INTRODUCTION TO AEROSPACE ENGINEERING

2018

MINISTRY OF EDUCATIONAL AND SCIENCE OF UKRAINE
National Aerospace University «Kharkov Aviation Institute»

INTRODUCTION TO AEROSPACE ENGINEERING

Tutorial

Kharkiv «KhAI» 2018

UDC 629.7(09)
I-69

Розглянуто найважливіші відомості з історії авіації. Основну увагу приділено базовим конструкціям літальних апаратів та головним означенням і концепціям основних елементів конструкції крила та фюзеляжу. У навчальному посібнику описано види авіаційних силових установок та існуючі системи шасі.

Для іноземних студентів першого курсу, які навчаються англійською мовою, як вступна дисципліна для ознайомлення з авіацією в цілому.

Composite authors:
D. A. Brega, V. V. Voronko, D. V. Tiniakov, I. O. Voronko

Reviewers : PhD in Military science, Docent V. I. Pushkarev,
Doctor of Engineering, Prof. D. M. Klets

I-69 **Introduction** to aerospace engineering [Text] : tutorial / D. A. Brega, V. V. Voronko, D. V. Tiniakov, I. O. Voronko. – Kharkiv : National Aerospace University named after N. Ye. Zhukovskiy «Kharkov Aviation Institute», 2018. – 87 p.

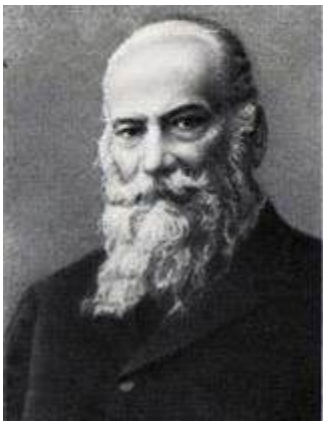
The text-book covers the most important information about the history of aviation. The authors focus on the aircraft basic constructions and the main definitions and concepts of the basic elements of the design of the wing and fuselage. The tutorial represents the types of aircraft power plants and the existing systems of Landing gear.

The book is intended for first-year foreign students who study in English as an introductory subject for an overall idea of aviation in general.

Fig. 81. Bibliogr. : 10 names

UDC 629.7(09)

INTRODUCTION



"A man has no wings and in relation to the weight of his body to the weight of muscles 72 times weaker than a bird ... But I think he will fly, not relying on the strength of his muscles, but on the strength of his mind."

N. Ye. Zhukovskiy, 1898

What is the flight? Flight is the process by which an object moves through atmosphere (or beyond it, as in the case of spaceflight) without contact with the surface. This can be achieved by generating aerodynamic lift associated with propulsive thrust, aerostatically using buoyancy, or by ballistic movement.

Many things can fly, from natural aviators such as birds, bats, and insects, to human inventions like aircraft, including airplanes, helicopters, balloons, and rockets which may carry spacecraft.

The engineering aspects of flight are the purview of aerospace engineering which is subdivided into aeronautics, the study of vehicles that travel through the air, and astronautics, the study of vehicles that travel through space, and in ballistics, the study of the flight of projectiles.

George Cayley studied flight scientifically in the first half of the 19th century, and in the second half of the 19th century Otto Lilienthal made over 200 gliding flights and was also one of the first to understand flight scientifically. His work was replicated and extended by the Wright brothers who made gliding flights and finally the first controlled and extended, manned powered flights.

Spaceflight, particularly human spaceflight became a reality in the 20th Century following theoretical and practical breakthroughs by Konstantin Tsiolkovsky and Robert H. Goddard. The first orbital spaceflight was in 1957 and Yuri Gagarin was carried aboard the first manned orbital spaceflight in 1961.

But not everyone believed that a person can fly. History has heard many skeptics.

"Is not it true that a true flying machine, self-raising, self-sustaining, self-propelling, is physically impossible?" (*Joseph LeConte, November 1888*)

"It is apparent to me that the possibilities of the aeroplane, which were the fate of the aeroplane, which had been exhausted, and that we must turn elsewhere." (*Thomas Edison, November 1895*)

"I can state flatly that heavier than air flying machines are impossible." (*Lord Kelvin, 1895*)

"I have not the smallest molecule of faith in aerial navigation, other than ballooning, or of the expectation of good. So you will understand that I would not care of a member of the Aeronautical Society." (*Lord Kelvin, 1896)*

"The present generation will not be in the next century." (*Worby Beaumont, January 1900*)

"There is no basis for the ardent hopes and positive statements made to the safe and successful use of the dirigible balloon or flying machine." (*George Melville, December 1901*)

"The demonstration that no possible combination of known substances, known forms of machinery and known forms of force, can be united in a practical machine by which it is possible for the demonstration to be." (*Simon Newcomb, 1900*)

"Flight by machines heavier than air is unpractical and insignificant, if not utterly impossible." (*Simon Newcomb, 1902*)

"It is complete nonsense to believe." (*Stanley Mosley, 1905*)

"The aeroplane will never fly." (*Lord Haldane, 1907*)

1 A BRIEF HISTORY OF AVIATION

Flying model craft and stories of manned flight go back many centuries, however the first manned ascent – and safe descent – in modern times took place by hot-air balloon in the 18th century. Each of the two World Wars led to great technical advances. Consequently the history of aircraft can be divided into five eras:

– Pioneers of flight, from the earliest experiments to 1914.
– First World War, 1914 to 1918.
– Aviation between the World Wars, 1918 to 1939.
– Second World War, 1939 to 1945.
– Post-war era, also called the jet age, 1945 to the present day.

The forerunner of the fixed-wing aircraft is the kite. Whereas a fixed-wing aircraft relies on its forward speed to create airflow over the wings, a kite is tethered to the ground and relies on the wind blowing over its wings to provide lift. Kites were the first kind of aircraft to fly, and were invented in China around 500 BC. Much aerodynamic research was done with kites before test aircraft, wind tunnels, and computer modelling programs became available.

Kites were used approximately 2,800 years ago in China, where materials ideal for kite building were readily available. Some authors hold that leaf kites were being flown much earlier in what is now Indonesia, based on their interpretation of cave paintings on Muna Island of Sulawesi. By at least 549 AD paper kites were being flown, as it was recorded in that year a paper kite was used as a message for a rescue mission. Ancient and medieval Chinese sources list other uses of kites for measuring distances, testing the wind, lifting men, signalling, and communication for military operations.

Stories of kites were brought to Europe by Marco Polo towards the end of the 13th century, and kites were brought back by sailors from Japan and Malaysia in the 16th and 17th centuries. Although they were initially regarded as mere curiosities, by the 18th and 19th centuries kites were being used as vehicles for scientific research.

The first heavier-than-air craft capable of controlled free-flight were gliders. A glider designed by Cayley carried out the first true manned, controlled flight in 1853.A glider is a heavier-than-air craft that is supported in flight by the dynamic reaction of the air against its lifting surfaces, and whose free flight does not depend on an engine. A sailplane is a fixed-wing glider designed for soaring - the ability to gain height in updrafts of air and to fly for long periods.

Gliders are mainly used for recreation, but have also been used for other purposes such as aerodynamics research, warfare and recovering spacecraft.

A Motor glider has an engine for extending its performance and some have engines powerful enough to take off, but the engine is not used in normal flight.

As in the case with planes, there are a wide variety of glider types differing in the construction of their wings, aerodynamic efficiency, location of the pilot and controls. Perhaps the most familiar type is the toy paper plane.

Large gliders are most commonly launched by a tow-plane or by a winch. Military gliders have been used in war to deliver assault troops, and specialised gliders have been used in atmospheric and aerodynamic research. Rocket-powered aircraft and space planes have also made unpowered landings.

Gliders and sailplanes that are used for the sport of gliding have high aerodynamic efficiency. The highest lift-to-drag ratio is 70:1, though 50:1 is more common. After launch, further energy is obtained through the skilful exploitation of rising air in the atmosphere. Flights of thousands of kilometres at average speeds over 200 km/h have been achieved.

The most numerous unpowered aircraft are hang gliders and paragliders. These are foot-launched and are in general slower, smaller, and less expensive than sailplanes. Hang gliders most often have flexible wings given shape by a frame, though some have rigid wings. Paragliders have no frames in their wings.

Gliders and sailplanes can share a number of features in common with powered aircraft, including many of the same types of fuselage and wing structures. For example the HortenH.IV was a tailless flying wing glider, and the delta wing-shaped Space Shuttle orbited flew much like a conventional glider in the lower atmosphere. Many gliders also use similar controls and instruments as powered craft.

Around 400 BC in Greece, Archytas was reputed to have designed and built the first artificial, self-propelled flying device, a bird-shaped model propelled by a jet of what was probably steam, said to have flown some 200 m (660 ft). This machine may have been suspended for its flight.

Some of the earliest recorded attempts with gliders were those by the 9th-century poet Abbas Ibn Firnas and the 11th-century monk Eilmer of Malmesbury; both experiments injured their pilots.

In 1799, Sir George Cayley set the forth concept of the modern aeroplane as a fixed-wing flying machine with separate systems for lift, propulsion, and control. Cayley was building and flying models of fixed-wing aircraft as early as 1803, and he built a successful passenger-carrying glider in 1853. In 1856, Frenchman Jean-Marie Le Bris made the first powered flight, by having his glider "L'Albatrosartificiel" pulled by a horse on a beach. Then Alexander F. Mozhaisky made the first ever plane as plane with two steam engines in 1882 and did the first ever plane which could have flown with more powerful engines. In 1883, the American John J. Montgomery made a controlled flight in a glider. Other aviators who made similar flights at that time were Otto Lilienthal, Percy Pilcher, and Octave Chanute.

The history of aircraft structures underlies the history of aviation in general. Advances in materials and processes used to construct aircraft have led to their evolution from simple wood truss structures to the sleek aerodynamic flying machines of today. Combined with continuous powerplant development, the structures of “flying machines” have changed significantly. The key discovery that “lift” could be created by passing air over the top of a curved surface set the development of fixed and rotary-wing aircraft in motion. George Cayley developed an efficient cambered airfoil in the early 1800s, as well as successful manned gliders later in that century. He established the principles of flight, including the existence of lift, weight, thrust, and drag. It was Cayley who first stacked wings and created a tri-wing glider that flew a man in 1853.Earlier, Cayley studied the center of gravity of flying machines, as well as the effects of wing dihedral. Furthermore, he pioneered directional control of aircraft by including the earliest form of a rudder on his gliders (Figure 1.1).

In the late 1800s, Otto Lilienthal built upon Cayley’s discoveries. He manufactured and flew his own gliders on over 2,000 flights. His willow and cloth aircraft had wings designed from extensive study of the wings of birds. Lilienthal also made standard use of vertical and horizontal fins behind the wings and pilot station. Above all, Lilienthal proved that man could fly (Figure 1.2).

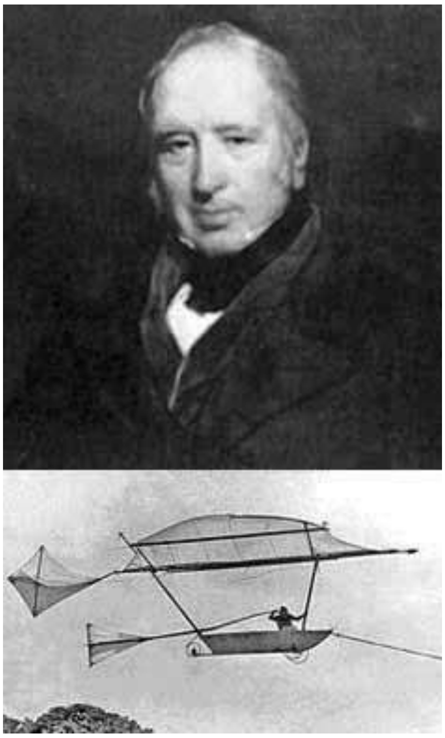


Figure 1.1 – George Cayley, the father of aeronautics (top) and a flying replica of his 1853 glider (bottom)

Figure 1.2 – Master of gliding and wing study, Otto Lilienthal (top) and one of his more than 2,000 glider flights (bottom)

Octave Chanute, a retired railroad and bridge engineer, was active in aviation during the 1890s (Figure 1.3). His interest was so great that, among other things, he published a definitive work called “Progress in Flying Machines.” This was the culmination of his effort to gather and study all the information available on aviation. With the assistance of others, he built gliders similar to Lilienthal’s and then his own. In addition to his publication, Chanute advanced aircraft structure development by building a glider with stacked wings incorporating the use of wires as wing supports.

Sir Hiram Maxim built a craft that weighed 3.5 tons, with a 110-foot (34-meter) wingspan that was powered by two 360-horsepower (270-kW) steam engines driving two propellers. In 1894, his machine was tested with overhead rails to prevent it from rising. The test showed that it had enough lift to take off. The craft was uncontrollable, which Maxim, it is presumed, realized, because he subsequently abandoned work on it.

Figure 1.3 – Octave Chanute gathered and published all of the aeronautical knowledge known to date in the late 1890s. Many early aviators benefited from this knowledge.

The work of all of these men was known to the Wright Brothers when they built their successful, powered airplane in 1903. The first of its kind to carry a man aloft, the Wright Flyer had thin, cloth-covered wings attached to what was primarily truss structures made of wood. The wings contained forward and rear spars and were supported with both struts and wires. Stacked wings (two sets) were also part of the Wright Flyer (Figure 1.4).

The Wright brothers' flights in 1903 are recognized by the *Fédération Aéronautique Internationale* (FAI), the standard setting and record-keeping body for aeronautics, as "the first sustained and controlled heavier-than-air powered flight". By 1905, the Wright Flyer III was capable of fully controllable, stable flight for substantial periods.

In 1906, Brazilian inventor Alberto Santos Dumont designed, built and piloted an aircraft that set the first world record recognized by the Aéro-Club de France by flying the 14 bis 220 metres (720 ft) in less than 22 seconds. The flight was certified by the FAI. This was the first controlled flight, to be officially recognised, by a plane able to take off under its own power alone without any auxiliary machine such as a catapult.

The Bleriot VIII design of 1908 was an early aircraft design that had the modern monoplanetractor configuration. It had movable tail surfaces controlling both yaw and pitch, a form of roll control supplied either by wing warping or by ailerons and controlled by its pilot with a joystick and rudder bar. It was an important predecessor of his later Bleriot XIChannel-crossing aircraft of the summer of 1909.

Figure 1.4 – The Wright Flyer was the first successful powered aircraft. It was made primarily of wood and fabric.

1.1 World War I

World War I served as a testbed for the use of the aircraft as a weapon. Initially seen by the generals as a "toy", aircraft demonstrated their potential as mobile observation platforms, then proved themselves to be machines of war capable of causing casualties to the enemy. The earliest known aerial victory with a synchronised machine gun-armed fighter aircraft occurred in 1915, by German LuftstreitkräfteLeutnantKurt Wintgens. Fighter aces appeared; the greatest (by number of air victories) was Manfred von Richthofen.

Following WWI, aircraft technology continued to develop. Alcock and Brown crossed the Atlantic non-stop for the first time in 1919. The first commercial flights took place between the United States and Canada in 1919.

1.2 World War II

Aeroplanes had a presence in all the major battles of World War II. They were an essential component of the military strategies of the period, such as the German Blitzkrieg or the American and Japanese aircraft carrier campaigns of the Pacific.

Military gliders were developed and used in several campaigns, but they did not become widely used due to the high casualty rate often encountered. The Focke-Achgelis Fa 330 Bachstelze (Wagtail) rotor kite of 1942 was notable for its use by German submarines (Figure 1.5).

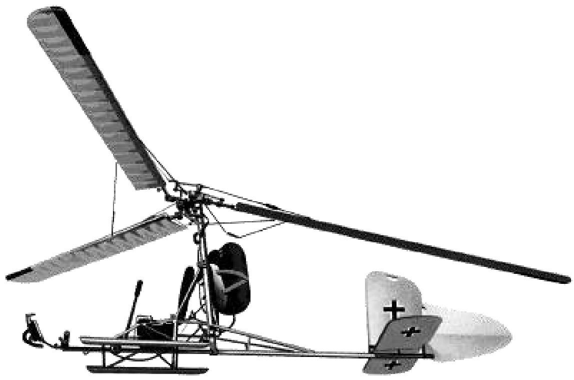


Figure 1.5 – The Focke-Achgelis Fa 330 Bachstelze (Wagtail).
They were towed behind German U-boats

Before and during the war, both British and German designers were developing jet engines to power aeroplanes. The first jet aircraft to fly, in 1939, was the German Heinkel He 178. In 1943 the first operational jet fighter, the Messerschmitt Me 262, went into service with the German Luftwaffe and later in the war the British Gloster Meteor entered service but never saw action.

1.3 Post-war

In October 1947, the Bell X-1 was the first aircraft to exceed the speed of sound. (Figure 1.6)

In 1948-49, aircraft transported supplies during the Berlin Blockade. New aircraft types, such as the B-52, were produced during the Cold War.

The first jet airliner, the de Havilland Comet, was introduced in 1952. The Boeing 707, the first widely successful commercial jet, was in commercial service for more than 50 years, from 1958 to 2010. The Boeing 747 was the world's biggest passenger aircraft from 1970 until it was surpassed by the Airbus A380 in 2005.

Figure 1.6 – The Bell X-1

1.4 General information

An **aircraft** is a machine that is able to fly by gaining support from the air, or, in general, the atmosphere of a planet. It counters the force of gravity by using either static lift or by using the dynamic lift of an airfoil, or in a few cases the downward thrust from jet engines. The human activity that surrounds aircraft is called *aviation*. Crewed aircraft are flown by an on board pilot, but unmanned aerial vehicles may be remotely controlled or self-controlled by on board computers. Aircraft may be classified by different criteria, such as lift type, propulsion, usage and others.

An **airplane** (also known as an **airplane** or simply a **plane**) is a powered fixed-wing aircraft that is propelled forward by thrust from a jet engine or propeller. Planes come in a variety of sizes, shapes, and wing configurations. The broad spectrum of uses for planes includes recreation, transportation of goods and people, military, and research.

1.5 Methods of lift

Heavier-than-air aircraft, such as airplanes, must find some way to push air or gas downwards, so that a reaction occurs (by Newton's laws of motion) to push the aircraft upwards. This dynamic movement through the air is the origin of the term *aerodyne*. There are two ways to produce dynamic up thrust: aerodynamic lift, and powered lift in the form of engine thrust.

Aerodynamic lift involving wings is the most common, with fixed-wing aircraft being kept in the air by the forward movement of wings, and rotorcraft by spinning wing-shaped rotors sometimes called rotary wings. A wing is a flat, horizontal surface, usually shaped in cross-section as an airfoil. To fly, air must flow over the wing and generate lift. A *flexible wing* is a wing made of fabric or thin sheet material, often stretched over a rigid frame. A *kite* is tethered to the ground and relies on the speed of the wind over its wings, which may be flexible or rigid, fixed, or rotary.

With powered lift, the aircraft directs its engine thrust vertically downward. V/STOL aircraft, such as the Harrier Jump Jet and F-35B take off and land vertically using powered lift and transfer to aerodynamic lift in steady flight.

A pure rocket is not usually regarded as an aerodyne, because it does not depend on the air for its lift (and can even fly into space); however, many aerodynamic lift vehicles have been powered or assisted by rocket motors. Rocket-powered missiles that obtain aerodynamic lift at very high speed due to airflow over their bodies are a marginal case.

Practical, powered, fixed-wing aircraft (the aeroplane or airplane) were invented by Wilbur and Orville Wright. Besides the method of propulsion, fixed-wing aircraft are in general characterized by their wing configuration. The most important wing characteristics are:

- Number of wings – Monoplane, biplane, etc.
- Wing support – Braced or cantilever, rigid, or flexible.
- Wing planform – including aspect ratio, angle of sweep, and any variations along the span (including the important class of delta wings)
- Location of the horizontal stabilizer, if any.
- Dihedral angle – positive, zero, or negative (anhedral).

