a dynamic pressure higher than the free stream dynamic pressure and would result in increase in wing lift. The increase in dynamic pressure would be higher when the propeller is farther ahead of the wing. However, an overhanging nacelle would need a heavier engine mount. The optimum overhang of the nacelle would have to be decided after detailed aerodynamic and structural calculation.