# Airframes – Instructor Training Manual

## Chapter 5 – WINGS & TAILPLANE

Learning Objectives

1. The purpose of this chapter is to discuss in more detail, two of the four major components, the Wing (or mainplane) and the Tailplane.

2. By the end of the lesson you should have an understanding of the main functions of this most important of the main components of an aircraft, as well as it's construction.

The Wing

3. From *'Principles of Flight'*, you will know that to be able to fly, an aircraft must have wings designed to generate lift from the air flowing over them.

4. To take off and climb, the wings must produce more lift than the aircraft's total weight. For example, an aircraft such as the Airbus A380, which weighs 550 tonnes, this is no mean task. If a fighter aircraft was to fly in a very tight turn, the wings must then produce lift equal to perhaps eight times the aircraft weight.

5. For level flight the lift produced must equal the aircraft's weight, whilst for landing, where the slowest possible landing speed is required, enough lift must be produced to keep the aircraft flying at low speeds. In order to achieve this the wing will normally have special devices added - flaps, leading-edge slats

6. Additionally, the shape of the aircraft is extremely important, because it dictates how well the aircraft can does its job. For a slow-flying aircraft which needs to lift heavy loads, a large wing is needed, together with a fairly light structure. However, for fast jets, a much smaller wing is required, and the aircraft will be more streamlined.

Wing Loading

7. One of the most important factors in an aircraft design is its wing loading, which is simply its weight divided by its wing area.

8. As the weight of the aircraft can vary, both with the load it is carrying and as a result of flight manoeuvres. For example, flying at 4g in a turn increases an aircraft's effective weight to four times its normal weight, so its wing loading will change.

9. A useful guide is to use the maximum take-off weight (MTOW) to calculate a 'standard' wing loading. The general rule of thumb is that a light aircraft will normally have the lowest wing loading, and fast jets the highest, with transport aircraft somewhere in between.

## Wing Design Considerations

10. For aircraft flying at, or near supersonic speeds, the way in which air flows over the aircraft is very different, and can create specific problems that the designer needs to overcome. An aircraft flying quite slowly through the air will generate pressure waves, which move at the speed of sound.

11. At aircraft speeds near the speed of sound, a shock wave forms on the leading parts of the aircraft. As a result, the air behind this shock wave becomes turbulent, causing loss of lift, increased drag, changes in trim and buffeting of controls.

12. Designers can reduce the effects of these problems with better designs, particularly the use of swept-back wings. However, these features can cause other complications, because swept back wings are more difficult and expensive to build.

However, once above the speed of sound, the airflow is steady again, although it's nature is very different to that at subsonic conditions. As a result the curved shapes that worked well at lower speeds are no longer the most efficient, and straight lines and sharp edges are now preferred.

## Wing Planforms

13. Therefore at speeds close to or above the speed of sound, the *planform* of wings becomes more important than their section, and low aspect ratio and sharper sweepback may be necessary.

14. The main disadvantage of using swept-back wings is that they produce much less lift than an un-swept wing of the same area and aspect ratio. This means that when an aircraft is flying slowly, for instance during landings, a larger angle of attack is required to provide enough lift. This can cause problems with landing gear and for pilot visibility during approach.

## Swing & Delta Wings

15. Given the problems, being able to change the amount of sweepback in flight would be one way towards getting the best in both situations. This has been achieved on many high speed military aircraft by utilizing *Swing Wings*.

16. In the swept forward position it gives high aspect ratio wing for low-speed performance, allowing tight turns at low speeds and making flaps more effective for take-off and landing. In the swept back position, it is highly suited to high-speed flight.

17. Another option for aircraft which need to fly at high speeds but also need to be able to turn tightly at all speeds is the delta wing.

This has the advantage of high sweepback, but the trailing edge is more suited to fitting effective flaps.

18. Because of the aerodynamics of delta wings, they are capable of producing lift at much higher angles of attack than other wing shapes, and so can be used on highly agile fighter aircraft.

Delta wings, which went out of fashion in the 1970s and 1980s, are becoming more common. Many examples can be seen, often in conjunction with Canard Foreplanes for control, as is the case with the Eurofighter Typhoon.

Aspect Ratio

19. The aspect ratio of an aircraft's wing is an important design feature, and is simply the ratio of the wing span to its average chord.