A variable geometry aircraft can change its wing configuration during flight.

A *flying wing* has no fuselage, though it may have small blisters or pods. The opposite of this is a *lifting body*, which has no wings, though it may have small stabilizing and control surfaces.

Wing-in-ground-effect vehicles may be considered as fixed-wing aircraft. They "fly" efficiently close to the surface of the ground or water, like conventional aircraft during take-off. An example is the Russian ekranoplan (nick-named the "Caspian Sea Monster"). Man-powered aircraft also rely on ground effect to remain airborne with a minimal pilot power, but this is only because they are so underpowered — in fact, the airframe is capable of flying higher.

The structural parts of a fixed-wing aircraft are called the airframe. The parts present can vary according to the aircraft's type and purpose. Early types were usually made of wood with fabric wing surfaces, When engines became available for powered flight around a hundred years ago, their mounts were made of metal. Then as speeds increased more and more parts became metal until by the end of WWII all-metal aircraft were common. In modern times, increasing use of composite materials has been made.

Aerostats use buoyancy to float in the air in much the same way that ships float on the water. They are characterized by one or more large gasbags or canopies, filled with a relatively low-density gas such as helium, hydrogen, or hot air, which is less dense than the surrounding air. When the weight of this is added to the weight of the aircraft structure, it adds up to the same weight as the air that the craft displaces.

Small hot-air balloons called sky lanterns date back to the 3rd century BC, and were only the second type of aircraft to fly, the first being kites.

A balloon was originally any aerostat, while the term airship was used for large, powered aircraft designs – usually fixed-wing – though none had yet been built. The advent of powered balloons, called dirigible balloons, and later of rigid hulls allowing a great increase in size, began to change the way these words were used. Huge powered aerostats, characterized by a rigid outer framework and separate aerodynamic skin surrounding the gas bags, were produced, the Zeppelins being the largest and most famous. There were still no fixed-wing aircraft or non-rigid balloons large enough to be called airships, so "airship" came to be synonymous with these aircraft. Then several accidents, such as the Hindenburg disaster in 1937, led to the demise of these airships. Nowadays a "balloon" is an unpowered aerostat, whilst an "airship" is a powered one.

A powered, steerable aerostat is called a *dirigible*. Sometimes this term is applied only to non-rigid balloons, and sometimes *dirigible balloon* is regarded as the definition of an airship (which may then be rigid or non-rigid). Non-rigid dirigibles are characterized by a moderately aerodynamic gasbag with stabilizing fins at the back. These soon became known as *blimps*. During the Second World War, this shape was widely adopted for tethered balloons; in windy weather, this reduces the strain on the tether and stabilizes the balloon. The nickname *blimp* was adopted along with the shape. In modern times, any small dirigible or airship is called a blimp, though a blimp may be unpowered as well as powered.

1.6 Aircraft Requirements and Safety

The design process of an aircraft starts with specification of the requirements. An aircraft design is always a compromise. The first and most important requirement of an aircraft part is that it fulfils its function in all circumstances, particularly in critical situations. The strength of a structure is a measure of the risks taken - the acceptance that the structure will fail

in extreme conditions. Society sets standards for such risks. We accept that all structures fail in certain conditions. When calculating the loads, we name the force which will just make the structure fail, the ultimate load. Structural failures often occur due to a very large series of normal repetitive loads that cause fracturing of the material: metal-fatigue. It is very important to know the rate of crack-growth and the residual strength (the strength in the presence of cracks) of a structure. A number of European countries have formulated a set of Joint Airworthiness Requirements, the J.A.R, which are based on the American Federal Airworthiness Requirements, or F.A.R. The airworthiness standards define primary structures, those that would endanger the aircraft upon failure, secondary structures, those that do not cause immediate danger upon failure, and non load-bearing structures, which do not carry loads. There are multiple ways of considering part safety. The fail-safe principle accepts that there is a chance that part of the structure fails. However, there should be no chance of the whole structure failing. In the safe-life philosophy, the chance of the structure failing within its prescribed lifetime should be zero. If this were to happen, then the chance of the whole structure failing is substantial. The stiffness of a structure is a measure of its resistance to a change in shape when subjected to forces. The stiffness of a complete structure is always a combination f its material properties and its geometry. Aircraft wings and tail-sections can be subjected to three types of forces, namely aerodynamic forces, elastic forces and mass forces. These forces can work together in such an unfortunate way that they induce a type of vibration known as flutter. Flutter only occurs above a certain speed, which we call the critical speed. Flutter is caused by two coordinated types of vibration that amplify each other’s effect. Air-transport safety is the responsibility of the manufacturer, the user and the government. As part of this responsibility, the government exercises control over the airfield through the State Air-Transport Service (In the Netherlands this is the Luchtvaart Autoriteit). The Luchtvaart Autoriteit is responsible for monitoring design, manufacturing, use and maintenance of aircraft, education, training and testing of personnel, and operational guidelines, accident investigation, traffic management and traffic regulations.

2 AIRCRAFT BASIC CONSTRUCTION

An aircraft is a device that is used for, or is intended to be used for, flight in the air. Major categories of aircraft are airplane, rotorcraft, glider, and lighter-than-air vehicles (Figure 2.1). Each of these may be divided further by major distinguishing features of the aircraft, such as airships and balloons. Both are lighter-than-air aircraft but have differentiating features and are operated differently. The concentration of this handbook is on the airframe of aircraft; specifically, the fuselage, booms, nacelles, cowlings, fairings, airfoil surfaces, and landing gear. Also included are the various accessories and controls that accompany these structures. Note that the rotors of a helicopter are considered part of the airframe since they are actually rotating wings. By contrast, propellers and rotating airfoils of an engine on an airplane are not considered part of the airframe. The most common aircraft is the fixed-wing aircraft. As the name implies, the wings on this type of flying machine are attached to the fuselage and are not intended to move independently in a fashion that results in the creation of lift. One, two, or three sets of wings have all been successfully utilized (Figure 2.2). Rotary-wing aircraft such as helicopters are also widespread. This handbook discusses features and maintenance aspects common to both fixed wing and rotary-wing categories of aircraft. Also, in certain cases, explanations focus on information specific to only one or the other. Glider airframes are very similar to fixed wing aircraft. Unless otherwise noted, maintenance practices described for fixed-wing aircraft also apply to gliders. The same is true for lighter-than-air aircraft, although thorough coverage of the unique airframe structures and maintenance practices for lighter-than-air flying machines is not included in this handbook.

Figure 2.1 – Examples of different categories of aircraft, clockwise from top left: lighter-than-air, glider, rotorcraft, and airplane.

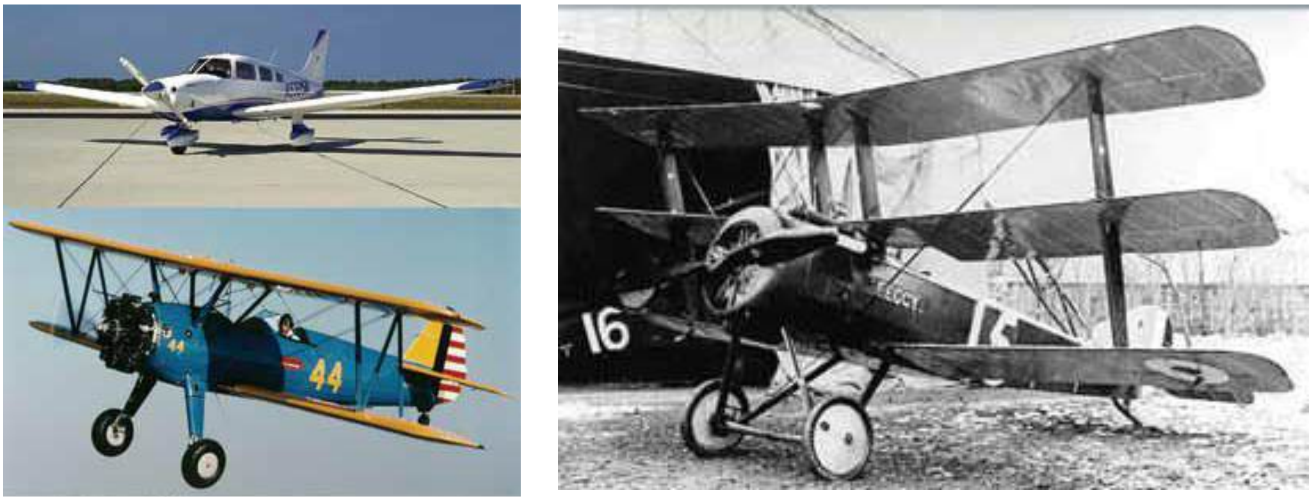


Figure 2.2 – A monoplane (top), biplane (middle), and tri-wing aircraft (bottom).

The airframe of a fixed-wing aircraft consists of five principal units: the fuselage, wings, stabilizers, flight control surfaces, and landing gear (Figure 2.3). Helicopter airframes consist of the fuselage, main rotor and related gearbox, tail rotor (on helicopters with a single main rotor), and the landing gear. Airframe structural components are constructed from a wide variety of materials. The earliest aircraft were constructed primarily of wood. Steel tubing and the most common material, aluminum, followed. Many newly certified aircraft are built from molded composite materials, such as carbon fiber. Structural members of an aircraft's fuselage include stringers, longerons, ribs, bulkheads, and more. The main structural member in a wing is called the wing spar. The skin of aircraft can also be made from a variety of materials, ranging from impregnated fabric to plywood, aluminum, or composites. Under the skin and attached to the structural fuselage are many components that support airframe function. The entire airframe and its components are joined by rivets, bolts, screws, and other fasteners. Welding, adhesives, and special bonding techniques are also used.

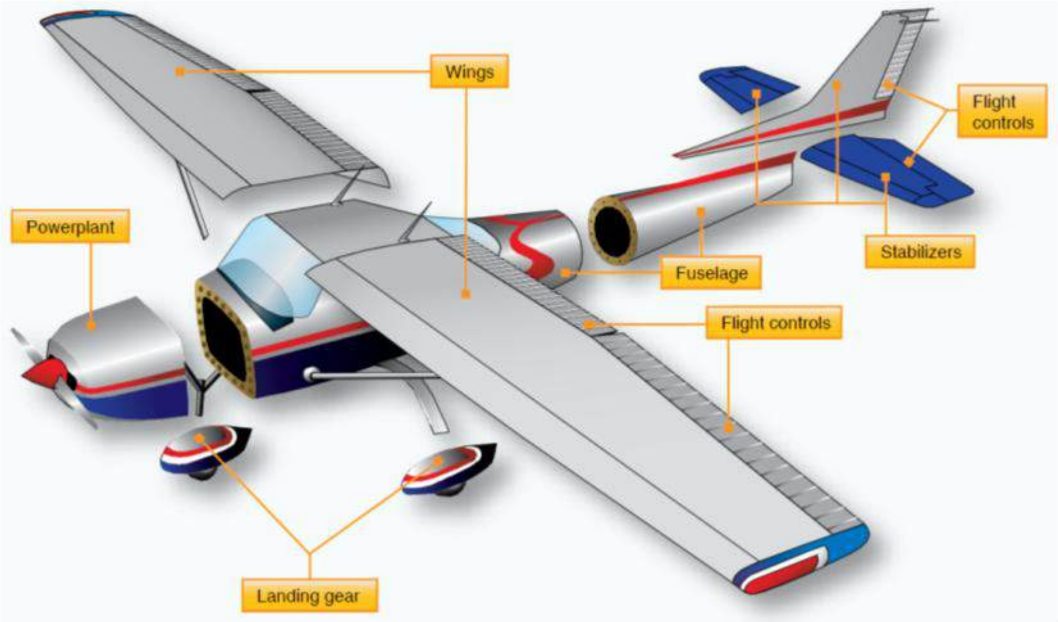


Figure 2.3 – Principal airframe units.

The primary factors to consider in aircraft structures are strength, weight, and reliability. These factors determine the requirements to be met by any material used to construct or repair the aircraft. Airframes must be strong and light in weight. An aircraft built so heavy that it couldn't support more than a few hundred pounds of additional weight would be useless. All materials used to construct an aircraft must be reliable. Reliability minimizes the possibility of dangerous and unexpected failures. Many forces and structural stresses act on an aircraft when it is flying and when it is static. When it bis static, the force of gravity produces weight, which bis supported by the landing gear. The landing gear absorbs the forces imposed on the aircraft by take offs and landings. During flight, any manoeuvres that causes acceleration or deceleration increases the forces and stresses on the wings and fuselage. Stresses on the wings, fuselage, and landing gear of aircraft are tension, compression, shear, bending, and torsion. These stresses are absorbed by each component of the wing structure and transmitted to the fuselage structure. The empennage (tail section) absorbs the same stresses and transmits them to the fuselage. These stresses are known as *loads*, and the study of loads bis called a *stress analysis.* Stresses are analysed and considered when an aircraft is designed.

The determination of such loads is called stress analysis. Although planning the design is not the function of the aircraft technician, it is, nevertheless, important that the technician understand and appreciate the stresses involved in order to avoid changes in the original design through improper repairs. The term “stress” is often used interchangeably with the word “strain.” While related, they are not the same thing. External loads or forces cause stress. Stress is a material’s internal resistance, or counterforce, that opposes deformation. The degree of deformation of a material is strain. When a material is subjected to a load or force, that material is deformed, regardless of how strong the material is or how light the load is. There are five major stresses (Figure 2.4) to which all aircraft are subjected:

- Tension
- Compression
- Torsion
- Shear
- Bending

Tension is the stress that resists a force that tends to pull something apart (Figure 2.4*, a*)*.* The engine pulls the aircraft forward, but air resistance tries to hold it back. The result is tension, which stretches the aircraft. The tensile strength of a material is measured in pounds per square inch (psi) and is calculated by dividing the load (in pounds) required to pull the material apart by its cross-sectional area (in square inches). Compression is the stress that resists a crushing force (Figure 2.4, *b*). The compressive strength of a material is also measured in psi. Compression is the stress that tends to shorten or squeeze aircraft parts.

Torsion is the stress that produces twisting (Figure 2.4, *c*)*.* While moving the aircraft forward, the engine also tends to twist it to one side, but other aircraft components hold it on course. Thus, torsion is created. The torsion strength of a material is its resistance to twisting or torque. Shear is the stress that resists the force tending to cause one layer of a material to slide over an adjacent layer (Figure 2.4, *d*). Two riveted plates in tension subject the rivets to a shearing force. Usually, the shearing strength of a material is either equal to or less than its tensile or compressive strength.

Aircraft parts, especially screws, bolts, and rivets, are often subject to a shearing force. Bending stress is a combination of compression and tension. The rod in Figure 2.4, *e* has been shortened (compressed) on the inside of the bend and stretched on the outside of the bend.

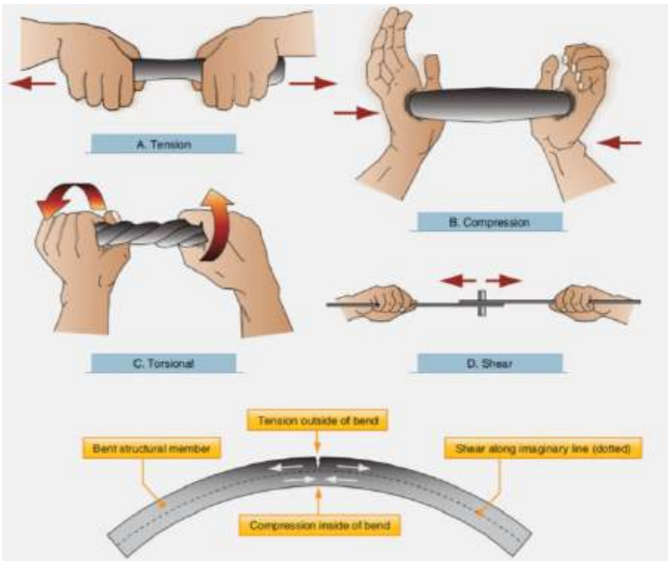


Figure 2.4 – The five stresses that may act on an aircraft and its parts.

2.1 Aircraft structures

Typical structural parts include:

- One or more large horizontal *wings*, often with an airfoil cross-section shape. The wing deflects air downward as the aircraft moves forward, generating lifting force to support it in flight. The wing also provides stability in roll to stop the aircraft from rolling to the left or right in steady flight.
- A *fuselage*, a long, thin body, usually with tapered or rounded ends to make its shape aerodynamically smooth. The fuselage joins the other parts of the airframe and usually contains important things such as the pilot, payload and flight systems.
- A *vertical stabiliser* or fin is a vertical wing-like surface mounted at the rear of the plane and typically protruding above it. The fin stabilises the plane's yaw (turn left or right) and mounts the rudder which controls its rotation along that axis.
- A *horizontal stabiliser*, usually mounted at the tail near the vertical stabilizer. The horizontal stabilizer is used to stabilise the plane's pitch (tilt up or down) and mounts the elevators which provide pitch control.
- *Landing gear,* a set of wheels, skids, or floats that support the plane while it is on the surface. On seaplanes the bottom of the fuselage or floats (pontoons) support it while on the water. On some planes the landing gear retracts during flight to reduce drag.

2.2 Wing Configurations

Wings are airfoils that, when moved rapidly through the air, create lift. They are built in many shapes and sizes. Wing design can vary to provide certain desirable flight characteristics. Control at various operating speeds, the amount of lift generated, balance, and stability all change as the shape of the wing is altered. Both the leading edge and the trailing edge of the wing may be straight or curved, or one edge may be straight and the other curved. One or both edges may be tapered so that the wing is narrower at the tip than at the root where it joins the fuselage. The wing tip may be square, rounded, or even pointed. Figure 2. 5 shows a number of typical wing leading and trailing edge shapes. The wings of an aircraft can be attached to the fuselage at the top, mid-fuselage, or at the bottom. They may extend perpendicular to the horizontal plain of the fuselage or can angle up or down slightly. This angle is known as the wing dihedral. The dihedral angle affects the lateral stability of the aircraft. Figure 2.6 shows some common wing attach points and dihedral angle.

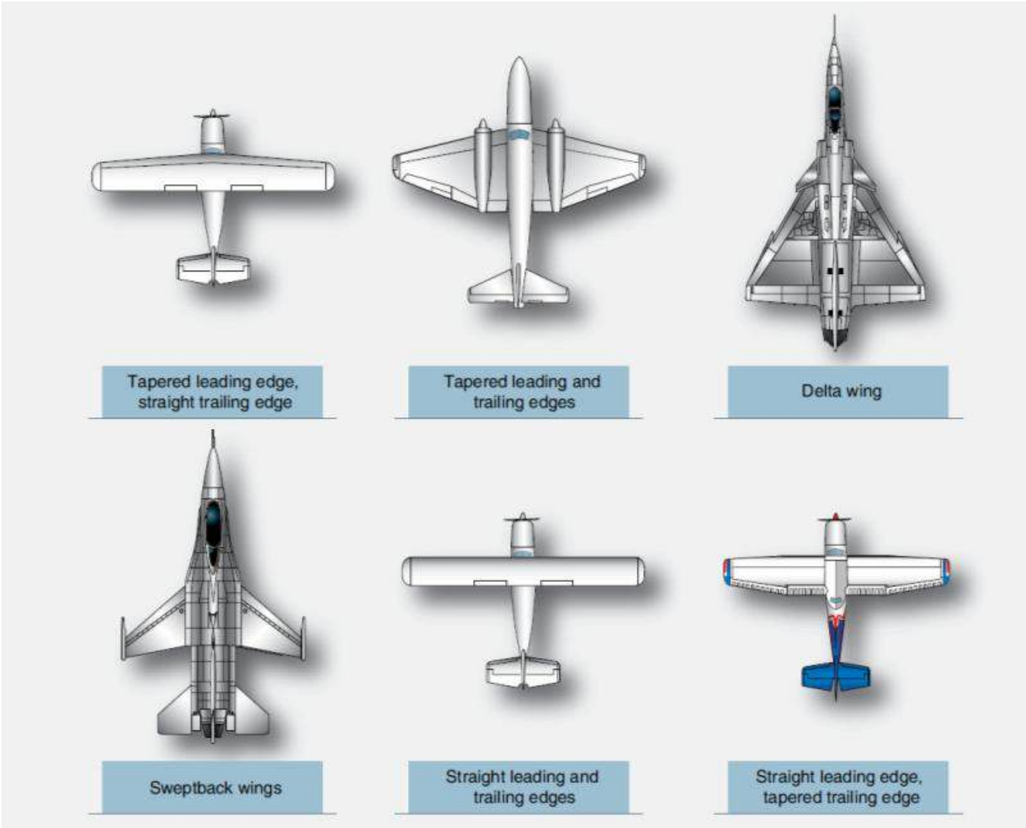


Figure 2.5 – Various wing design shapes yield different performance.

