1 The Fuselage

1.1 Introduction
The contents of this book will focus on the anatomy of the aeroplane and the various systems that enable it to operate both on the ground and in the air.

Typically, an aeroplane is made up of the following main component parts:

- Fuselage (the central body)
- Wings (mainplanes)
- Horizontal stabiliser (tailplane), Vertical stabiliser (fin), all called the Empennage.
- Flight controls
- Landing gear
- Powerplant (engine)

(See fig. AS 1.1)

The fuselage is the central body of the aeroplane since the powerplant, wings, empennage and landing gear are attached.
to it. Fuselages may be manufactured using various design principals. A fuselage structure is a rigid body to which the wings, empennage, engine and landing gear are attached. It also contains the flight crew, passengers, equipment and cargo. The fuselage can be made from a wide range of materials which can be riveted, bolted, screwed, welded or bonded together.

We will examine the fuselage construction in more detail later, and will briefly describe some of the stresses that act on the whole aircraft structure. Additionally, we will look at the various methods of securing panels and other major structural components (wings, empennage, and powerplants) to the airframe.

Meanwhile, control surfaces are attached to other main structural members such as the wings, horizontal and vertical stabilisers, by means of major hinge assemblies, or attached by load path routes direct to hydraulic or electrically operated actuators and systems.

Engines are attached to the fuselage (single engine aeroplanes) or wings by major sub frame assemblies, which may hold a turbo-prop engine ahead of the wing, and are secured to the main or auxiliary spars and ribs in the wing. Engines mounted under the wing are also attached by sub frames or pylons which are attached to wing spars by high strength bolt/pin assemblies to enable quick engine or pylon changes.

Engines attached to the rear fuselage are attached by stub wing type spars. Centre mounted engines can either be mounted directly on the fuselage or on to the vertical fin.

This chapter will also focus on the types of material that are commonly used in aircraft construction.

### 1.2 Types of Aircraft Construction

At the beginning of aviation development, aeroplanes were made with a structure of wood or bamboo. Problems connected to those structures were lack of strength, poor streamline shape and hence high drag. In the late 1920s, the aeroplane manufacturer Lockheed developed a monocoque structure composed of moulded-plywood. This improved streamlining to improve speed and minimise drag.

The next step in aviation evolution was an aeroplane structure of thin sheet metal instead of wood. This improvement reduced the weight and allowed mass-production of aircraft. During World War I, the Germans developed aluminium alloys by adding copper, manganese and magnesium, which increased the strength without increasing the weight. They called the alloy Duralumin. This alloy was the forerunner of the high-strength and lightweight alloys that the aviation industry uses today.

Two main types of aircraft construction exists:
- Girder framework, and
- All metal stressed skin structures.

Most modern aircraft constructors use various types of stressed skin construction,
but some light aircraft are still constructed according to the girder framework principles.

1.2.1 Girder Framework Construction
This type of construction consists of four longitudinal or lengthwise steel tube members (termed longerons) that are supported and held in position by horizontally, vertically and diagonally mounted tie and strut members. These tie and strut members are often also of steel tubular construction and are attached to the longerons either by bolting or welding, see fig. AS 1.2.

The longerons are the main strength members of the fuselage and are designed to withstand the main bending and torsional (twisting) loads and their generated stresses. The supporting ties are members subjected to tension loads and their generated stresses, and, the struts are supporting members subjected to compression loads and their generated stresses. On some girder framework designs, there can be some tubular supporting members that act as both struts and ties depending on their location.

Attached to this girder framework of longerons, ties and struts are attachments for the wings, empennage, powerplant and landing gear.

Fuselages of girder framework construction often result in a cross section which is rectangular shaped and has to be streamlined by the addition of fairing sections and a skin of either doped fabric or thin plywood. Girder frameworks are only used today in a limited range of light aircraft (Examples: Piper Cub, de Havilland Tiger Moth and Pitts Special) see fig. AS 1.3.

1.2.2 Stressed Skin Construction
Modern aircraft structures are of the stressed skin type, where some of the applied loads and generated stresses are carried by the outside skin. The stressed skin type provides a good streamline shape together with maximum internal space. There are three types of metal stressed skin construction, namely:

- Monocoque
- Semi-monocoque
- Reinforced structure.

Monocoque Structure
In a monocoque structure, the outside skin carries all the strength. The name monocoque means single shell and in fig. AS 1.4 the structure consists of three main parts. The thin metal skin carries the entire flight load while the bulkhead and formers (or frames)
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The skin is riveted to formers and bulkheads.

**Semi-Monocoque Structure**

The main problem in the design of a fuselage is to obtain adequate strength whilst keeping the structural weight within acceptable limits (a high strength to weight ratio). The monocoque structure has the disadvantage that any damage deformation will decrease its ability to carry the flight loads. The development of the semi-monocoque structure overcomes this limitation and gives a good strength to weight ratio.