This is not always simple to calculate if a wing shape is complex, so another way of defining it is;

$$\text{Aspect Ratio} = \frac{\text{Span}^2}{\text{Area}}$$

20. So if a wing has an area of 80 square metres and a span of 20 metres the aspect ratio is ($20^2/80 = 5$).

21. It is usual to use the projected area of the wing to calculate the aspect ratio, that is, to include that part of the wing which is inside the belly fairing of the fuselage in the case of commercial airliners.

22. For example, high performance sailplanes have aspect ratios in the region of 25 to 30, and fighters somewhere around 5 to 10.

23. A high aspect ratio wing reduces the induced drag caused by air flowing around the wing tips, and is ideal where long slow flights are required, but the major drawback is that the long, thin wings are heavier, and as a result need to be very flexible.

Monoplanes

24. Although there are still a few bi-planes around, most aircraft are monoplanes. This provides a very stiff, strong wing, without the drag penalty of the biplane arrangement.

25. Many light aircraft are braced monoplanes, having a diagonal bracing tie between the wing and fuselage. This allows a lighter structure in the wing,

because some of the lift load is taken by the brace. The extra drag caused is acceptable at low speeds.

26. However, for higher speed aircraft, the braced monoplane is not acceptable and therefore the cantilever wing is used, because it offers the lowest drag. As a result the wings have to be strong enough and stiff enough to carry the whole weight of the aircraft, plus its aerodynamic loads, without the need for external bracing.

Cantilever monoplane aircraft can be categorised as;

- Low Wing: Grob 115E ‘Tutor’
- Mid Wing: Gen Dynamics F-16
- High Wing: BAe Harrier GR9

## Function of a Wing

27. Obviously the primary function of the wings on an aircraft are to provide the lift required to enable it to fly.

28. However, there are other functions that a wing is expected to do, such as

- Carry Fuel
- Change Geometry
- Carry Weapons & Stores
- House Engines
- House Landing Gear

Therefore, the wing can sometimes do lots of jobs as well as providing lift!

## Flying Wings

29. So we can see that the wings are the main component of an airframe. However, there have been aircraft designed and built which consist only of a pair of wings like the Northrop ‘Flying Wing’ and the B.2 ‘Spirit’ Bomber.


Wing Loads & Forces

30. The wing is subject to a number of loads and forces, both whilst the aircraft is on the ground and when it is in the air.

- When an aircraft is moving through the air, the *'drag'* effect from the air to it's forward motion places a force on the wing.
- Likewise, the act of the wing in generating lift also places forces on the structure.
- On the ground, the weight of the fuel, undercarriage, engines, wing structure and in military aircraft – weapon loads will all try and bend the wing under the force of gravity.

31. The designer has to make the wings strong and stiff enough to resist not only the forces of lift and drag, which try to bend them upwards and backwards, but also the loads that gravity will place on the structure.

Methods of Construction

32. As already seen, different sizes and types of aircraft can be constructed in different ways. This applies to the mainplanes, or wings, as much as to any other part.

33. The component parts of the structure that make up a complete wing include Spars, Ribs, Skin, Flaps and Ailerons.

34. Each wing is basically made up of two parts;

- The internal structure, such as the spars and the ribs

- The skin, which can be of fabric, metal or composites.

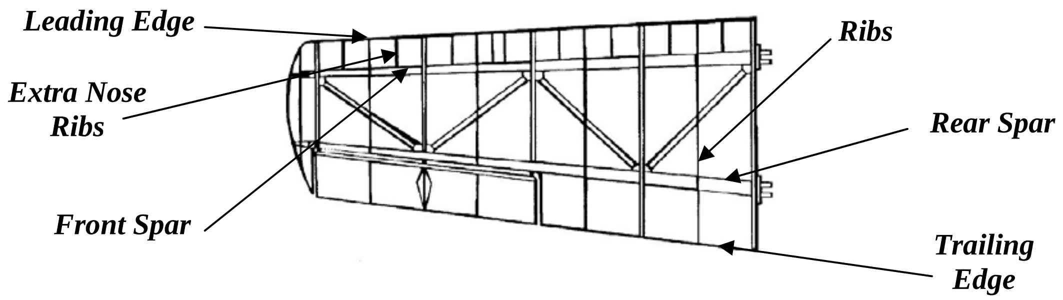
Although the distinction between metal and composite wings may not be very apparent in modern fast jets or large transport aircraft.