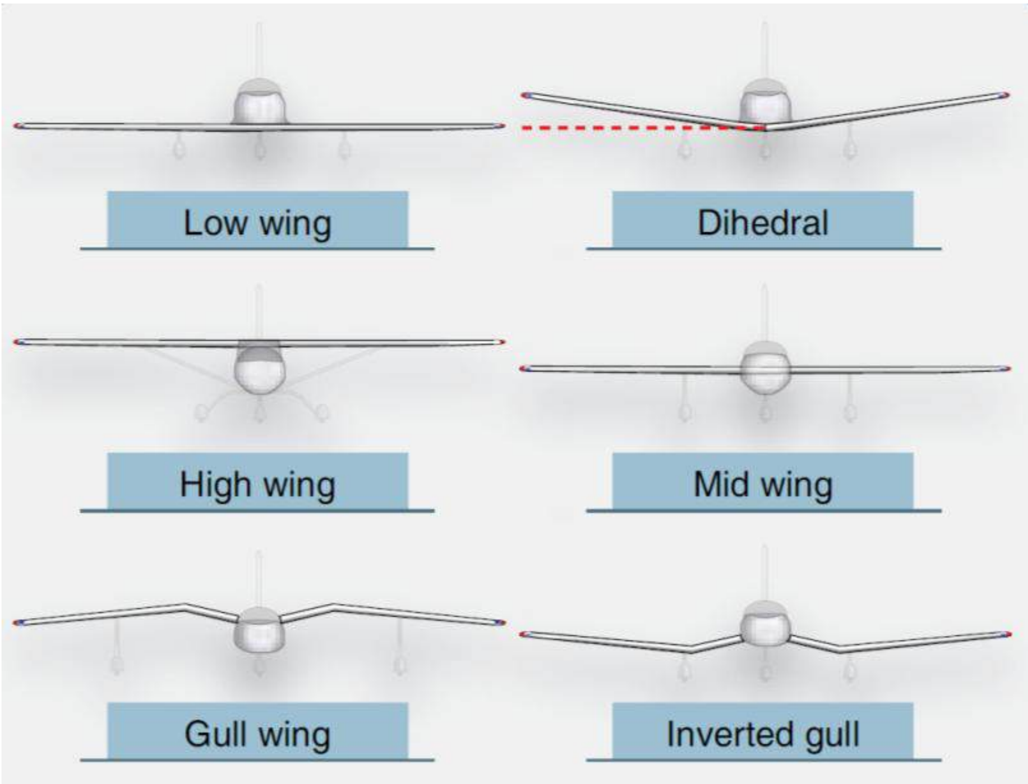


Figure 2.6 – Wing attach points and wing dihedrals.

2.3 Conventional airfoils and laminar flow airfoils

The type of operation for which an airplane is intended has a very important bearing on the selection of the shape and design of the wing for that airplane. If the airplane is designed for low speed, a thick airfoil is most efficient. A thin airfoil is the best for high speed.

Conventional airfoils and laminar flow airfoils are in common use in airplane design.

Laminar flow airfoils were originally developed for the purpose of making an airplane fly faster. The laminar flow wing is usually thinner than the conventional airfoil, the leading edge is more pointed and its upper and lower surfaces are nearly symmetrical. The major and most important difference between the two types of airfoil is this, the thickest part of a laminar wing occurs at 50% chord while in the conventional design the thickest part is at 25% chord.

The effect achieved by this type of design of a wing is to maintain the laminar flow of air throughout a greater percentage of the chord of the wing and to control the transition point. Drag is therefore considerably reduced since the laminar airfoil takes less energy to slide through the air. The pressure distribution on the laminar flow wing is much more even since the camber of the wing from the leading edge to the point of maximum camber is more gradual than on the conventional airfoil. However, at the point of stall, the transition point moves more rapidly forward.

2.4 NACA airfoil numbering system

Many times you will see airfoils described as NACA xxxx or NACA xxxxx or NACA xx_y-xxx series. From the book *Airplane Aerodynamics*, by Dommasch, Sherby and Connally, Pitman Press, 1967, the following definitions are given to this nomenclature.

The NACA 4-digit airfoils mean the following: The first digit expresses the camber in percent chord, the second digit gives the location of the maximum camber point in tenths of chord, and the last two digits give the thickness in percent chord. Thus 4412 has a maximum camber of 4% of chord located at 40% chord back from the leading edge and is 12% thick, while 0006 is a symmetrical section of 6% thickness.

The NACA 5 digit series airfoil means the following: The first digit designates the approximate camber in percent chord, the second digit indicates twice the position of the maximum camber in tenths chord, the third (either 0 or 1) distinguishes the type of mean-camber line, and the last two digits give the thickness in percent chord. Thus, the 23012 airfoil has a maximum camber of about 2% of the chord located at 15% of the chord from the leading edge (3 tenths divided by 2) and is 12% thick.

The NACA six, seven and even eight series were designed to highlight some aerodynamic characteristic. For example, NACA 65_3-421 is a 6-series airfoil for which the minimum pressure's position in tenths chord is indicated by the second digit (here, at the 50% chord location), the subscript 3 means that the drag coefficient is near its minimum value over a range of lift coefficients of 0.3 above and below the design lift coefficient, the next digit indicates the lift coefficient in tenths (here, 0.4) and the last two digits give the maximum thickness in percent chord (here, 21% of chord). The description for this example comes from *Foundations of Aerodynamics*, Kuethe and Schetzer, 2nd Edition, 1959, John Wiley and Sons, New York.

There are formulas that define all the stations of the airfoil section from these digits and you can probably find those in your library in any good aerodynamics book. Also, you are referred to two other references listed below for more information on these classifications. HOWEVER, in all cases, the last two digits of the classification gives the thickness in percent chord.

Summary of Airfoil Data, NACA Report 824, 1945, by Abbott, von Doenhoff and Stivers. It was originally issued as ACR L5C05.

Theory of Wing Sections, Including a Summary of Airfoil Data, by Abbott and von Doenhoff, Mc-Graw Hill, New York, 1949, in which families of airfoils constructed according to a certain plan were tested and their characteristics recorded.

3 WING STRUCTURE

The wings of an aircraft are designed to lift it into the air. Their particular design for any given aircraft depends on a number of factors, such as size, weight, use of the aircraft, desired speed in flight and at landing, and desired rate of climb. The wings of aircraft are designated left and right, corresponding to the left and right sides of the operator when seated in the cockpit (Figure 3.1). Often wings are of full cantilever design. This means they are built so that no external bracing is needed. They are supported internally by structural members assisted by the skin of the aircraft. Other aircraft wings use external struts or wires to assist in supporting the wing and carrying the aerodynamic and landing loads. Wing support cables and struts are generally made from steel. Many struts and their attach fittings have fairings to reduce drag. Short, nearly vertical supports called jury struts are found on struts that attach to the wings a great distance from the fuselage. This serves to subdue strut movement and oscillation caused by the air flowing around the strut in flight. Figure 3.2 shows samples of wings using external bracing, also known as semi cantilever wings. Cantilever wings built with no external bracing are also shown.

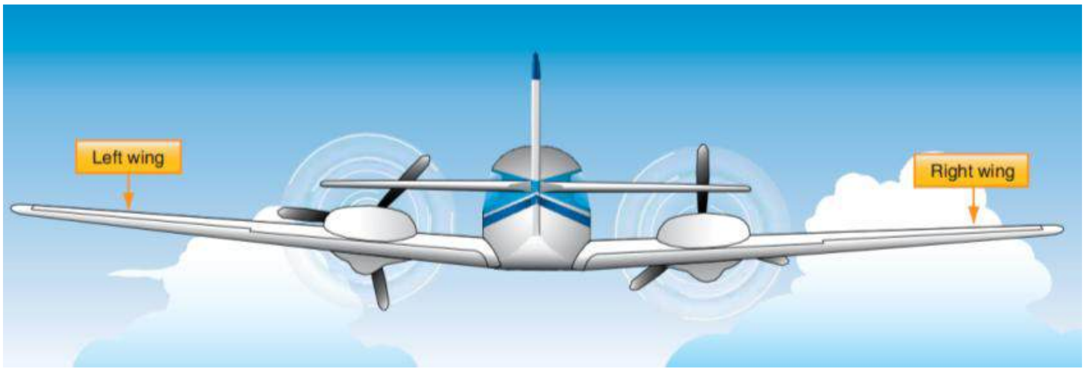


Figure 3.1 – “Left” and “right” on an aircraft are oriented to the perspective of a pilot sitting in the cockpit

Aluminum is the most common material from which to construct wings, but they can be wood covered with fabric, and occasionally a magnesium alloy has been used. Moreover, modern aircraft are tending toward lighter and stronger materials throughout the airframe and in wing construction. Wings made entirely of carbon fiber or other composite materials exist, as well as wings made of a combination of materials for maximum strength to weight performance.

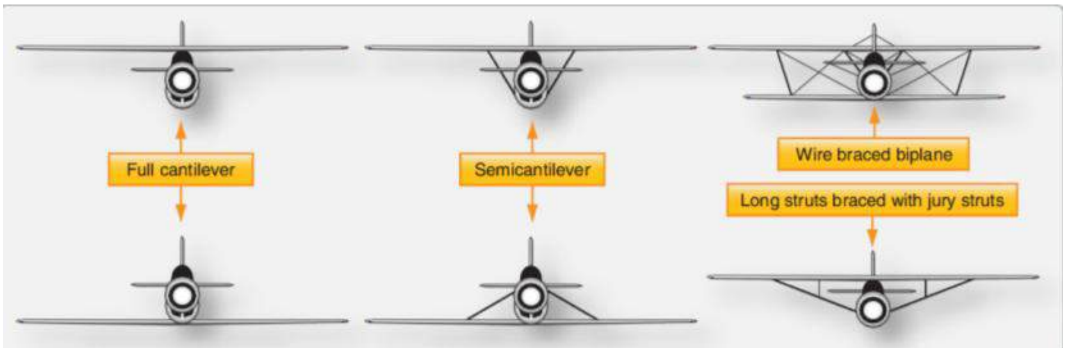


Figure 3.2 – Externally braced wings, also called semi cantilever wings, have wires or struts to support the wing. Full cantilever wings have no external bracing and are supported internally

The internal structures of most wings are made up of spars and stringers running spanwise and ribs and formers or bulkheads running chord wise (leading edge to trailing edge). The spars are the principle structural members of a wing. They support all distributed loads, as well as concentrated weights such as the fuselage, landing gear, and engines. The skin, which is attached to the wing structure, carries part of the loads imposed during flight. It also transfers the stresses to the wing ribs. The ribs, in turn, transfer the loads to the wing spars. In general, wing construction is based on one of three fundamental designs:

1. Monospar
2. Multispar
3. Box beam

Modification of these basic designs may be adopted by various manufacturers. The monospar wing incorporates only one main spanwise or longitudinal member in its construction. Ribs or bulkheads supply the necessary contour or shape to the airfoil. Although the strict monospar wing is not common, this type of design modified by the addition of false spars or light shear webs along the trailing edge for support of control surfaces is sometimes used.

The multispar wing incorporates more than one main longitudinal member in its construction. To give the wing contour, ribs or bulkheads are often included. The box beam type of wing construction uses two main longitudinal members with connecting bulkheads to furnish additional strength and to give contour to the wing (Figure 3.3). A corrugated sheet may be placed between the bulkheads and the smooth outer skin so that the wing can better carry tension and compression loads. In some cases, heavy longitudinal stiffeners are substituted for the corrugated sheets. A combination of corrugated sheets on the upper surface of the wing and stiffeners on the lower surface is sometimes used. Air transport category aircraft often utilize box beam wing construction.

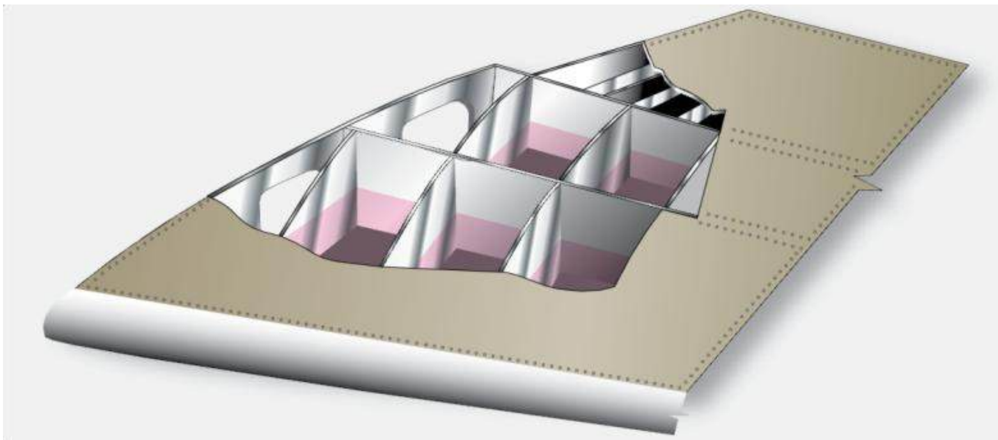


Figure 3.3 – Box beam construction

3.1 Wing Spars

Spars are the principal structural members of the wing. They correspond to the longerons of the fuselage. They run parallel to the lateral axis of the aircraft, from the fuselage toward the tip of the wing, and are usually attached to the fuselage by wing fittings, plain beams, or a truss. Spars may be made of metal, wood, or composite materials depending on the design criteria of a specific aircraft. Wooden spars are usually made from spruce. They can be generally classified into four different types by their cross sectional configuration.

As shown in Figure 3.4, they may be (*A*) solid, (*B*) box shaped, (*C*) partly hollow, or (*D*) in the form of an I-beam. Lamination of solid wood spars is often used to increase strength. Laminated wood can also be found in box shaped spars. The spar in Figure 3.4 *E* has had material removed to reduce weight but retains the strength of a rectangular spar. As can be seen, most wing spars are basically rectangular in shape with the long dimension of the cross-section oriented up and down in the wing.

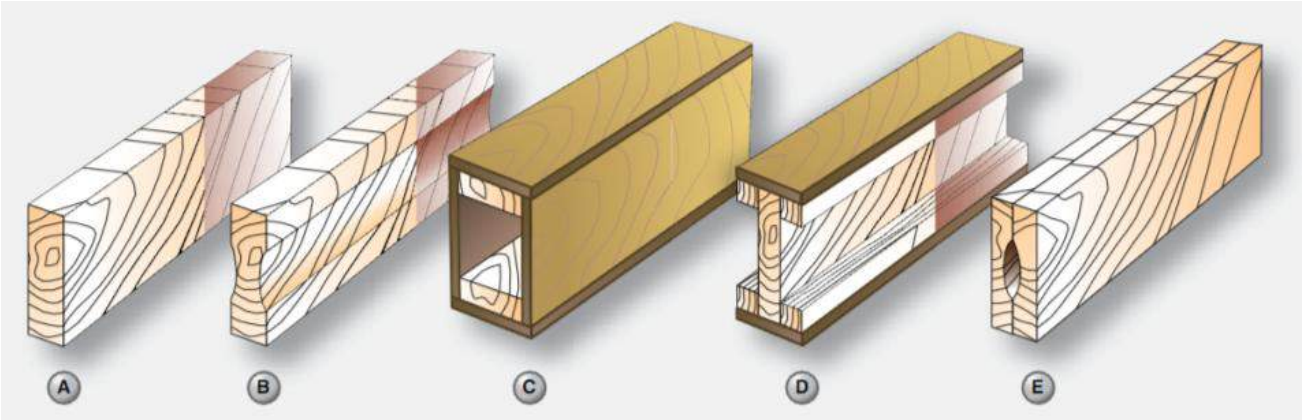


Figure 3.4 – Typical wooden wing spar cross-sections

Currently, most manufactured aircraft have wing spars made of solid extruded aluminum or aluminum extrusions riveted together to form the spar. The increased use of composites and the combining of materials should make airmen vigilant for wings spars made from a variety of materials. Figure 3.5 shows examples of metal wing spar cross-sections. In an I–beam spar, the top and bottom of the I–beam are called the caps and the vertical section is called the web.

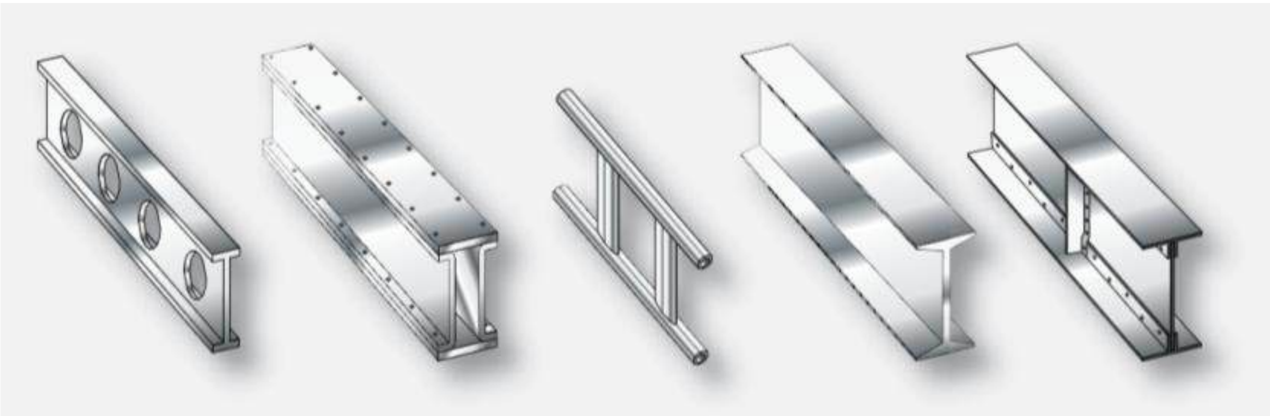


Figure 3.5 – Examples of metal wing spar shapes

The entire spar can be extruded from one piece of metal but often it is built up from multiple extrusions or formed angles. The web forms the principal depth portion of the spar and the cap strips (extrusions, formed angles, or milled sections) are attached to it. Together, these members carry the loads caused by wing bending, with the caps providing a foundation for attaching the skin. Although the spar shapes in Figure 3.5 are typical, actual wing spar configurations assume many forms. For example, the web of a spar may be a plate or a truss as shown in Figure 3.6. It could be built up from lightweight materials with vertical stiffeners employed for strength (Figure 3.7).