A semi-monocoque fuselage depends primarily on bulkheads, formers and frames.
for vertical strength, and longerons and stringers for longitudinal strength (see fig. AS 1.5).

**Reinforced Structure**

It is the most commonly used structure in modern all-metal aircraft. As illustrated in fig. AS 1.6 the shape is provided by stringers, formers and bulkheads, and is reinforced with longerons which will tolerate bending stress.

Longerons and stringers are joined with the bulkheads to form the desired shape. When the skin is attached to these parts the whole structure forms a rigid fuselage. The fuselage structure must be designed with openings for doors, windshields and windows. The area around the openings must be reinforced, thereby safely supporting the loads that normally would have been supported by material in the cut out area. Stringers, formers, bulkheads and longerons help to carry these loads. With regard to the other structures, it is the sheet-metal skin over the structure that carries the most part of the flight loads.

Where skin sheets are bolted or riveted together on to stringers, formers or longerons, it may be necessary to add further strengthening to the joint. This is achieved by the introduction of a doubler (see fig. AS 1.7), which is basically a strap that is riveted to both pieces of skin along its edges. Doublers are often placed at areas where stress cracks may appear. On windshield fittings, they will prevent loss of the windshield because a crack, seeking the line of least resistance will find one of the many rivets which will prevent the crack extending along the windshield mounting.
Sandwich Construction
Aluminium alloy has a high enough tensile strength that a very thin sheet may be strong enough for a given application, but this thin sheet does not have enough stiffness to make it a totally adequate structural material. The sandwich construction solves this by using a lightweight core material which is bonded between face plies of metal or reinforced fabric. The method is used for all types of aircraft from home built machines to high speed state of the art military aircraft.

1.3 Materials Used in Aircraft Construction
The parts in an aircraft structure are manufactured using a wide range of materials, which are riveted, bolted, screwed, welded or bonded together. Both metallic and non-metallic materials are used in modern aircraft construction, the most common ones being:

- Metals
- Wood
- Composite materials

1.3.1 Metals
At the beginning of modern aviation, welded steel tubular trusses (another name for girder framework construction) formed the primary structures of metal aircraft. Later, improvements were made with aluminium alloys. Pure aluminium is lightweight and corrosion resistant, but lacks strength for use as a structural material. When mixed with other elements, its strength can be increased but becomes susceptible to corrosion. Only when it became possible to protect aluminium alloys from corrosion did they become popular as aircraft structural material.

Most modern aircraft are made from aluminium alloys, but the aviation industry also uses a range of other base materials in alloy form, as listed below:

Aluminium Alloys (General)
There are several different types of aluminium alloys presently in use in aircraft constructions. Copper, manganese, magnesium, chromium and zinc are all used in different alloys to achieve the best properties for different constructions. The majority of aircraft structures are made of an alloy of aluminium, copper, magnesium and manganese. Zinc is used in alloys with high strength requirements.

Duralumin Alloys
One of the most widely used traditional aluminium alloys used in aircraft
construction is that of the Duralumin (Dural) range.

Duralumin contains approximately 4% of Copper establishing the material with an Aluminium - Copper base. The Copper is added to improve the alloy’s strength following what is called the “Age Hardening” process after heat treatment. Although Duralumin has great structural strength and is a good conductor of heat and electricity, its natural corrosion resistance is reduced as a result of the alloying process. Its surfaces therefore require the application of specialised surface protection techniques. Duralumin is also a difficult material to weld, requiring the use of specialised equipment and operating skills.

**Magnesium Alloys**
Magnesium is the lightest structural metal, weighing approximately two thirds as much as aluminium. Pure magnesium does not have sufficient strength for use as a structural material, but when it is alloyed with aluminium, zinc or manganese, its strength is increased. Magnesium has two disadvantages. It is highly susceptible to corrosion and it has a tendency to crack when subjected to vibration. Magnesium dust and fine chips are easily ignited. Should a fire occur, it must be extinguished by smothering it with a dry sand or a dry-powder fire extinguishant. Using water and foam must be avoided, as these may cause the fire to burn with greater intensity.

**Titanium Alloys**
Titanium has been developed within the past fifty years into an important aircraft structural material. Titanium’s popularity is based on its low weight, corrosion resistance, temperature resistance and high structural strength. It is workable, but requires special techniques and sharp tools. One problem concerning titanium is the relatively high cost. It has many areas of application, but substitutes are often preferred due to the high cost.

**Monel Alloys**
Monel is an alloy of copper and nickel with small amounts of iron and manganese. Monel alloy’s high resistance to corrosion, its low coefficient of expansion and its high strength make it useful for applications that require these characteristics. It is often used in the exhaust system for aircraft engines.