35. Wing construction itself comes in two forms. The modern Stress Skin standard and the older Fabric Covered wing. However, both forms of construction rely on a similar internal construction.

Fabric Covered Wings

36. The main structural members, as for most aircraft wings, are the **front** and **rear spars**, which are attached to each other by a series of **ribs**.

The ribs give the wing it's section, and transfer loads from the covering into the spars




37. Attached to the front spar is the leading edge section, in this case it is made up of nose ribs and the leading edge itself.

38. The trailing edge section is similar, but of a different shape, and contains the ailerons and flaps.

39. Although the fabric covering takes very little load, it does strengthen and stiffen the structure a little, especially in torsion (twisting). The main structural ribs help to support the fabric to keep a good aerodynamic section along the whole wing.

Along the leading edge, where the aerodynamic section curves most, extra nose ribs are added to make sure this important part of the wings is not upset by sagging of the covering fabric.

Stressed Skin Wings

40. Air loads on the wing increase at the square of the speed increase. For instance, at 400 knots the air loads are four times as great as the 200 knots achieved by the fastest of light aircraft.

The Eurofighter Typhoon easily reaches speeds in excess of 1200 knots. Therefore, fabric covered wings cannot meet these higher loads, and so a more rigid ‘Stressed’ skin must be used.

41. Aluminium alloys are most often used for this, but composite materials (carbon fibre) are now becoming more common place.

Both aluminium alloy and composite provide a smoother finish and more contour to the shape than a fabric covering, but if it is very thin it does not give much extra strength.

42. If the skin is thicker, it can share the loads taken by the structure underneath, which can then be made lighter. Almost all aircraft have their structure made entirely in metal, or a mixture of metal and composite materials.

The main spars are still the main strength members, but a large contribution to the strength is made by the skin.

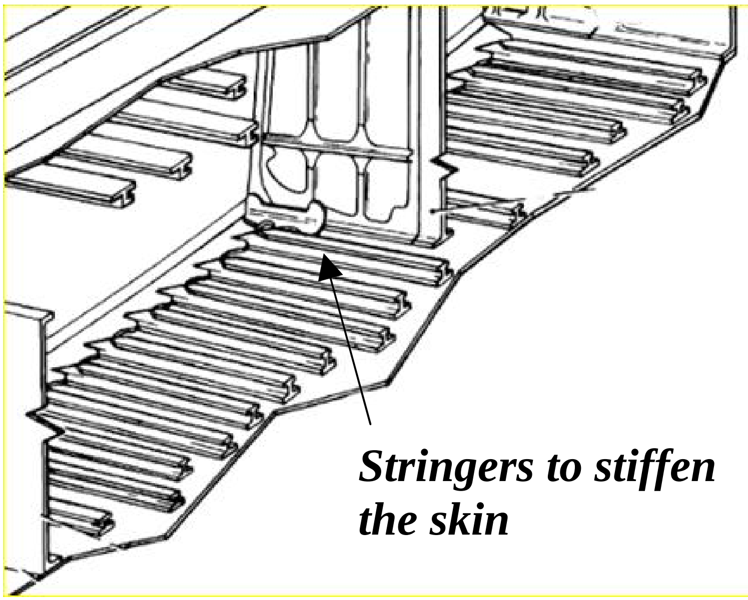
43. In a Stressed Skin wing, the whole wing is normally of metal construction, although the wing tip, ailerons and leading edge may be of composites. As the use of composites increase, more and more of the airframe will be made this way.

44. To reduce weight the ribs (both metallic and composite) may have large lightening holes, with flanged edges to keep the required stiffness. The skin may be fixed to the internal structure by rivets and bolts, as shown on the following diagram, or by bonding (gluing), using special adhesives.

Stiffening Stringers

45. Unlike the fabric covered wing skin, a stressed wing skin must be stiffened to prevent buckling between the ribs.

A simple solution is to add stringers which would be bonded or riveted to them, or integrally machined into the skin itself.