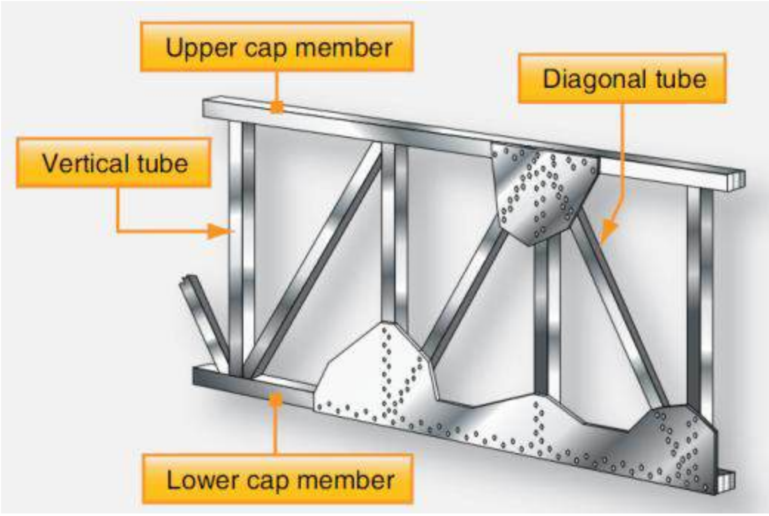


Figure 3.6 – A truss wing spar

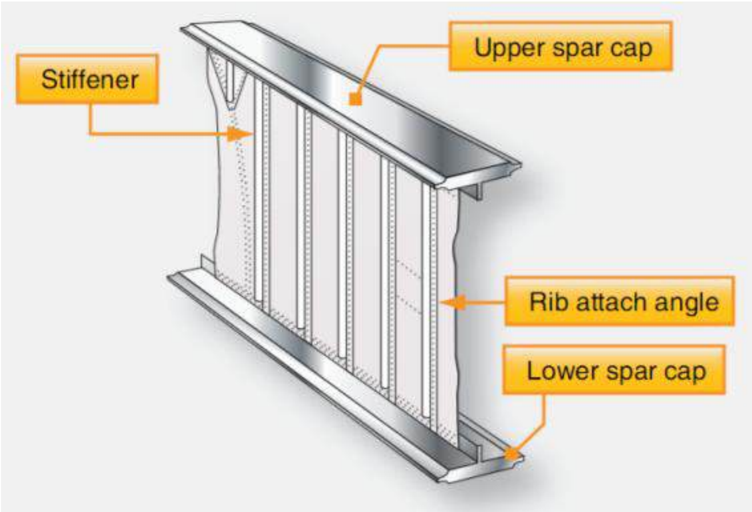


Figure 3.7 – A plate web wing spar with vertical stiffeners

It could also have no stiffeners but might contain flanged holes for reducing weight but maintaining strength. Some metal and composite wing spars retain the I-beam concept but use a sine wave web (Figure 3.8).

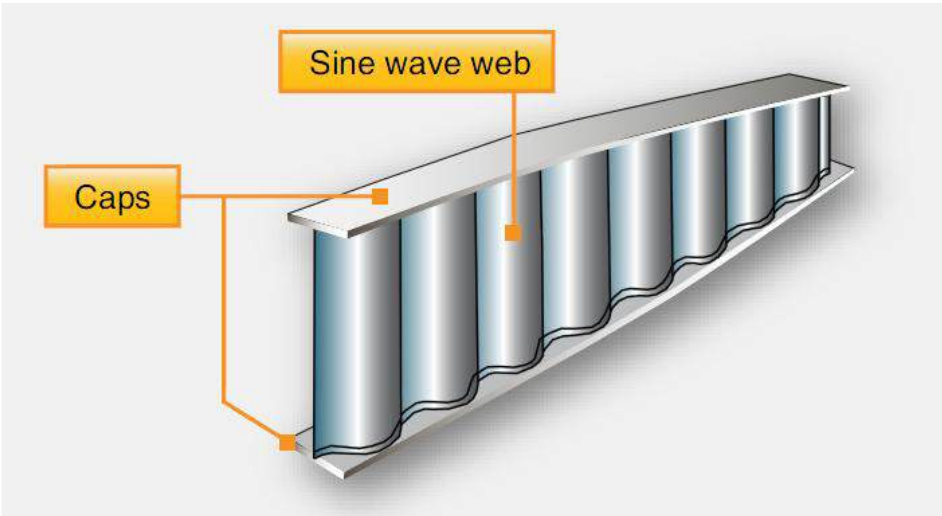


Figure 3.8 – A sine wave wing spar can be made from aluminum or composite materials

Additionally, fail-safe spar web design exists. Fail-safe means that should one member of a complex structure fail, some other part of the structure assumes the load of the failed member and permits continued operation. A spar with failsafe construction is shown in Figure 3.9.

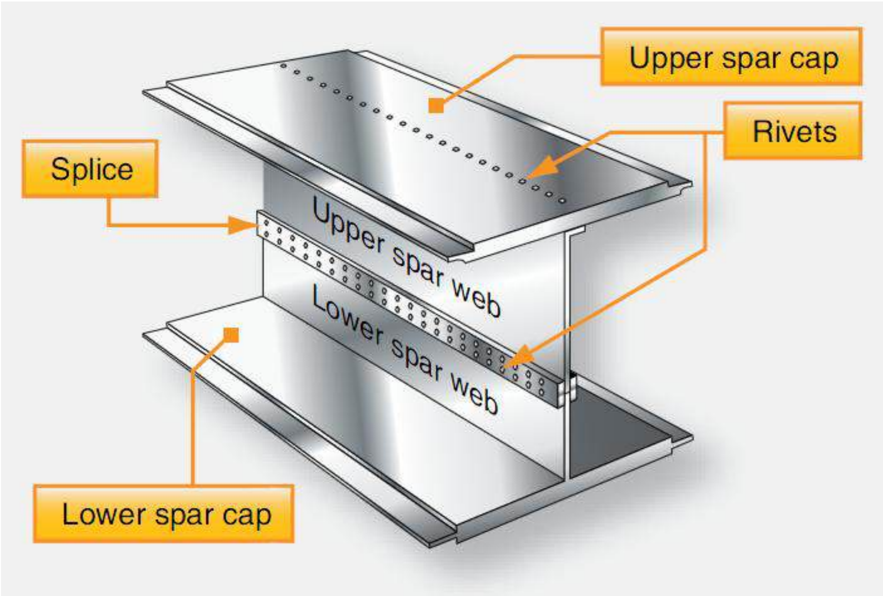


Figure 3.9 – A fail-safe spar with a riveted spar web

This spar is made in two sections. The top section consists of a cap riveted to the upper web plate. The lower section is a single extrusion consisting of the lower cap and web plate. These two sections are spliced together to form the spar. If either section of this type of spar breaks, the other section can still carry the load. This is the fail-safe feature. As a rule, a wing has two spars. One spar is usually located near the front of the wing, and the other about two-thirds of the distance toward the wing's trailing edge. Regardless of type, the spar is the most important part of the wing. When other structural members of the wing are placed under load, most of the resulting stress is passed on to the wing spar. False spars are commonly used in wing design. They are longitudinal members like spars but do not extend the entire spanwise length of the wing. Often, they are used as hinge attach points for control surfaces, such as an aileron spar.

3.2 Wing Ribs

Ribs are the structural crosspieces that combine with spars and stringers to make up the framework of the wing. They usually extend from the wing leading edge to the rear spar or to the trailing edge of the wing. The ribs give the wing its cambered shape and transmit the load from the skin and stringers to the spars. Similar ribs are also used in ailerons, elevators, rudders, and stabilizers. Wing ribs are usually manufactured from either wood or metal. Aircraft with wood wing spars may have wood or metal ribs while most aircraft with metal spars have metal ribs. Wood ribs are usually manufactured from spruce. The three most common types of wooden ribs are the plywood web, the lightened plywood web, and the truss types. Of these three, the truss type is the most efficient because it is strong and lightweight, but it is also the most complex to construct. Figure 3.10 shows wood truss web ribs and a lightened plywood web rib. Wood ribs have a rib cap or cap strip fastened around the entire perimeter of the rib. It is usually made of the same material as the rib itself. The rib cap stiffens and strengthens the rib and provides an attaching surface for the wing covering. In Figure 3.10 *A,* the cross-section of a wing rib with a truss-type web is illustrated.

The dark rectangular sections are the front and rear wing spars. Note that to reinforce the truss, gussets are used. In Figure 3.10 *B,* a truss web rib is shown with a continuous gusset. It provides greater support throughout the entire rib with very little additional weight. A continuous gusset stiffens the cap strip in the plane of the rib. This aids in preventing buckling and helps to obtain better rib/skin joints where nail-gluing is used. Such a rib can resist the driving force of nails better than the other types.

Continuous gussets are also more easily handled than the many small separate gussets otherwise required. Figure 3.10 *C* shows a rib with a lighten plywood web. It also contains gussets to support the web/cap strip interface. The cap strip is usually laminated to the web, especially at the leading edge. A wing rib may also be referred to as a plain rib or a main rib. Wing ribs with specialized locations or functions are given names that reflect their uniqueness.

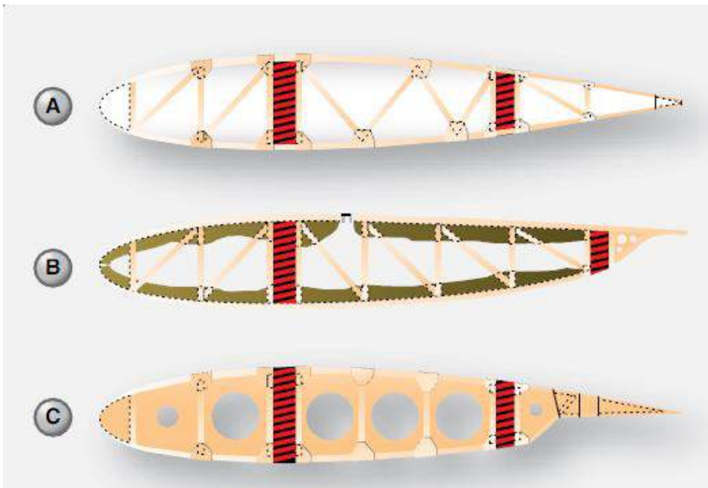


Figure 3.10 – Examples of wing ribs constructed of wood

For example, ribs that are located entirely forward of the front spar that are used to shape and strengthen the wing leading edge are called nose ribs or false ribs. False ribs are ribs that do not span the entire wing chord, which is the distance from the leading edge to the trailing edge of the wing. Wing butt ribs may be found at the inboard edge of the wing where the wing attaches to the fuselage. Depending on its location and method of attachment, a butt rib may also be called a bulkhead rib or a compression rib if it is designed to receive compression loads that tend to force the wing spars together. Since the ribs are laterally weak, they are strengthened in some wings by tapes that are woven above and below rib sections to prevent sidewise bending of the ribs. Drag and anti-drag wires may also be found in a wing. In Figure 3.11, they are shown crisscrossed between the spars to form a truss to resist forces acting on the wing in the direction of the wing chord. These tension wires are also referred to as tie rods. The wire designed to resist the backward forces is called a drag wire; the anti-drag wire resists the forward forces in the chord direction. Figure 3.11 illustrates the structural components of a basic wood wing. At the inboard end of the wing spars is some form of wing attach fitting as illustrated in Figure 3.11. These provide a strong and secure method for attaching the wing to the fuselage. The interface between the wing and fuselage is often covered with a fairing to achieve smooth airflow in this area. The fairing(s) can be removed for accesses to the wing attach fittings (Figure 3.12).

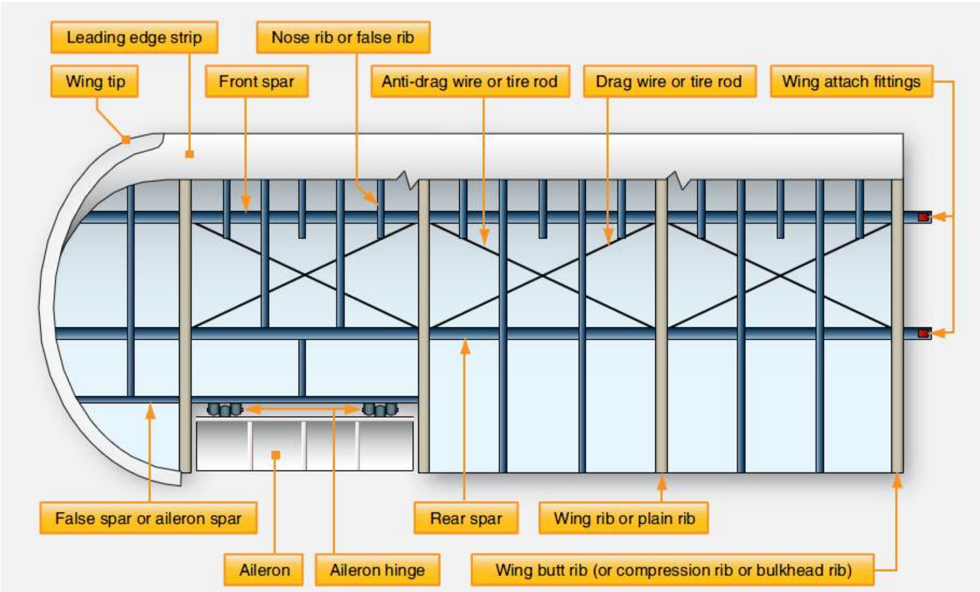


Figure 3.10 – Basic wood wing structure and components

Figure 3.11 – Wing root fairings smooth airflow and hide wing attach fittings

The wing tip is often a removable unit, bolted to the outboard end of the wing panel. One reason for this is the vulnerability of the wing tips to damage, especially during ground handling and taxiing. Figure 3.12 shows a removable wing tip for a large aircraft wing. Others are different. The wing tip assembly is of aluminum alloy construction. The wing tip cap is secured to the tip with countersunk screws and is secured to the interspar structure at four points with ¼-inch diameter bolts. To prevent ice from forming on the leading edge of the wings of large aircraft, hot air from an engine is often channeled through the leading edge from wing root to wing tip. A louver on the top surface of the wingtip allows this warm air to be exhausted overboard. Wing position lights are located at the center of the tip and are not directly visible from the cockpit. As an indication that the wing tip light is operating, some wing tips are equipped with a Lucite rod to transmit the light to the leading edge.

3.3 Wing Skin

Often, the skin on a wing is designed to carry part of the flight and ground loads in combination with the spars and ribs. This is known as a stressed-skin design. The all-metal, full cantilever wing section illustrated in Figure 3.13 shows the structure of one such design. The lack of extra internal or external bracing requires that the skin share some of the load. Notice the skin is stiffened to aid with this function.

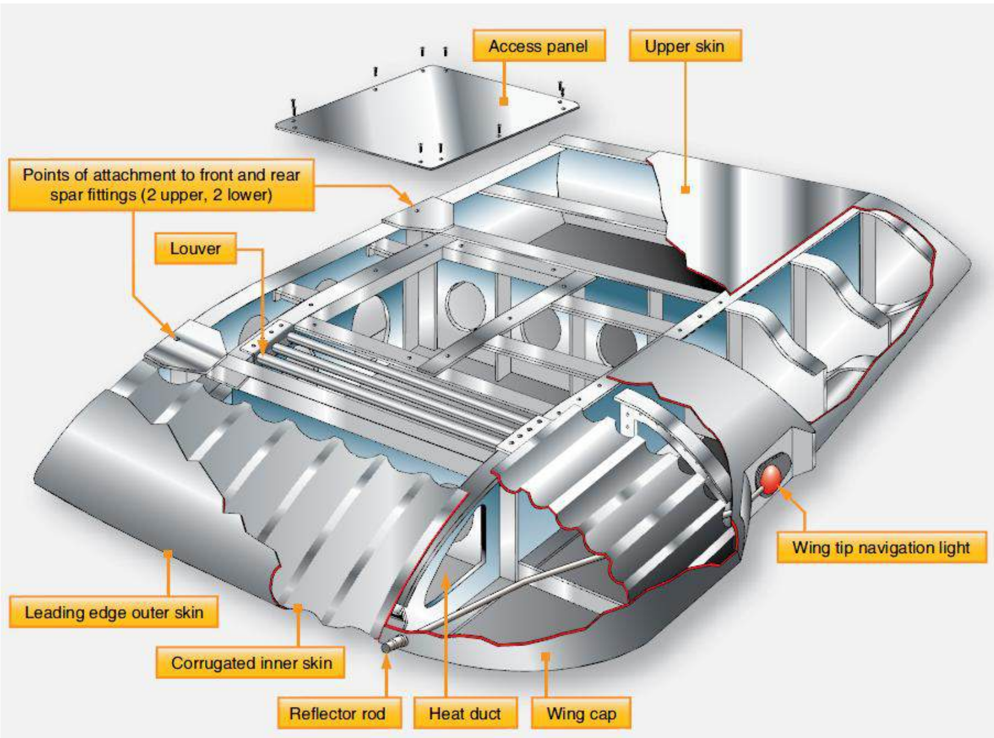


Figure 3.12 – A removable metal wing tip

Fuel is often carried inside the wings of a stressed-skin aircraft. The joints in the wing can be sealed with a special fuel resistant sealant enabling fuel to be stored directly inside the structure. This is known as wet wing design. Alternately, a fuel-carrying bladder or tank can be fitted inside a wing. Figure 3.14 shows a wing section with a box beam structural design such as one that might be found in a transport category aircraft. This structure increases strength while reducing weight. Proper sealing of the structure allows fuel to be stored in the box sections of the wing. The wing skin on an aircraft may be made from a wide variety of materials such as fabric, wood, or aluminum. But a single thin sheet of material is not always employed. Chemically milled aluminum skin can provide skin of varied thicknesses.

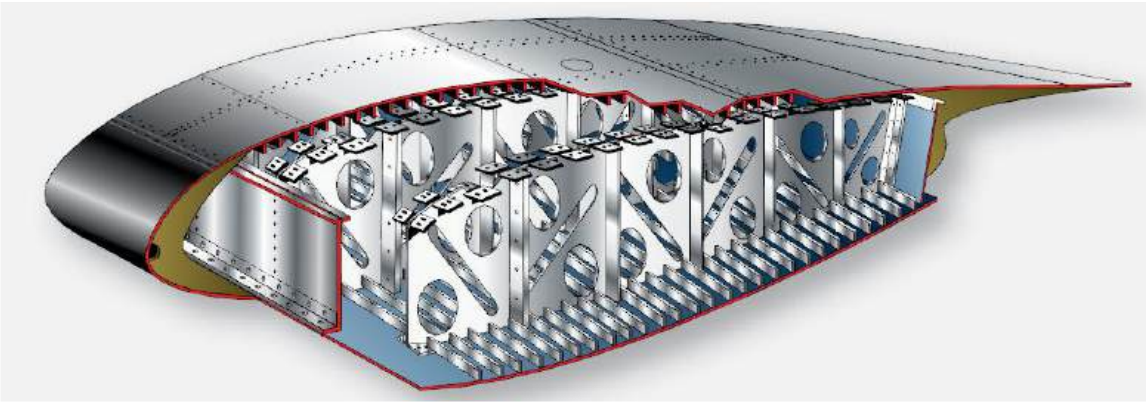


Figure 3.13 – The skin is an integral load carrying part of a stressed skin design

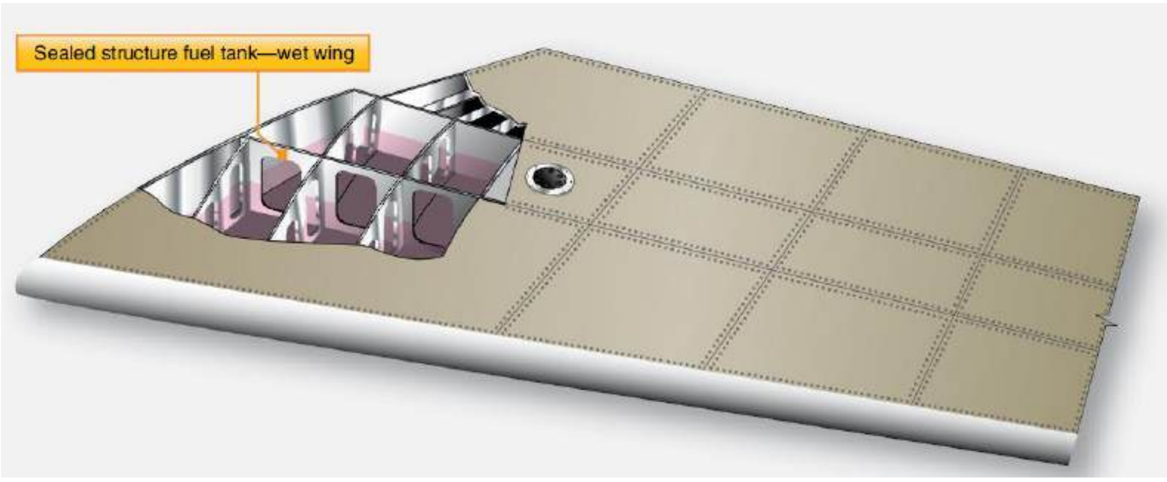


Figure 3.14 – Fuel is often carried in the wings

On aircraft with stressed-skin wing design, honeycomb structured wing panels are often used as skin. A honeycomb structure is built up from a core material resembling a bee hive’s honeycomb which is laminated or sandwiched between thin outer skin sheets. Figure 3.15 illustrates honeycomb panes and their components. Panels formed like this are lightweight and very strong. They have a variety of uses on the aircraft, such as floor panels, bulkheads, and control surfaces, as well as wing skin panels.