**1.3.2 Wood**
The aviation industry has replaced wood with aluminium alloys in many applications. Wood as a primary structural material, is only used on a few types of light aircraft and amateur home-built aircraft. However, wood for aircraft structures is still used for wing spars and fuselage former stringers in some aeroplanes using girder framework construction, *see fig. AS 1.3.* Moreover, certain types of wood are used for the outside skin of monocoque structures and to reinforce wing spars. Some low horsepower engines have propellers made of strips of birch-wood glued together, but even these are being replaced by other materials such as composites.

**1.3.3 Composite Materials**
New generations of aircraft consist of materials that will eventually replace much
of the metal structure in the aircraft. These materials are plastic resins reinforced with filaments of glass, carbon, kevlar and boron. The resins are used to bind fibres of various materials together, see fig. AS 1.8. It is the fibres themselves that produce the strength and rigidity needed in aircraft construction. The fibres most widely used in aircraft construction are:

**Kevlar**
This is a fibre which is exceptionally well adapted for use in aircraft structures due to its high tensile strength and excellent stiffness. It is lighter than either glass or graphite, and superior in toughness and impact resistance.

**Glass Fibre**
Glass fibre was the first composite material used in aircraft construction. This material is still used for many applications, but other fibres which are stronger and weigh less, tend to replace it.

**Graphite**
This composite material is also called carbon and is extremely stiff and strong. However, it is corrosive when it is combined directly with aluminium alloys. Moreover, it breaks more easily due to its inherent brittlenes than, for example, kevlar, and can also present repair difficulties.

**Bonding for Even Load Distribution**
**The REDUX Bonding**
The REDUX bounding process consists of joining metal surfaces together gluing with special high strength adhesives that are curing under heat and pressure.

The REDUX bounding process, with its benefits to fatigue life and the even distribution of structural loads, is often found on final assembly lines. Skin/stringer bonding is used extensively throughout the airframe fuselage, wing, fin and tailplane. The resultant reduction in the overall components count can be considereable and the improvement in the efficiency of the structure is correspondingly impressive.

**1.4 Major Structural Stresses**
In designing an aircraft, every square centimetre of wing and fuselage, every rib, spar and even each metal fitting must be considered in relation to the physical characteristics of the metal of which it is made. Every part of the aircraft must be planned to carry the load to be imposed on it. The determination of such loads is called stress analysis. Although planning the design is not the function of the pilot, it is, nevertheless, important that you understand
and appreciate the stresses involved in order to appreciate the consequences of over stressing the aeroplane.

There are five major stresses to which all aircraft are subjected:
- Tension
- Compression
- Torsion
- Shear
- Bending

The term “stress” is often used interchangeably with the term “strain”, although there is a distinct difference between the two as will be described later.

**Tension**
This is the stress that resists a force or forces that are tending to pull apart or stretch a material. The tensile stress of a material is calculated by dividing the value of the applied load by its cross-sectional area and is expressed in units of Newtons per square millimetres (N/mm²), kilograms per square centimetres (kg/cm²) or pounds per square inch (lb/in²). Aircraft structural members that are loaded to produce tension are often termed ties. *Fig. AS 1.9* shows stress due to tension.

**Compression**
This is the stress that resists a crushing force. The compressive stress of a material is also measured as a load or force per unit area (applied load or force divided by surface area exposed to that load or force), and is expressed in units of pounds per square inch (lb/in²), kilograms per square centimetre (kg/cm²) or newtons per square millimetres (N/mm²). Compression is the stress that tends to shorten or crush aircraft parts. Aircraft structural members that are loaded to produce compression, are often termed struts, see *fig. AS 1.10*.

**Stress on Wings**
The wing loads and their generated stresses varies between the aircraft’s ground and flight modes. The natural weight of the aircraft on the ground will cause the wing (especially the outer portion of the wings) to sag or droop downwards, therefore placing the top wing skins under tension (or tensile stress), and the bottom wing skins under compression (or compressive stress).
In flight, the opposite applies as a result of wing lift generated. The top wing skins are under compression (compressive stress), whilst the lower wing skins are under tension (or tensile stress). *Fig. AS 1.11* shows the wing stress caused by the lift produced in flight.

**Shear**

This is the stress that resists the force tending to cause one layer of a material to slide over an adjacent layer. Two riveted plates in tension subject the rivets to a shearing force. Usually, the shearing stress of a material is either equal to or less than its tensile or compressive stress. Aircraft parts, especially screws, bolts and rivets, are often subject to a shearing force, *see fig. AS 1.12.*

**Torsion**

A propeller shaft, driven by the engine torque on one side that is balanced by an air resistance torque on the other side, is an example of a shaft subjected to a torsion load. The torsional stress of a structural component is its resistance to twisting.