Utilising the Wing Internal Volume

46. ight and commercial aircraft, it is commonplace for the volume between the front and rear spars to be used for storing fuel. By manufacturing holes in the ribs, the fuel is allowed to flow inside this space.

47. There are also spaces in the leading and trailing edges i.e. in front of and behind the spars. Therefore, the space available within the leading- and trailing-edge sections is used for carrying electrical cables, control wires and other items along the length of the wing.

Benefits of Using Stressed Skin Wing Construction

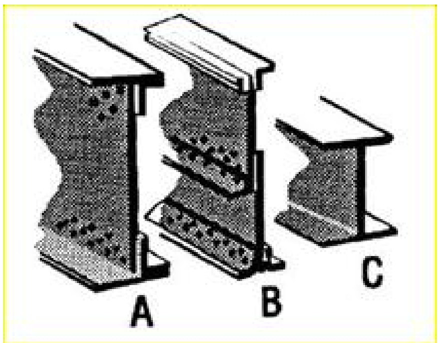
48. The benefits of utilizing stressed skin wing construction is that it allows thin cantilever wings to be produced.

These wings are strong enough to resist the tension, compression and twisting loads caused by high speeds. Therefore a wing of stressed skin construction is the ONLY option for an aircraft that travels at medium to high speeds.

Wing Spars

49. An ideal spar is given depth so it may resist the bending forces that are imposed on it. An example of this is an ordinary measuring ruler, which will flex easily when loaded on its top or bottom surfaces, but is very stiff when a load is applied to the edge.

50. Generally, there are three typical spar sections utilised within wing spar designs.

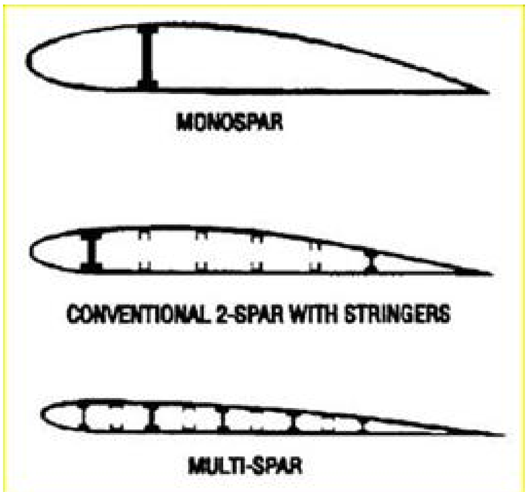



A & B are made of sections fastened together, but some modern aircraft would have the spar made from a single piece of metal, as in C, making it stronger and lighter.

Of course, this means it has to be made more accurately to a tighter manufacturing tolerance, as no 'adjustments' can be made during assembly.

Also in examples A and B shown, the flanges could be made as part of the skin, if the skin is machined from a thicker material.

51. However, for high-speed flight, a thin wing is needed, but it may not be possible to get a deep enough spar for the wing to cope with the stresses placed upon it. Therefore, to make the wing strong enough, more than one spar will be used. Using two or more spars is quite usual on many aircraft and is referred to as a multi-spar wing.




For example, supersonic aircraft, such as the Eurofighter Typhoon, require extremely thin wings, and hence use a multi-spar layout.

<u>Torsion Box</u>

52. Most modern large aircraft use two main spars, with stressed skin between them, to form a torsion box construction. The leading and trailing edge sections are then added in a lighter construction and carry very little of the loads applied to the wing.

The major advantage of this is that, as mentioned earlier, the space within the torsion box is an ideal space to store fuel.

Wing Assembly

53. In a wing assembly, the whole volume is sealed using special compounds to prevent leakage, and may be divided up into several large tanks, so that the fuel may be moved around as required to balance the aircraft or reduce loads in flight.

Machined Skin Wing Construction

54. As an alternative to making stressed skins by fastening stringers to the skin (fabricated), the skin, stringers and spar flanges can all be machined from a single piece of alloy, called a billet.

This billet may be many metres long, since it is possible to make the skin for one wing in a single piece. As a result, the billet is much thicker and heavier then the final machined skin.

55. During the manufacture of the machined skin, up to 90% of the billet will be removed during machining! Although this is more expensive, in both material and machining cost, the final result is a lighter and stronger skin than a fabricated one.