Figure 3.16 shows the locations of honeycomb construction wing panels on a jet transport aircraft. A honeycomb panel can be made from a wide variety of materials. Aluminum core honeycomb with an outer skin of aluminum is common. But honeycomb in which the core is an Arimid® fiber and the outer sheets are coated Phenolic® is common as well. In fact, a myriad of other material combinations such as those using fiberglass, plastic, Nomex®, Kevlar®, and carbon fiber all exist. Each honeycomb structure possesses unique characteristics depending upon the materials, dimensions, and manufacturing techniques employed. Figure 3.17 shows an entire wing leading edge formed from honeycomb structure.

3.4 Nacelles

Nacelles (sometimes called “pods”) are streamlined enclosures used primarily to house the engine and its components. They usually present a round or elliptical profile to the wind thus reducing aerodynamic drag. On most single-engine aircraft, the engine and nacelle are at the forward end of the fuselage. On multiengine aircraft, engine nacelles are built into the wings or attached to the fuselage at the empennage (tail section). Occasionally, a multiengine aircraft is designed with a nacelle in line with the fuselage aft of the passenger compartment. Regardless of its location, a nacelle contains the engine and accessories, engine mounts, structural members, a firewall, and skin and cowling on the exterior to fare the nacelle to the wind. Some aircraft have nacelles that are designed to house the landing gear when retracted. Retracting the gear to reduce wind resistance is standard procedure on high-performance/ high-speed aircraft. The wheel well is the area where the landing gear is attached and stowed when retracted. Wheel wells can be located in the wings and/or fuselage when not part of the nacelle. *Figure 3.18* shows an engine nacelle incorporating the landing gear with the wheel well extending into the wing root.

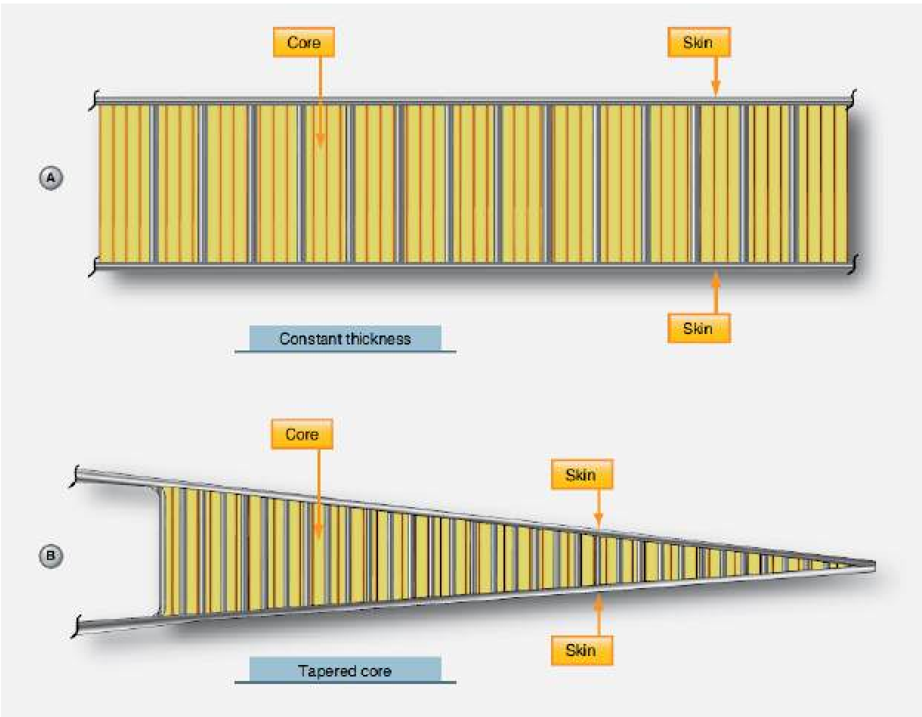


Figure 3.15 – The honeycomb panel is a staple in aircraft construction. Cores can be either constant thickness (A) or tapered (B). Tapered core honeycomb panels are frequently used as flight control surfaces and wing trailing edges

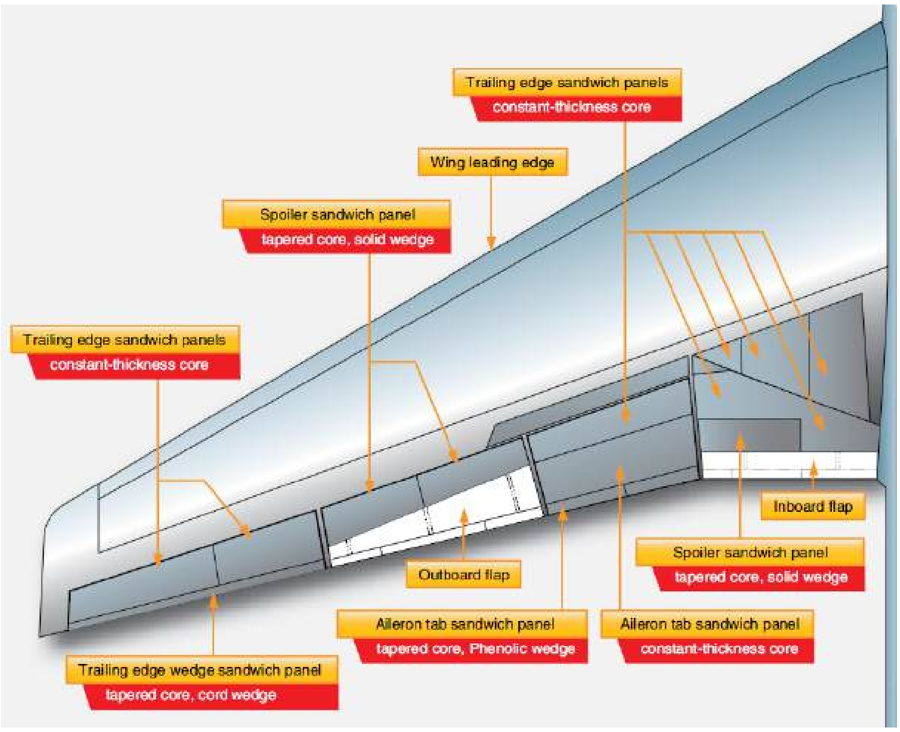


Figure 3.16 – Honeycomb wing construction on a large jet transport aircraft

The framework of a nacelle usually consists of structural members similar to those of the fuselage. Lengthwise members, such as longerons and stringers, combine with horizontal/vertical members, such as rings, formers, and bulkheads, to give the nacelle its shape and structural integrity. A firewall is incorporated to isolate the engine compartment from the rest of the aircraft. This is basically a stainless steel or titanium bulkhead that contains a fire in the confines of the nacelle rather than letting it spread throughout the airframe (Figure 3.19).

Engine mounts are also found in the nacelle. These are the structural assemblies to which the engine is fastened. They are usually constructed from chrome/molybdenum steel tubing in light aircraft and forged chrome/nickel/ molybdenum assemblies in larger aircraft (Figure 3.20).

The exterior of a nacelle is covered with a skin or fitted with a cowling which can be opened to access the engine and components inside. Both are usually made of sheet aluminum or magnesium alloy with stainless steel or titanium alloys being used in high-temperature areas, such as around the exhaust exit. Regardless of the material used, the skin is typically attached to the framework with rivets. Cowling refers to the detachable panels covering those areas into which access must be gained regularly, such as the engine and its accessories. It is designed to provide a smooth airflow over the nacelle and to protect the engine from damage. Cowl panels are generally made of aluminum alloy construction. However, stainless steel is often used as the inner skin aft of the power section and for cowl flaps and near cowl flap openings. It is also used for oil cooler ducts. Cowl flaps are moveable parts of the nacelle cowling that open and close to regulate engine temperature.

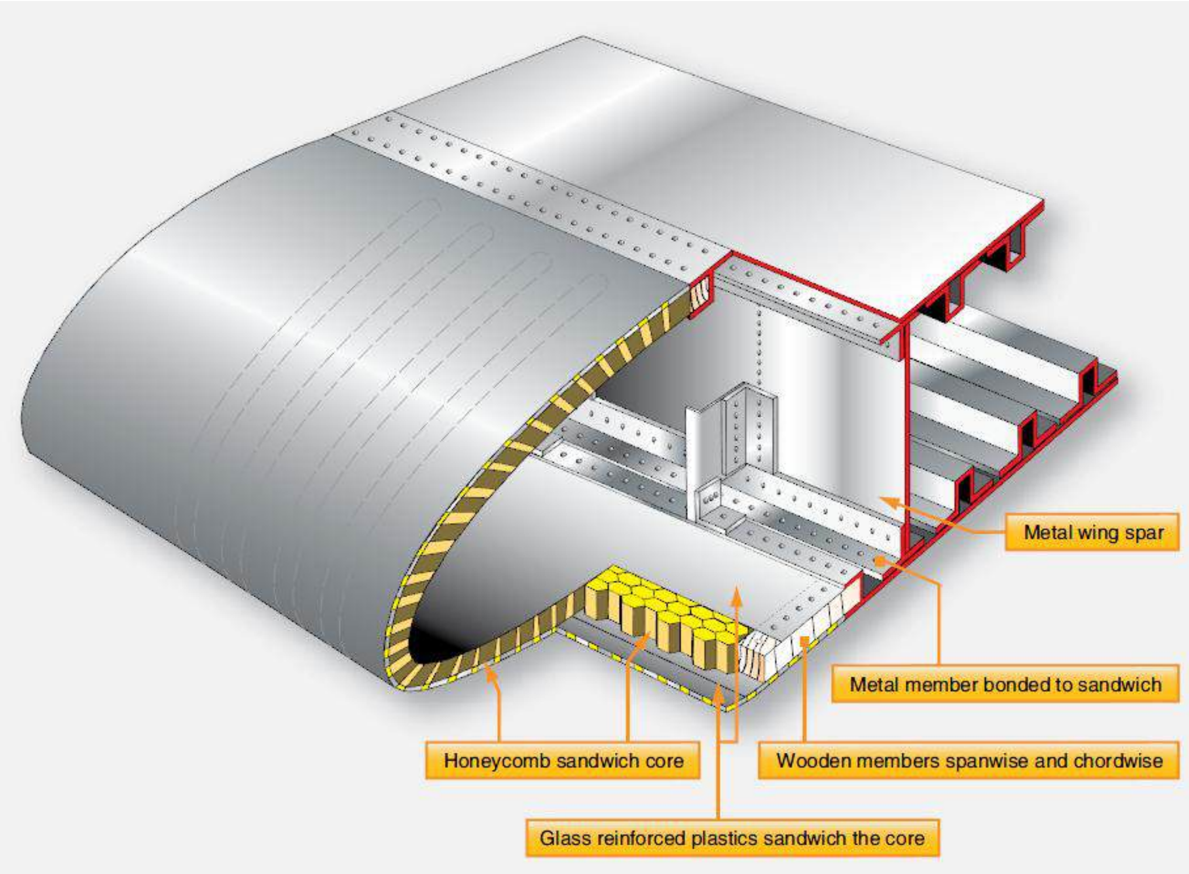


Figure 3.17 –A wing leading edge formed from honeycomb material bonded to the aluminum spar structure

Figure 3.18 – Wheel wells in a wing engine nacelle with gear coming down (inset)

Figure 3.19 – An engine nacelle firewall

Figure 3.20 – Various aircraft engine mounts

3.5 Flight Control Surfaces

The directional control of a fixed-wing aircraft takes place around the lateral, longitudinal, and vertical axes by means of flight control surfaces designed to create movement about these axes. These control devices are hinged or movable surfaces through which the attitude of an aircraft is controlled during takeoff, flight, and landing. They are usually divided into two major groups: 1 – primary or main flight control surfaces and 2 – secondary or auxiliary control surfaces.

3.6 Free-flying aircraft controls

Gliders and aeroplanes have more complex control systems, especially if they are piloted.

The main controls allow the pilot to direct the aircraft in the air. Typically these are:

- The *yoke* or *joystick* controls rotation of the plane about the pitch and roll axes. A yoke resembles a steering wheel, and a control stick is a joystick. The pilot can pitch the plane down by pushing on the yoke or stick, and pitch the plane up by pulling on it. Rolling the plane is accomplished by turning the yoke in the direction of the desired roll, or by tilting the control stick in that direction.
- *Rudder pedals* control rotation of the plane about the yaw axis. There are two pedals that pivot so that when one is pressed forward the other moves backward, and vice versa. The pilot presses on the right rudder pedal to make the plane yaw to the right, and pushes on the left pedal to make it yaw to the left. The rudder is used mainly to balance the plane in turns, or to compensate for winds or other effects that tend to turn the plane about the yaw axis.

- On powered types, an engine stop control ("fuel cutoff", for example) and, usually, a *Throttle* or *thrust lever* and other controls, such as a fuel-mixture control (to compensate for air density changes with altitude change).

Other common controls include:

- *Flap levers,* which are used to control the deflection position of flaps on the wings.
- *Spoiler levers,* which are used to control the position of spoilers on the wings, and to arm their automatic deployment in planes designed to deploy them upon landing. The spoilers reduce lift for landing.
- *Trim controls,* which usually take the form of knobs or wheels and are used to adjust pitch, roll, or yaw trim. These are often connected to small airfoils on the trail edge of the control surfaces called 'trim tabs'. Trim is used to reduce the amount of pressure on the control forces needed to maintain a steady course.
- On wheeled types, *Brakes* are used to slow and stop the plane on the ground, and sometimes for turns on the ground.

A craft may have two pilots' seats with dual controls, allowing two pilots to take turns. This is often used for training or for longer flights.

The control system may allow full or partial automation of flight, such as an autopilot, a wing leveler, or a flight management system. An unmanned aircraft has no pilot but is controlled remotely or via means such as gyroscopes or other forms of autonomous control.

3.7 Cockpit instrumentation

On manned types, instruments provide information to the pilots, including flight, engines, navigation, communications and other aircraft systems that may be installed.

The six basic instruments (sometimes referred to as the six pack) include:

- An *airspeed indicator,* which indicates the speed at which the plane is moving through the surrounding air.
- An *altimeter,* which indicates the altitude or height of the plane above mean sea level.
- A *heading indicator,* (sometimes referred to as a "directional gyro (DG)"), which indicates the magnetic compass heading that the plane's fuselage is pointing towards. The actual direction the plane is flying towards is affected by the wind conditions.
- An *attitude indicator,* sometimes called an *artificial horizon,* which indicates the exact orientation of the plane about its pitch and roll axes.
- A *vertical speed indicator,* which shows the rate at which the plane is climbing or descending.
- A *turn coordinator,* or *turn and bank indicator* which helps the pilot maintain the plane in a coordinated attitude while turning.

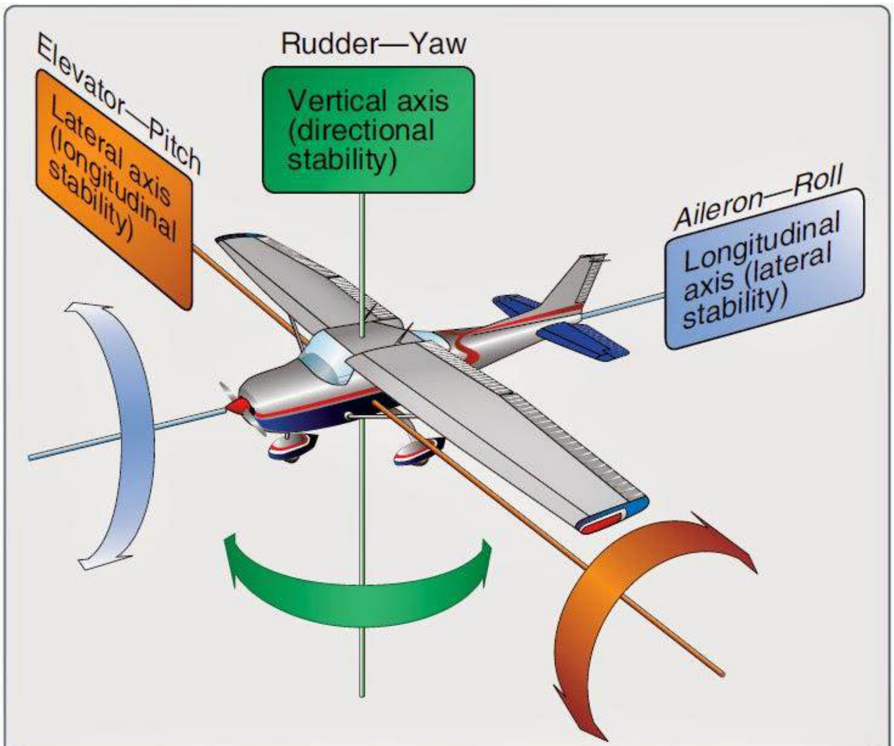
Other instruments might include:

- A *two-way radio* to enable communications with other planes and air traffic control. Planes built before World War II may not have been equipped with a radio but they are nearly essential now.
- A *horizontal situation indicator,* shows the position and movement of the plane as seen from above with respect to the ground, including course/heading and other information.
- Instruments showing the status of each engine in the plane (operating speed, thrust, temperature, RPM, and other variables).
- Combined display systems such as *primary flight displays* or *navigation displays.*
- Information displays such as on-board *weather radar* displays.
- A *radio direction finder* which indicates the direction to one or more radio beacons and which can be used to determine the plane's position.

A *satellite navigation* system to provide an accurate position.

3.8 Primary Flight Control Surfaces

The primary flight control surfaces on a fixed-wing aircraft include: ailerons, elevators, and the rudder. The ailerons are attached to the trailing edge of both wings and when moved, rotate the aircraft around the longitudinal axis. The elevator is attached to the trailing edge of the horizontal stabilizer. When it is moved, it alters aircraft pitch, which is the attitude about the horizontal or lateral axis. The rudder is hinged to the trailing edge of the vertical stabilizer. When the rudder changes position, the aircraft rotates about the vertical axis (yaw). Figure 3.21 shows the primary flight controls of a light aircraft and the movement they create relative to the three axes of flight. Primary control surfaces are usually similar in construction to one another and vary only in size, shape, and methods of attachment. On aluminum light aircraft, their structure is often similar to an all-metal wing. This is appropriate because the primary control surfaces are simply smaller aerodynamic devices. They are typically made from an aluminum alloy structure built around a single spar member or torque tube to which ribs are fitted and a skin is attached. The lightweight ribs are, in many cases, stamped out from flat aluminum sheet stock. Holes in the ribs lighten the assembly. An aluminum skin is attached with rivets. Figure 3.22 illustrates this type of structure, which can be found on the primary control surfaces of light aircraft as well as on medium and heavy aircraft.



Primary Control Surface	Airplane Movement	Axes of Rotation	Type of Stability
Aileron	Roll	Longitudinal	Lateral
Elevator/ Stabilator	Pitch	Lateral	Longitudinal
Rudder	Yaw	Vertical	Directional

Figure 3.21 – Flight control surfaces move the aircraft around the three axes of flight

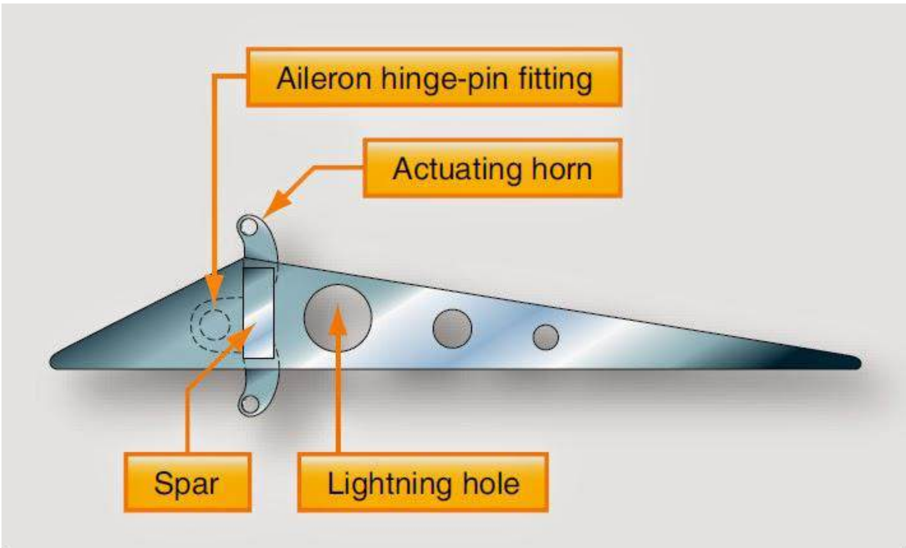


Figure 3.22 – Typical structure of an aluminum flight control surface

4 FUSELAGE

A *fuselage* is a long, thin body, usually with tapered or rounded ends to make its shape aerodynamically smooth. The fuselage may contain the flight crew, passengers, cargo or payload, fuel and engines. The pilots of manned aircraft operate them from a *cockpit* located at the front or top of the fuselage and equipped with controls and usually windows and instruments. A plane may have more than one fuselage, or it may be fitted with booms with the tail located between the booms to allow the extreme rear of the fuselage to be useful for a variety of purposes.

4.1 Flying wing

The US-produced B-2 Spirit (Figure 4.1), a strategic bomber using a flying wing configuration which is capable of intercontinental missions

A flying wing is a tailless aircraft which has no definite fuselage, with most of the crew, payload and equipment being housed inside the main wing structure.

Figure 4.1 – B-2 Spirit (the Stealth Bomber) it is a flying wing design with a crew of two

The flying wing configuration was studied extensively in the 1930s and 1940s, notably by Jack Northrop and Cheston L. Eshelman in the United States, and Alexander Lippisch and the Horten brothers in Germany. After the war, a number of experimental designs were based on the flying wing concept. Some general interest continued until the early 1950s but designs did not necessarily offer a great advantage in range and presented a number of technical problems, leading to the adoption of "conventional" solutions like the Convair B-36 and the B-52 Stratofortress. Due to the practical need for a deep wing, the flying wing concept is most practical for designs in the slow-to-medium speed range, and there has been continual interest in using it as a tactical airlifter design.

Interest in flying wings was renewed in the 1980s due to their potentially low radar reflection cross-sections. Stealth technology relies on shapes which only reflect radar waves in certain directions, thus making the aircraft hard to detect unless the radar receiver is at a specific position relative to the aircraft -

a position that changes continuously as the aircraft moves. This approach eventually led to the Northrop B-2 Spirit stealth bomber. In this case the aerodynamic advantages of the flying wing are not the primary needs. However, modern computer-controlled fly-by-wire systems allowed for many of the aerodynamic drawbacks of the flying wing to be minimised, making for an efficient and stable long-range bomber.

4.2 Blended wing body

Blended wing body aircraft have a flattened and airfoil shaped body, which produces most of the lift to keep itself aloft, and distinct and separate wing structures, though the wings are smoothly blended in with the body (Figure 4.2).

Figure 4.2 – Project: X-48B Blended Wing Body

Thus blended wing bodied aircraft incorporate design features from both a futuristic fuselage and flying wing design. The purported advantages of the blended wing body approach are efficient high-lift wings and a wide airfoil-shaped body. This enables the entire craft to contribute to lift generation with the result of potentially increased fuel economy.

4.3 Lifting body

A lifting body is a configuration in which the body itself produces lift (Figure 4.3). In contrast to a flying wing, which is a wing with minimal or no conventional fuselage, a lifting body can be thought of as a fuselage with little or no conventional wing. Whereas a flying wing seeks to maximize cruise efficiency at subsonic speeds by eliminating non-lifting surfaces, lifting bodies generally minimize the drag and structure of a wing for subsonic, supersonic, and hypersonic flight, or, spacecraft re-entry. All of these flight regimes pose challenges for proper flight stability.

Figure 4.3 – X-24A, M2-F3 and HL-10 lifting bodies

Lifting bodies were a major area of research in the 1960s and 1970s as a means to build a small and lightweight manned spacecraft. The US built a number of famous lifting body rocket planes to test the concept, as well as several rocket-launched re-entry vehicles that were tested over the Pacific. Interest waned as the US Air Force lost interest in the manned mission, and major development ended during the Space Shuttle design process when it became clear that the highly shaped fuselages made it difficult to fit fuel tankage.

4.4 Empennage and fore plane

The classic aerofoil section wing is unstable in flight and difficult to control. Flexible-wing types often rely on an anchor line or the weight of a pilot hanging beneath to maintain the correct attitude. Some free-flying types use an adapted aerofoil that is stable, or other ingenious mechanisms including, most recently, electronic artificial stability.

But in order to achieve trim, stability and control, most fixed wing types have an empennage comprising a fin and rudder which act horizontally and a tailplane and elevator which act vertically. This is so common that it is known as the conventional layout. Sometimes there may be two or more fins, spaced out along the tailplane.

Some types have a horizontal "canard" (Figure 4.4) foreplane ahead of the main wing, instead of behind it. This foreplane may contribute to the trim, stability or control of the aircraft, or to several of these.

Figure 4.4 – A Saab 37 Viggen, the first modern canard aircraft to go into production

4.5 Design and manufacture

Most fixed-wing aircraft are constructed by companies with the objective of producing them in quantity for customers. The design and planning process, including safety tests, can last up to four years for small turboprops, and up to 12 years for airplanes with the capacity of the A380.

During this process, the objectives and design specifications of the aircraft are established. First the construction company uses drawings and equations, simulations, wind tunnel tests and experience to predict the behavior of the aircraft. Computers are used by companies to draw, plan and do initial simulations of the aircraft. Small models and mockups of all or certain parts of the plane are then tested in wind tunnels to verify its aerodynamics.

When the design has passed through these processes, the company constructs a limited number of prototypes for testing on the ground. Representatives from an aviation governing agency often make a first flight. The flight tests continue until the aircraft has fulfilled all the requirements. Then, the governing public agency of aviation of the country authorises the company to begin production.

In the United States, this agency is the Federal Aviation Administration (FAA), and in the European Union, Joint Aviation Authorities (JAA). In Canada, the public agency in charge and authorising the mass production of aircraft is Transport Canada.

In the case of international sales, a license from the public agency of aviation or transport of the country where the aircraft is to be used is also necessary. For example, aeroplanes made by Airbus need to be certified by the FAA to be flown in the United States and vice versa, airplanes made by Boeing need to be approved by the JAA to be flown in the European Union.

Quieter planes are becoming more and more needed due to the increase in air traffic, particularly over urban areas, as aircraft noise pollution is a major concern.

Small planes can be designed and constructed by amateurs as homebuilts. Other homebuilt aircraft can be assembled using pre-manufactured kits of parts that can be assembled into a basic plane and must then be completed by the builder.

There are few companies that produce planes on a large scale. However, the production of a plane for one company is a process that actually involves dozens, or even hundreds, of other companies and plants, that produce the parts that go into the plane. For example, one company can be responsible for the production of the landing gear, while another one is responsible for the radar. The production of such parts is not limited to the same city or country; in the case of large plane manufacturing companies, such parts can come from all over the world.

The parts are sent to the main plant of the plane company, where the production line is located. In the case of large planes, production lines dedicated to the assembly of certain parts of the plane can exist, especially the wings and the fuselage.

When complete, a plane is rigorously inspected to search for imperfections and defects. After approval by inspectors, the plane is put through a series of flight tests to assure that all systems are working correctly and that the plane handles properly. Upon passing these tests, the plane is ready to receive the "final touchups" (internal configuration, painting, etc.), and is then ready for the customer.

5 AIRCRAFT POWER PLANT

During the period between the World Wars, aircraft engines improved dramatically and made possible unprecedented progress in aircraft design. Engine development in those days and to a large extent even today, is a very laborious, detailed process of building an engine, running it to destruction, analysing what broke, designing a fix, and repeating the process. No product ever comes to market without some engineer(s) having spent many long, lonely, anxious hours perfecting that product. This is especially true of aircraft engines, which by their very nature push all the limits of ingenuity, materials, and manufacturing processes.

5.1 Aircraft Engine Requirements and Measures of Performance

In order to compare engines, we must discuss the special requirements of aircraft engines and introduce some measures of performance. The requirements are in some ways contradictory, and therein lies the engineering challenge.

The first and most important requirement for an aircraft engine is that it must be reliable. Secondly, aircraft engines must produce as much power as possible while weighing as little as possible. This is usually expressed in terms of pounds per horsepower (lb/hp). One way to make an engine more powerful is to make it bigger, but this also makes it heavier. Moreover, if you shave away metal to make it lighter, parts start to crack, break, and generally become less reliable. You can see the conflicting objectives faced by the engineer. Another option is to get more power from a given size. Engine size is usually expressed in cubic inches (cu in) of swept volume (the volume displaced by all the pistons going up and down). If you can make an engine get more horsepower per cubic inch (hp/in), then you have made it lighter.

5.2 Turboprop

A **turboprop** engine is a type of turbine engine which drives an aircraft propeller using a reduction gear. The gas turbine is designed specifically for this application, with almost all of its output being used to drive the propeller. The engine's exhaust gases do not contain enough energy, compared to a jet engine, to create significant thrust in the propulsion of the aircraft. The propeller is coupled to the turbine through a reduction gear that converts the high RPM, low torque output to low RPM, high torque. The propeller itself is normally a constant speed (variable pitch) type similar to that used with larger reciprocating aircraft engines.

Turboprop engines are generally used on small subsonic aircraft, but some aircraft outfitted with turboprops have cruising speeds in excess of 500 kt (926 km/h, 575 mph). Large military and civil aircraft, such as the Lockheed L-188 Electra and the Tupolev Tu-95, have also used turboprop power. The Airbus A400M is powered by four Europrop TP400 engines, which are the third most powerful turboprop engines ever produced, after the Kuznetsov NK-12 and Progress D-27.

In its simplest form a turboprop consists of an intake, compressor, combustor, turbine, and a propelling nozzle. Air is drawn into the intake and compressed by the compressor. Fuel is then added to the compressed air in the combustor, where the fuel-air mixture then combusts. The hot combustion gases expand through the turbine. Some of the power generated by the turbine is used to drive the compressor. The rest is transmitted through the reduction gearing to the propeller. Further expansion of the gases occurs in the propelling nozzle, where the gases exhaust to atmospheric pressure. The propelling nozzle provides a relatively small proportion of the thrust generated by a turboprop (Figure 5.1).

Turboprops are very efficient at flight speeds below 725 km/h (450 mph; 390 knots) because the jet velocity of the propeller (and exhaust) is relatively low. Due to the high price of turboprop engines, they are mostly used where high-performance short-take-off and landing (STOL) capability and efficiency at modest flight speeds are required. The most common application of turboprop engines in civilian aviation is in small commuter aircraft, where their greater reliability than reciprocating engines offsets their higher initial cost. Turboprop airliners now operate at near the same speed as small turbofan-powered aircraft but burn two-thirds of the fuel per passenger. However, compared to a turbojet (which can fly at high altitude for enhanced speed and fuel efficiency) a propeller aircraft has a much lower ceiling. Turboprop-powered aircraft have become popular for bush airplanes such as the Cessna Caravan and Quest Kodiak as jet fuel is easier to obtain in remote areas than is aviation-grade gasoline (avgas).

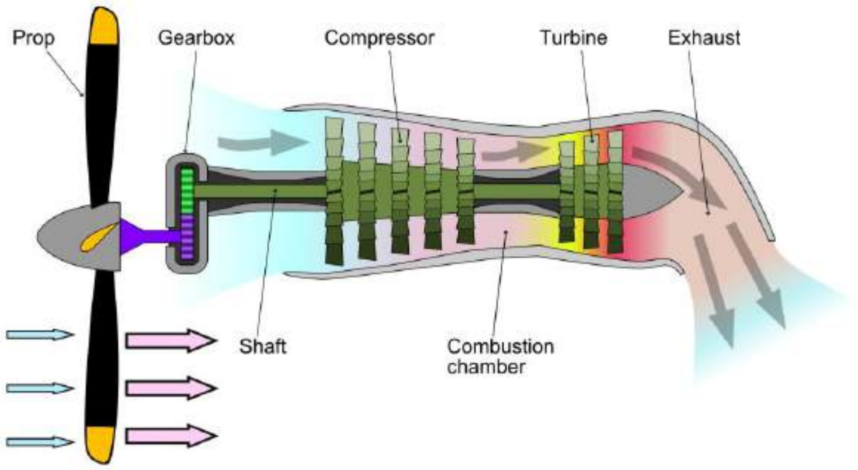


Figure 5.1 – Schematic diagram showing the operation of a turboprop engine

Thrust in a turboprop is sacrificed in favour of shaft power, which is obtained by extracting additional power (up to that necessary to drive the compressor) from turbine expansion. While the power turbine may be integral with the gas generator section, many turboprops today feature a free power turbine on a separate coaxial shaft. This enables the propeller to rotate freely, independent of compressor speed. Owing to the additional expansion in the turbine system, the residual energy in the exhaust jet is low. Consequently, the exhaust jet produces (typically) less than 10% of the total thrust. Propellers are not efficient when the tips reach or exceed supersonic speeds. For this reason, a reduction gearbox is placed in the drive line between the power turbine and the propeller to allow the turbine to operate at its most efficient speed. The gearbox is a part of the engine and contains the parts necessary to operate a constant speed propeller. This differs from the turboshaft engines used in helicopters, where the gearbox is remote from the engine. Residual thrust on a turboshaft is avoided by further expansion in the turbine system and/or truncating and turning the exhaust 180 degrees, to produce two opposing jets. Apart from the above, there is very little difference between a turboprop and a turboshaft. While the most modern turbojet and turbofan engines use axial-flow compressors, turboprop engines usually contain at least one stage of centrifugal compression. Centrifugal compressors have the advantage of being simple and lightweight, at the expense of a streamlined shape. Propellers lose efficiency as aircraft speed increases, so turboprops are normally not used on high-speed aircraft. However, propfan engines, which are very similar to turboprop engines, can cruise at flight speeds approaching Mach 0.75. To increase the efficiency of the propellers, a mechanism can be used to alter the pitch, thus adjusting the pitch to the airspeed. A variable pitch propeller, also called a controllable pitch propeller, can also be used to generate negative thrust while decelerating on the runway. Additionally, in the event of an engine outage, the pitch can be adjusted to a vanning pitch (called feathering), thus minimizing the drag of the non-functioning propeller.

5.3 Turbofan

The **turbofan** or **fanjet** is a type of airbreathing jet engine that finds wide use in aircraft propulsion (Figure 5.2). The word "turbofan" is a portmanteau of "turbine" and "fan", the *turbo portion* refers to a gas turbine engine which takes mechanical energy from combustion, and the *fan*, a ducted fan that uses the mechanical energy from the gas turbine to accelerate air rearwards. The ratio of the mass-flow of air bypassing the engine core compared to the mass-flow of air passing through the core is referred to as the bypass ratio. The engine produces thrust through a combination of these two portions working in concert; engines that use more jet thrust relative to fan thrust are known as *low bypass turbofans*, while those that have considerably more fan thrust than jet are known as *high bypass*. Most commercial aviation jet engines in use today are of the high-bypass type, and most modern military fighter engines are low-bypass. Afterburners are not used on high-bypass turbofan engines but may be used on either low-bypass turbofan or turbojet engines.

Most of the air flow through a high-bypass turbofan is low-velocity bypass flow: even when combined with the much higher velocity engine exhaust, the net average exhaust velocity is considerably lower than in a pure turbojet. Engine noise is largely a function of exhaust velocity, therefore turbofan engines are significantly quieter than a pure-jet of the same thrust. Other factors include turbine blade and exhaust outlet geometries, such as noise-reducing "chevrons" seen on the Rolls-Royce Trent 1000 and General Electric GEnx engines used on the Boeing 787 (Figure 5.3).

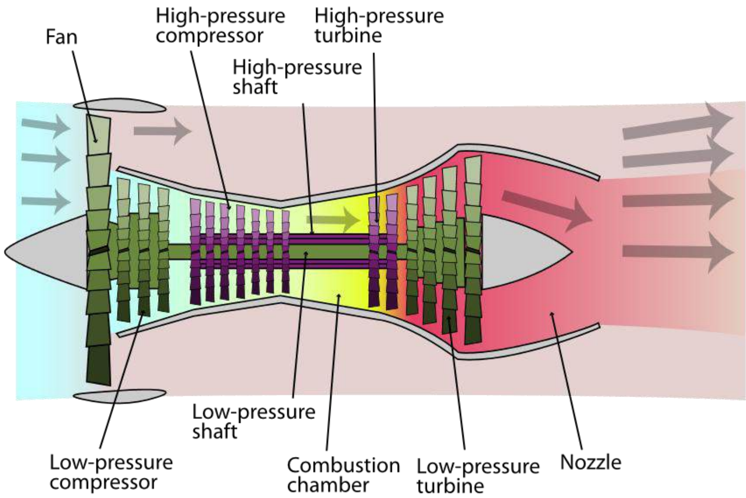


Figure 5.2 – Schematic diagram showing the operation of a turbofan engine

Schematic diagram illustrating a 2-spool, high-bypass turbofan engine with an unmixed exhaust. The low-pressure spool is coloured green and the high-pressure one purple. Again, the fan (and booster stages) are driven by the low-pressure turbine, but more stages are required. A mixed exhaust is often employed nowadays.

Since the efficiency of propulsion is a function of the relative airspeed of the exhaust to the surrounding air, propellers are most efficient for low speed, pure jets for high speeds, and ducted fans in the middle. Turbofans are thus the most efficient engines in the range of speeds from about 500 to 1,000 km/h (310 to 620 mph), the speed at which most commercial aircraft operate. Turbofans retain an efficiency edge over pure jets at low supersonic speeds up to roughly Mach 1.6, but have also been found to be efficient when used with continuous afterburner at Mach 3 and above.

The vast majority of turbofans follow the same basic design, with a large fan at the front of the engine and a relatively small jet engine behind it. There have been a number of variations on this design, however, including rear-mounted fans which can easily be added to an existing pure-jet design, or designs that combine a low-pressure turbine and a fan stage in a single rear-mounted unit.

The turbofan is a derivative of the turbojet engine. In a turbojet, air undergoes four main phases, a process known as the Brayton cycle:

1) a compression phase in a compressor, approximately adiabatic, where its pressure and temperature increase;

2) a heating phase in a combustor, where its temperature and volume increase at approximately constant pressure;

3) an expansion phase in a turbine, approximately adiabatic, where mechanical work is extracted from the air to power the compressor;

4) a further expansion phase in a nozzle, where its speed increases as it returns to inlet pressure.

Thrust is provided by the difference in speed between the outlet and inlet.

It is important to note that in a turbojet the compressor and turbine taken together form a net-zero mechanical energy system, i.e. all the mechanical shaft power produced by the turbine is consumed by the compressor. The net output of a turbojet is not shaft power, instead it is the kinetic energy of the jet exhaust itself. Although the expansion process in the turbine reduces the gas pressure (and temperature), there remains considerable thermal energy and pressure in the gases leaving the turbine. These energy forms are partly converted into kinetic energy by expansion to ambient pressure through a propelling nozzle, forming a high-velocity flow which provides reactive propulsion.