56. The advantages of using Machined Skin in an airframe design are;

- Riveting is no longer required, so a smoother surface can be achieved – providing a better aerodynamic wing.
- The resultant wing has a lighter structure and a more even loading than an equivalent fabricated wing.
- Computer-controlled machining means mistakes or faults are less likely, and more easily detected.
- Allows for easy inspection during manufacture and in service.
- Little or no maintenance is required.
- Fuel spaces are easily sealed.

57. However, there are some disadvantages to utilising Machined Skin in airframes

- The associated high cost of manufacturing – particularly the tooling set-up costs

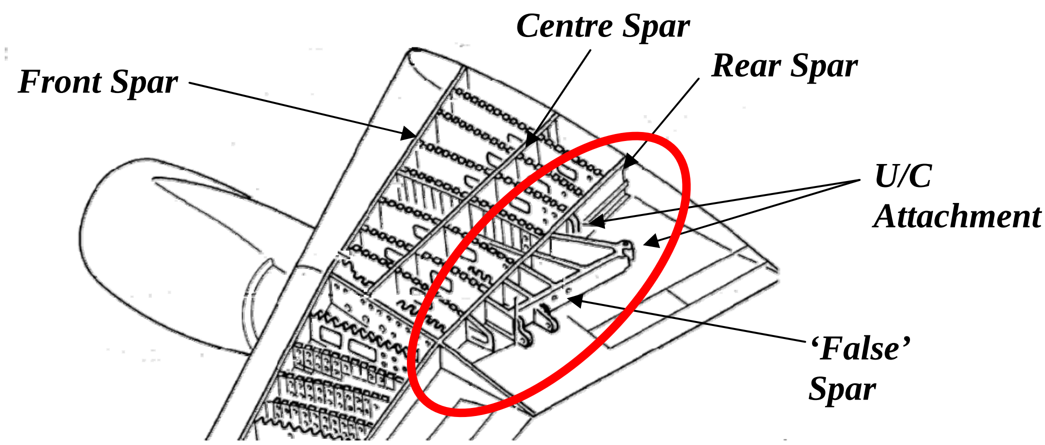
- Battle damage repair in combat aircraft with machined skin wings can be more difficult.
- Careful design is needed in order to maintain fail safety by limiting spreading of fatigue cracking.

The False Spar

58. As they are very different in shape to other types of wing, delta and heavily swept wings have different construction to other wings.

Delta wings have a very high chord at the wing root, and so thickness for structural stiffness is not a problem. However, swept wings may have to house the undercarriage when it is retracted, and the sweep means that it must be located near to the trailing edge.

59. A solution to this problem is to add another short spar (or false spar) and to increase the chord of the wing at the root. This then gives enough depth in the wing to fit the retracted undercarriage, and provides a strong point for the undercarriage mounting.




Tailplane & Fin

60. Tailplanes on light aircraft may be built in a similar way to a fabric-covered wing. However, it is more common for stressed skin tailplanes to be used.

Stressed-skin tailplanes are usually similar in construction to stressed-skin wings, but they are obviously smaller and usually have a different section, because they are not required to produce lift in normal flight.

61. The construction of the fin is similar to that of the tailplane & wing and will consist of ribs, spars and stressed skin panels.

Tailplane & Fin Configurations

62. Designers have tried many different configurations of Tailplane & Fin over the years. For example, the Lockheed Super Constellation uses 3 smaller fins rather than a single large fin.

Another configuration, is the ‘T’ tail – such as the VC-10, where the tailplane is mounted on top of the fin

63. On large aircraft, the fin may also contain fuel. Not only does this increase the fuel capacity, but it also allows for trimming of the aircraft by providing the ability for the crew to transfer weight rather than by deflecting aerodynamic control surfaces, and so reduces drag.

Foreplanes

64. Foreplanes are of similar construction to tailplanes, but are generally smaller in size. Because of this smaller size, foreplanes lend themselves to being made of composite materials.

They are almost always ‘all-flying’, that is, the entire foreplane moves to provide the control movements.

Conclusions

65. As has been discussed, the wing is not only the most important part of the airframe, but it is also one of the most complex.

66. As technology advances, so the designers of wings will create evermore efficient wings.

67. Even so, the underlying structure of the wing has not changed in many years. Methods of constructing the wing, and the materials it is made from are the factors that are changing most.