After World War II, two-spool (or two-shaft) turbojets were developed to make it easier to throttle back compression systems with a high design overall pressure ratio (i.e., combustor inlet pressure/intake delivery pressure). Adopting the two-spool arrangement enables the compression system to be split in two, with a low pressure (LP) compressor supercharging a high pressure (HP) compressor. Each compressor is mounted on a separate (co-axial) shaft, driven by its own turbine (i.e., the HP turbine and LP turbine). Otherwise, a two-spool turbojet is much like a single-spool engine.

Figure 5.3 – View into the outer (propelling or "cold") nozzle of a GEnx-2B turbofan engine

Modern turbofans evolved from the two-spool axial-flow turbojet engine, essentially by increasing the relative size of the low pressure (LP) compressor to the point where some (if not most) of the air exiting the unit actually bypasses the core (or gas-generator) stream passing through the main combustor. Civil-aviation high-bypass turbofans usually have a single large fan disk, whereas most military-aviation low-bypass turbofans (e.g. combat and trainer aircraft applications) have multi-disk compressors as a compromise between greater power-to-weight ratios, supersonic performance, and the capability of using afterburners, versus the higher fuel economy of a high-bypass design. Modern military transport turbofan engines are virtually identical to their civilian counterparts.

5.4 Turbojet engine

The **turbojet** is a kind of general-purpose airbreathing jet engine. Two engineers, Hans von Ohain in Germany and Frank Whittle in the United Kingdom, developed the concept independently into practical engines during the late 1930s.

Turbojets consist of an air inlet, an air compressor, a combustion chamber, a gas turbine (that drives the air compressor) and a nozzle. The air is compressed into the chamber, heated and expanded by the fuel combustion and then allowed to expand out through the turbine into the nozzle where it is accelerated to high speed to provide propulsion (Figure 5.4).

Compared to turbofans, turbojets are quite inefficient if flown below about Mach 2 and are very noisy. Turbojet efficiency only comes into play at supersonic Mach numbers and high altitudes where small frontal area is optimal, and large fan blades are inefficient. Few aircraft cruise in this expensive regime, so most modern aircraft use turbofans instead for fuel economy and low altitude performance. However, turbojets are still common in medium range cruise missiles, due to their high exhaust speed, small frontal area, and relative simplicity.

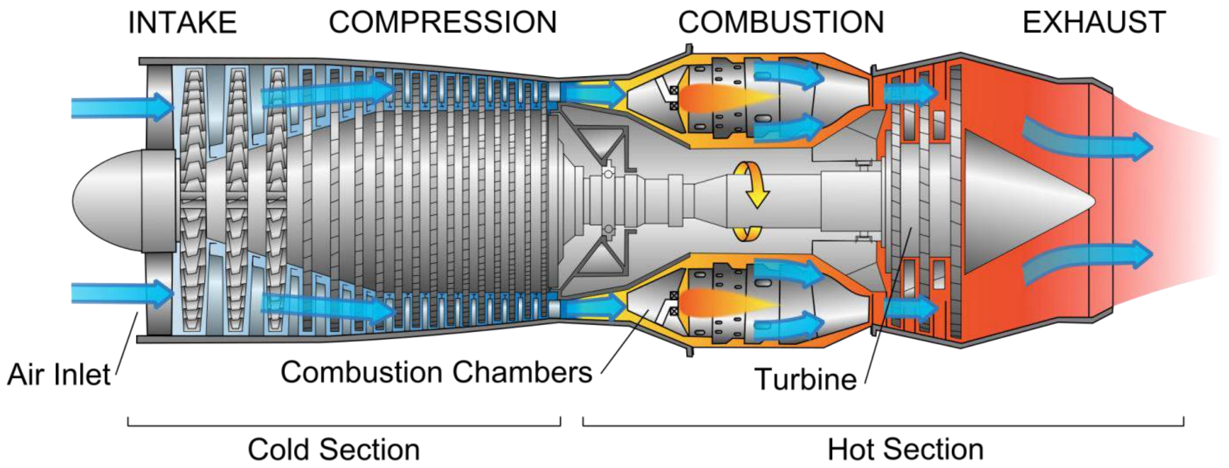


Figure 5.4 – Diagram of a typical gas turbine jet engine

Turboprop engines are gas-turbine engines that deliver almost all of their power to a shaft to drive a propeller. Turboprops remain popular on very small or slow aircraft, such as small commuter airliners, for their fuel efficiency at lower speeds, as well as on medium military transports and patrol planes, such as the C-130 Hercules and P-3 Orion, for their high take-off performance and mission endurance benefits. Like reciprocating propeller engines, turboprops can be used with controllable pitch propellers which allow thrust to be adjusted independently of the engine rotation speed.

If the turboprop is better at moderate flight speeds and the turbojet is better at very high speeds, it might be imagined that at some speed range in the middle a mixture of the two is best. Such an engine is the turbofan (originally termed *bypass turbojet* by the inventors at Rolls-Royce). Another name sometimes used is ducted fan, though that term is also used for propellers and fans used in vertical-flight applications.

Figure 5.5 – The Dassault/Dornier Alpha Jet is a light attack jet and advanced jet trainer co-manufactured by Dassault Aviation of France and Dornier Flugzeugwerke of Germany

Duct work on an Dassault /Dornier Alpha Jet – At subsonic speeds, the increasing diameter of the inlet duct slows incoming air (according to the principle of continuity). As the incoming air slows, its static pressure increases according to Bernoulli's Principle (Figure 5.5).

The difference between a turbofan and a propeller, besides direct thrust, is that the intake duct of the former slows the air before it arrives at the fan face. As both propeller and fan blades must operate at subsonic inlet velocities to be efficient, ducted fans allow efficient operation at higher vehicle speeds. Some large modern turbofans, like the Trent, have blade tip speeds at 1,730 km/h (1,070 mph).

Depending on specific thrust (i.e., net thrust to intake airflow), ducted fans operate best from about 400 to 2,000 km/h (250 to 1,240 mph), which is why turbofans are the most common type of engine for aviation use today – in airliners as well as in subsonic and supersonic military fighter and trainer aircraft. It should be noted, however, that turbofans use extensive ducting to force incoming air to subsonic velocities (thus reducing shock waves throughout the engine).

Bypass ratio (bypassed airflow to combustor airflow) is a parameter often used for classifying turbofans; when the low-bypass Conway engine entered service in 1960, no one even called it a turbofan, that term first being applied to Pratt and Whitney's JT3D with its 1-to-1 bypass.

The noise of any type of jet engine is strongly related to the velocity of the exhaust gases, typically being proportional to the eighth power of the jet velocity. High-bypass-ratio (i.e., low-specific-thrust) turbofans are relatively quiet compared to turbojets and low-bypass-ratio (i.e., high-specific-thrust) turbofans. A low-specific-thrust engine has a low jet velocity by definition, as the following approximate equation for net thrust implies:

$$F_n = \dot{m} \cdot (\mathbf{V}_{jfe} - \mathbf{V}_a)$$

where:

$\dot{m}$ – intake mass flow;

$\mathbf{V}_{jfe}$ – fully expanded jet velocity (in the exhaust plume);

$\mathbf{V}_a$ – aircraft flight velocity.

Rearranging the above equation, specific thrust is given by:

$$\frac{F_n}{\dot{m}} (\mathbf{V}_{jfe} - V_a)$$

So for zero flight velocity, specific thrust is directly proportional to jet velocity. Relatively speaking, low-specific-thrust engines are large in diameter to accommodate the high airflow required for a given thrust.

Although jet aircraft are loud, a conventional piston engine or a turboprop engine delivering the same thrust would be much louder.

A **turboprop** engine is a type of turbine engine which drives an aircraft propeller using a reduction gear.

The gas turbine is designed specifically for this application, with almost all of its output being used to drive the propeller. The engine's exhaust gases do not contain enough energy, compared to a jet engine, to create significant thrust in the propulsion of the aircraft.

The propeller is coupled to the turbine through a reduction gear that converts the high RPM, low torque output to low RPM, high torque. The propeller itself is normally a constant speed (variable pitch) type similar to that used with larger reciprocating aircraft engines.

Turboprop engines are generally used on small subsonic aircraft, but some aircraft outfitted with turboprops have cruising speeds in excess of 500 kt (926 km/h, 575 mph). Large military and civil aircraft, such as the Lockheed L-188 Electra and the Tupolev Tu-95, have also used turboprop power. The Airbus A400M is powered by four Europrop TP400 engines, which are the third most powerful turboprop engines ever produced, after the Kuznetsov NK-12 and Progress D-27.

In its simplest form a turboprop consists of an intake, compressor, combustor, turbine, and a propelling nozzle. Air is drawn into the intake and compressed by the compressor. Fuel is then added to the compressed air in the combustor, where the fuel-air mixture then combusts. The hot combustion gases expand through the turbine. Some of the power generated by the turbine is used to drive the compressor. The rest is transmitted through the reduction gearing to the propeller. Further expansion of the gases occurs in the propelling nozzle, where the gases exhaust to atmospheric pressure. The propelling nozzle provides a relatively small proportion of the thrust generated by a turboprop.

Turboprops are very efficient at flight speeds below 725 km/h (450 mph; 390 knots) because the jet velocity of the propeller (and exhaust) is relatively low. Due to the high price of turboprop engines, they are mostly used where high-performance short-takeoff and landing (STOL) capability and efficiency at modest flight speeds are required. The most common application of turboprop engines in civilian aviation is in small commuter aircraft, where their greater reliability than reciprocating engines offsets their higher initial cost. Turboprop airliners now operate at near the same speed as small turbofan-powered aircraft but burn two-thirds of the fuel per passenger. However, compared to a turbojet (which can fly at high altitude for enhanced speed and fuel efficiency) a propeller aircraft has a much lower ceiling. Turboprop-powered aircraft have become popular for bush airplanes such as the Cessna Caravan and Quest Kodiak as jet fuel is easier to obtain in remote areas than is aviation-grade gasoline (avgas).

What we can see from the diagram (Figure 5.6) is that with increasing speeds the reaction engines become progressively more "efficient", getting closer to the infinite mass case.

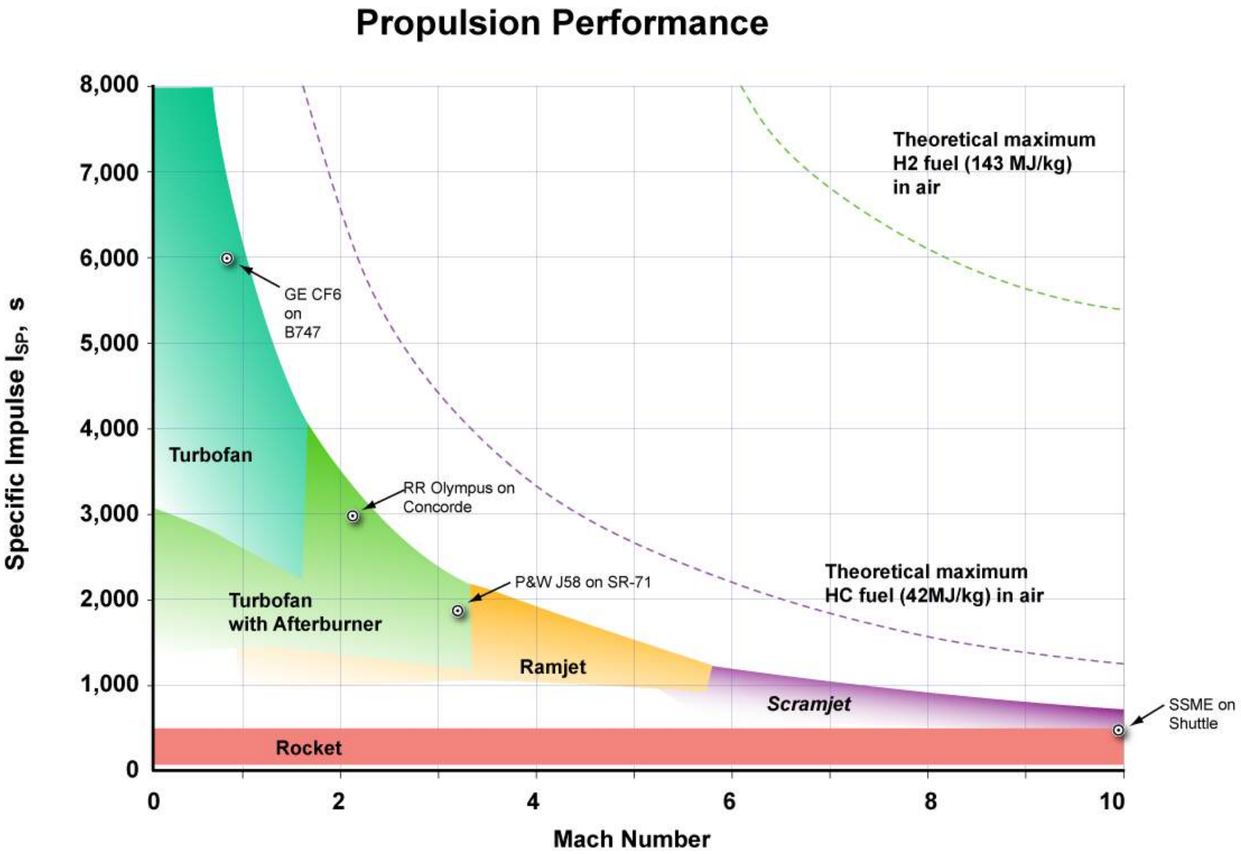


Figure 5.6 – Specific Impulse ranges for different kind of propulsion engines compared

6 LANDING GEAR

Aircraft landing gear supports the entire weight of an aircraft during landing and ground operations. They are attached to primary structural members of the aircraft. The type of gear depends on the aircraft design and its intended use. Most landing gear have wheels to facilitate operation to and from hard surfaces, such as airport runways. Other gear feature skids for this purpose, such as those found on helicopters, balloon gondolas, and in the tail area of some tail dragger aircraft. Aircraft that operate to and from frozen lakes and snowy areas may be equipped with landing gear that have skis. Aircraft that operate to and from the surface of water have pontoon-type landing gear. Regardless of the type of landing gear utilized, shock absorbing equipment, brakes, retraction mechanisms, controls, warning devices, cowling, fairings, and structural members necessary to attach the gear to the aircraft are considered parts of the landing gear system (Figure 6.1).

Figure 6.1 – Basic landing gear types include those with wheels (*a*), skids (*b*), skis (*c*), and floats or pontoons (*d*)

Numerous configurations of landing gear types can be found. Additionally, combinations of two types of gear are common. Amphibious aircraft are designed with gear that allow landings to be made on water or dry land. The gear features pontoons for water landing with extendable wheels for landings on hard surfaces. A similar system is used to allow the use of skis and wheels on aircraft that operate on both slippery, frozen surfaces and dry runways. Typically, the skis are retractable to allow use of the wheels when needed. Figure 13-2 illustrates this type of landing gear.

NOTE: References to auxiliary landing gear refer to the nose gear, tail gear, or outrigger-type gear on any particular aircraft. Main landing gear are the two or more large gear located close to the aircraft's center of gravity.

6.1 Landing Gear Arrangement

Three basic arrangements of landing gear are used: tail wheel- type landing gear (also known as conventional gear), tandem landing gear, and tricycle-type landing gear.

Figure 6.2 – An amphibious aircraft with retractable wheels (left) and an aircraft with retractable skis (right)

6.2 Tail Wheel-Type Landing Gear

Tail wheel-type landing gear is also known as conventional gear because many early aircraft use this type of arrangement. The main gear are located forward of the center of gravity, causing the tail to require support from a third wheel assembly. A few early aircraft designs use a skid rather than a tail wheel. This helps slow the aircraft upon landing and provides directional stability. The resulting angle of the aircraft fuselage, when fitted with conventional gear, allows the use of a long propeller that compensates for older, underpowered engine design. The increased clearance of the forward fuselage offered by tail wheel-type landing gear is also advantageous when operating in and out of non-paved runways. Today, aircraft are manufactured with conventional gear for this reason and for the weight savings accompanying the relatively light tail wheel assembly (Figure 6.3).

The proliferation of hard surface runways has rendered the tail skid obsolete in favor of the tail wheel. Directional control is maintained through differential braking until the speed of the aircraft enables control with the rudder. A steerable tail wheel, connected by cables to the rudder or rudder pedals, is also a common design. Springs are incorporated for dampening (Figure 6.4).

6.3 Tandem Landing Gear

Few aircraft are designed with tandem landing gear. As the name implies, this type of landing gear has the main gear and tail gear aligned on the longitudinal axis of the aircraft. Sailplanes commonly use tandem gear, although many only have one actual gear forward on the fuselage with a skid under the tail. A few military bombers, such as the B-47 and the B-52, have tandem gear, as does the U2 spy plane. The VTOL Harrier has tandem gear but uses small outrigger gear under the wings for support. Generally, placing the gear only under the fuselage facilitates the use of very flexible wings (Figure 6.5).

6.4 Tricycle-Type Landing Gear

The most commonly used landing gear arrangement is the tricycle-type landing gear. It is comprised of main gear and nose gear (Figure 6.6).

Tricycle-type landing gear is used on large and small aircraft with the following benefits:

1. Allows more forceful application of the brakes without nosing over when braking, which enables higher landing speeds.

Figure 6.3 – Tail wheel configuration landing gear on a DC-3 (left) and a STOL Maule MX-7-235 Super Rocket

Figure 6.4 – The steerable tail wheel of a Pitts Special

Figure 6.5 – Tandem landing gear along the longitudinal axis of the aircraft permits the use of flexible wings on sailplanes (left) and select military aircraft like the B-52 (center). The VTOL Harrier (right) has tandem gear with outrigger-type gear

Figure 6.6 – Tricycle-type landing gear with dual main wheels on a Learjet (left) and a Cessna 172, also with tricycle gear (right)

2. Provides better visibility from the flight deck, especially during landing and ground manoeuvring.

3. Prevents ground-looping of the aircraft. Since the aircraft center of gravity is forward of the main gear, forces acting on the center of gravity tend to keep the aircraft moving forward rather than looping, such as with a tail wheel-type landing gear.

The nose gear of a few aircraft with tricycle-type landing gear is not controllable. It simply casters as steering is accomplished with differential braking during taxi. However, nearly all aircraft have steerable nose gear. On light aircraft, the nose gear is directed through mechanical linkage to the rudder pedals. Heavy aircraft typically utilize hydraulic power to steer the nose gear. Control is achieved through an independent tiller in the flight deck (Figure 6.7).

The main gear on a tricycle-type landing gear arrangement is attached to reinforced wing structure or fuselage structure. The number and location of wheels on the main gear vary. Many main gear have two or more wheels (Figure 6.8).

Multiple wheels spread the weight of the aircraft over a larger area. They also provide a safety margin should one tire fail. Heavy aircraft may use four or more wheel assemblies on each main gear. When more than two wheels are attached to a landing gear strut, the attaching mechanism is known as a bogie. The number of wheels included in the bogie is a function of the gross design weight of the aircraft and the surface type on which the loaded aircraft is required to land. Figure 6.9 illustrates the triple bogie main gear of a Boeing 777.

Figure 6.7 – A nose wheel steering tiller located on the flight deck

Figure 6.8 – Dual main gear of a tricycle-type landing gear

Figure 6.9 – Triple bogie main landing gear assembly on a Boeing 777

The tricycle-type landing gear arrangement consists of many parts and assemblies. These include air/oil shock struts, gear alignment units, support units, retraction and safety devices, steering systems, wheel and brake assemblies, etc. A main landing gear of a transport category aircraft is illustrated in Figure 6.10 with many of the parts identified as an introduction to landing gear nomenclature.

6.5 Fixed and Retractable Landing Gear

Further classification of aircraft landing gear can be made into two categories: fixed and retractable. Many small, single engine light aircraft have fixed landing gear, as do a few light twins. This means the gear is attached to the airframe and remains exposed to the slipstream as the aircraft is flown. As discussed in Chapter 2 of this handbook, as the speed of an aircraft increases, so does parasite drag. Mechanisms to retract and stow the landing gear to eliminate parasite drag add weight to the aircraft. On slow aircraft, the penalty of this added weight is not overcome by the reduction of drag, so fixed gear is used. As the speed of the aircraft increases, the drag caused by the landing gear becomes greater and a means to retract the gear to eliminate parasite drag is required, despite the weight of the mechanism.

A great deal of the parasite drag caused by light aircraft landing gear can be reduced by building gear as aerodynamically as possible and by adding fairings or wheel pants to streamline the airflow past the protruding assemblies. A small, smooth profile to the oncoming wind greatly reduces landing gear parasite drag. Figure 6.11 illustrates a Cessna aircraft landing gear used on many of the manufacturer's light planes. The thin cross section of the spring steel struts combine with the fairings over the wheel and brake assemblies to raise performance of the fixed landing gear by keeping parasite drag to a minimum.

Retractable landing gear stow in fuselage or wing compartments while in flight. Once in these wheel wells, gear are out of the slipstream and do not cause parasite drag. Most retractable gear have a close fitting panel attached to them that fairs with the aircraft skin when the gear is fully retracted (Figure 6.12). Other aircraft have separate doors that open, allowing the gear to enter or leave, and then close again.

NOTE: The parasite drag caused by extended landing gear can be used by the pilot to slow the aircraft. The extension and retraction of most landing gear is usually accomplished with hydraulics. Landing gear retraction systems are discussed later in this chapter.

6.6 Shock Absorbing and Non-Shock Absorbing Landing Gear

In addition to supporting the aircraft for taxi, the forces of impact on an aircraft during landing must be controlled by the landing gear. This is done in two ways:

1) the shock energy is altered and transferred throughout the airframe at a different rate and time than the single strong pulse of impact;

2) the shock is absorbed by converting the energy into heat energy.

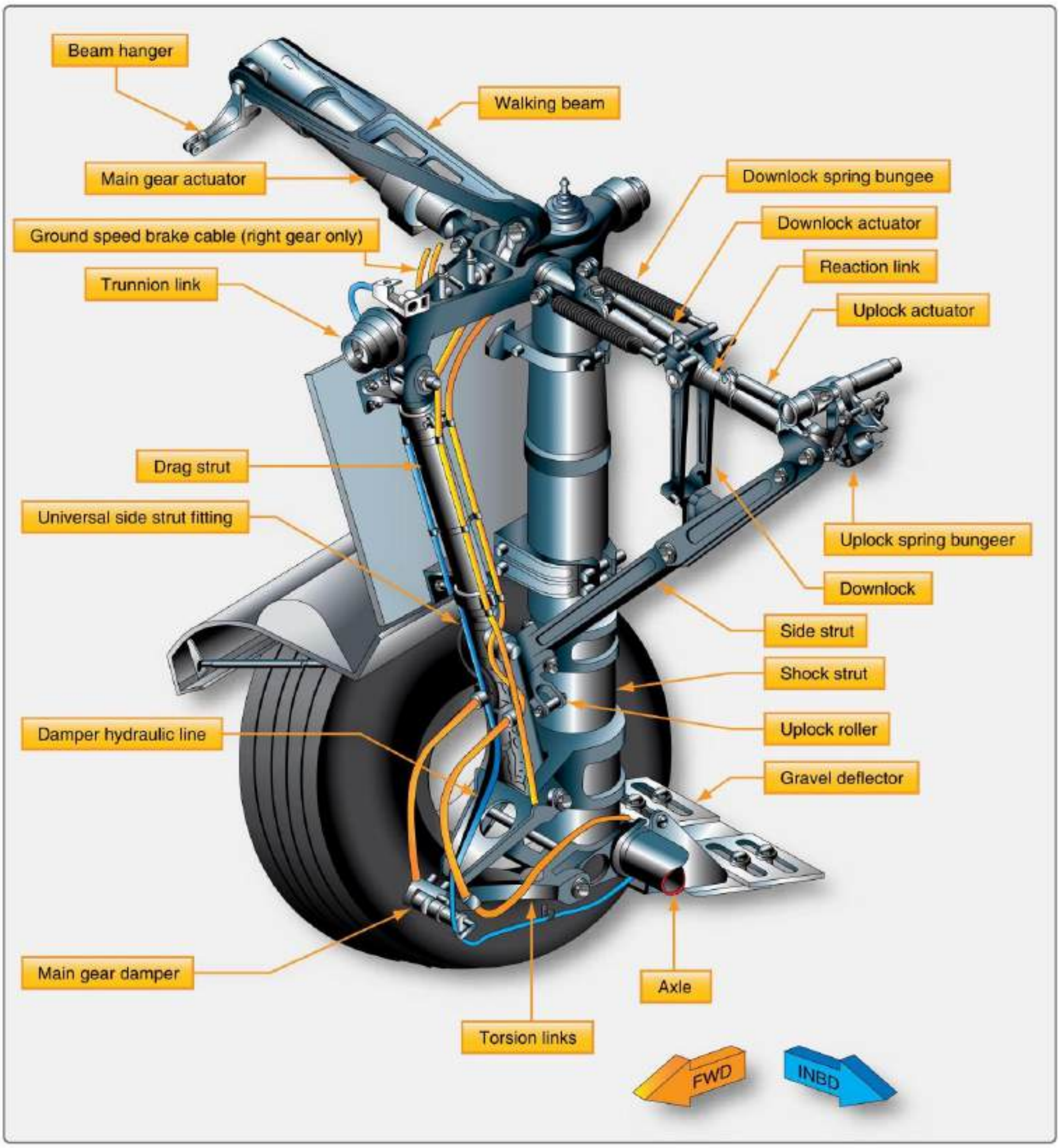


Figure 6.10 – Nomenclature of a main landing gear bogie truck

6.7 Leaf-Type Spring Gear

Many aircraft utilize flexible spring steel, aluminium, or composite struts that receive the impact of landing and return it to the airframe to dissipate at a rate that is not harmful. The gear flexes initially and forces are transferred as it returns to its original position (Figure 6.13). The most common example of this type of non-shock absorbing landing gear are the thousands of single-engine Cessna aircraft that use it. Landing gear struts of this type made from composite materials are lighter in weight with greater flexibility and do not corrode.

6.8 Rigid

Before the development of curved spring steel landing struts, many early aircraft were designed with rigid, welded steel landing gear struts. Shock load transfer to the airframe is direct with this design. Use of pneumatic tires aids in softening the impact loads (Figure 6.14). Modern aircraft that use skid-type landing gear make use of rigid landing gear with no significant ill effects. Rotorcraft, for example, typically experience low impact landings that are able to be directly absorbed by the airframe through the rigid gear (skids).

Figure 6.11 – Wheel fairings, or pants, and low profile struts reduce parasite drag on fixed gear aircraft

6.9 Bungee Cord

The use of bungee cords on non-shock absorbing landing gear is common. The geometry of the gear allows the strut assembly to flex upon landing impact. Bungee cords are positioned between the rigid airframe structure and the flexing gear assembly to take up the loads and return them to the airframe at a non-damaging rate. The bungees are made of many individual small strands of elastic rubber that must be inspected for condition. Solid, donut-type rubber cushions are also used on some aircraft landing gear (Figure 6.15).

6.10 Shock Struts

True shock absorption occurs when the shock energy of landing impact is converted into heat energy, as in a shock strut landing gear. This is the most common method of landing shock dissipation in aviation. It is used on aircraft of all sizes. Shock struts are self-contained hydraulic units that support an aircraft while on the ground and protect the structure during landing. They must be inspected and serviced regularly to ensure proper operation.

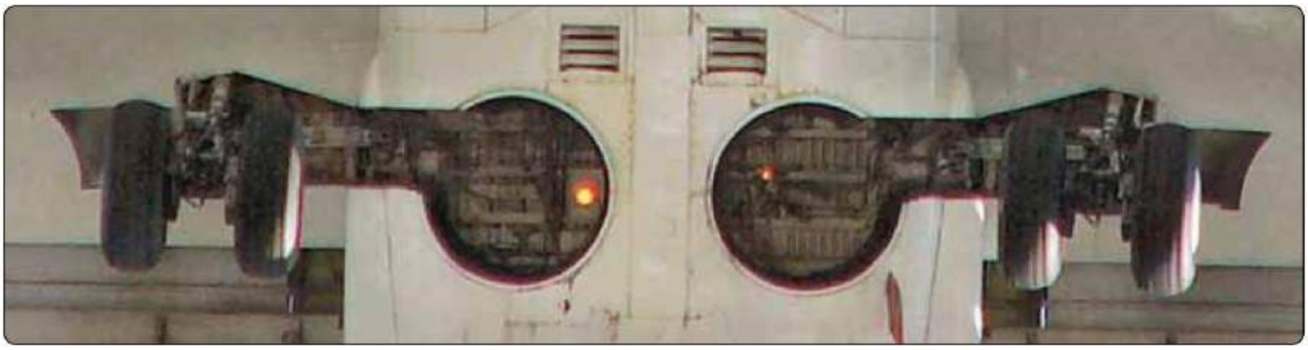


Figure 6.12 – The retractable gear of a Boeing 737 fair into recesses in the fuselage. Panels attached to the landing gear provide smooth airflow over the struts. The wheel assemblies mate with seals to provide aerodynamic flow without doors

Figure 6.13 – Non-shock absorbing struts made from steel, aluminum, or composite material transfer the impact forces of landing to the airframe at a non-damaging rate

Figure 6.14 – Rigid steel landing gear is used on many early aircraft

Figure 6.15 – Piper Cub bungee cord landing gear transfer landing loads to the airframe (left and center). Rubber, donut-type shock transfer is used on some Mooney aircraft (right)

There are many different designs of shock stmts, but most operate in a similar manner. The following discussion is general in nature. For information on the construction, operation, and servicing of a specific aircraft shock, consult the manufacturer's maintenance instructions.

A typical pneumatic/hydraulic shock strut uses compressed air or nitrogen combined with hydraulic fluid to absorb and dissipate shock loads. It is sometimes referred to as an air/oil or oleo strut. A shock strut is constructed of two telescoping cylinders or tubes that are closed on the external ends. The upper cylinder is fixed to the aircraft and does not move. The lower cylinder is called the piston and is free to slide in and out of the upper cylinder. Two chambers are formed. The lower chamber is always filled with hydraulic fluid and the upper chamber is filled with compressed air or nitrogen. An orifice located between the two cylinders provides a passage for the fluid from the bottom chamber to enter the top cylinder chamber when the strut is compressed (Figure 6.16).

Most shock struts employ a metering pin similar to that shown in Figure 6.16 for controlling the rate of fluid flow from the lower chamber into the upper chamber. During the compression stroke, the rate of fluid flow is not constant. It is automatically controlled by the taper of the metering pin in the orifice. When a narrow portion of the pin is in the orifice, more fluid can pass to the upper chamber. As the diameter of the portion of the metering pin in the orifice increases, less fluid passes. Pressure build-up caused by strut compression and the hydraulic fluid being forced through the metered orifice causes heat. This heat is converted impact energy. It is dissipated through the structure of the strut.

On some types of shock struts, a metering tube is used. The operational concept is the same as that in shock struts with metering pins, except the holes in the metering tube control the flow of fluid from the bottom chamber to the top chamber during compression (Figure 6.17).

Upon lift off or rebound from compression, the shock strut tends to extend rapidly. This could result in a sharp impact at the end of the stroke and damage to the strut. It is typical for shock struts to be equipped with a damping or snubbing device to prevent this. A recoil valve on the piston or a recoil tube restricts the flow of fluid during the extension stroke, which slows the motion and prevents damaging impact forces.

Most shock struts are equipped with an axle as part of the lower cylinder to provide installation of the aircraft wheels. Shock struts without an integral axle have provisions on the end of the lower cylinder for installation of the axle assembly. Suitable connections are provided on all shock strut upper cylinders to attach the strut to the airframe (Figure 6.18).

The upper cylinder of a shock strut typically contains a valve fitting assembly. It is located at or near the top of the cylinder. The valve provides a means of filling the strut with hydraulic fluid and inflating it with air or nitrogen as specified by the manufacturer. A packing gland is employed to seal the sliding joint between the upper and lower telescoping cylinders. It is installed in the open end of the outer cylinder. A packing gland wiper ring is also installed in a groove in the lower bearing or gland nut on most shock struts. It is designed to keep the sliding surface of the piston from carrying dirt, mud, ice, and snow into the packing gland and upper cylinder. Regular cleaning of the exposed portion of the strut piston helps the wiper do its job and decreases the possibility of damage to the packing gland, which could cause the strut to a leak.

To keep the piston and wheels aligned, most shock struts are equipped with torque links or torque arms. One end of the links is attached to the fixed upper cylinder. The other end is attached to the lower cylinder (piston) so it cannot rotate. This keeps the wheels aligned. The links also retain the piston in the end of the upper cylinder when the strut is extended, such as after takeoff (Figure 6.19).

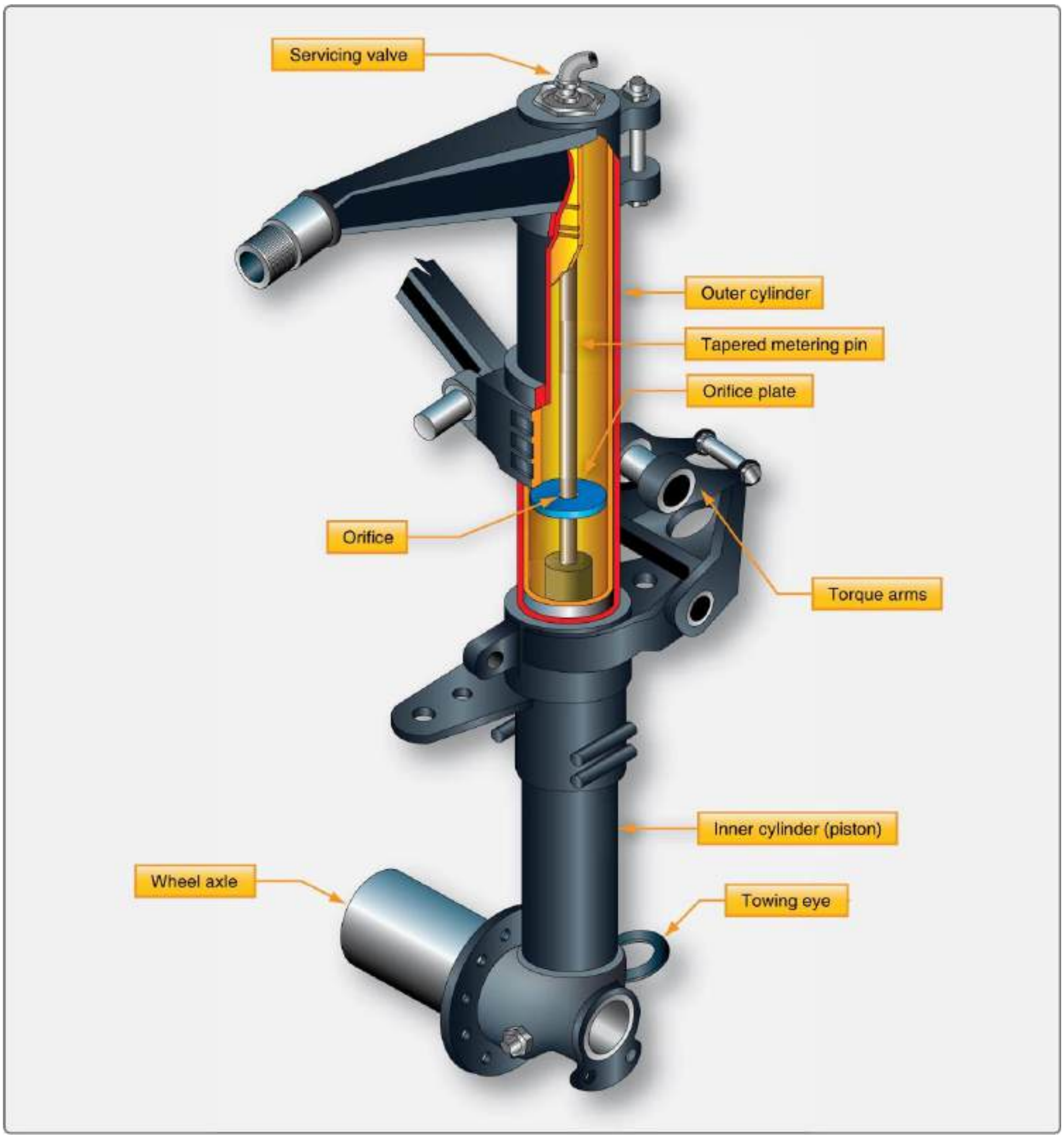


Figure 6.16 – A landing gear shock strut with a metering pin to control the flow of hydraulic fluid from the lower chamber to the upper chamber during compression

Nose gear shock struts are provided with a locating cam assembly to keep the gear aligned. A cam protrusion is attached to the lower cylinder, and a mating lower cam recess is attached to the upper cylinder. These cams line up the wheel and axle assembly in the straight-ahead position when the shock strut is fully extended. This allows the nose wheel to enter the wheel well when the nose gear is retracted and prevents structural damage to the aircraft. It also aligns the wheels with the longitudinal axis of the aircraft prior to landing when the strut is fully extended (Figure 6.20). Many nose gear shock struts also have attachments for the installation of an external shimmy damper (Figure 6.21).

Nose gear struts are often equipped with a locking or disconnect pin to enable quick turning of the aircraft while towing or positioning the aircraft when on the ramp or in a hangar. Disengagement of this pin allows the wheel fork spindle on some aircraft to rotate 360°, thus enabling the aircraft to be turned in a tight radius. At no time should the nose wheel of any aircraft be rotated beyond limit lines marked on the airframe.

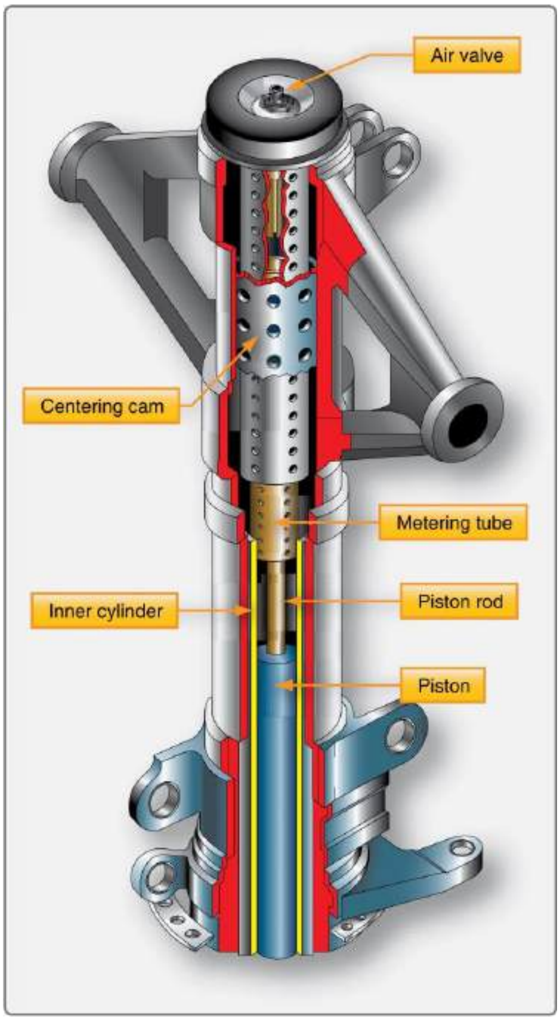


Figure 6.17 – Some landing gear shock struts use an internal metering tube rather than a metering pin to control the flow of fluid from the bottom cylinder to the top cylinder

Nose and main gear shock struts on many aircraft are also equipped with jacking points and towing lugs. Jacks should always be placed under the prescribed points. When towing lugs are provided, the towing bar should be attached only to these lugs (Figure 6.22).

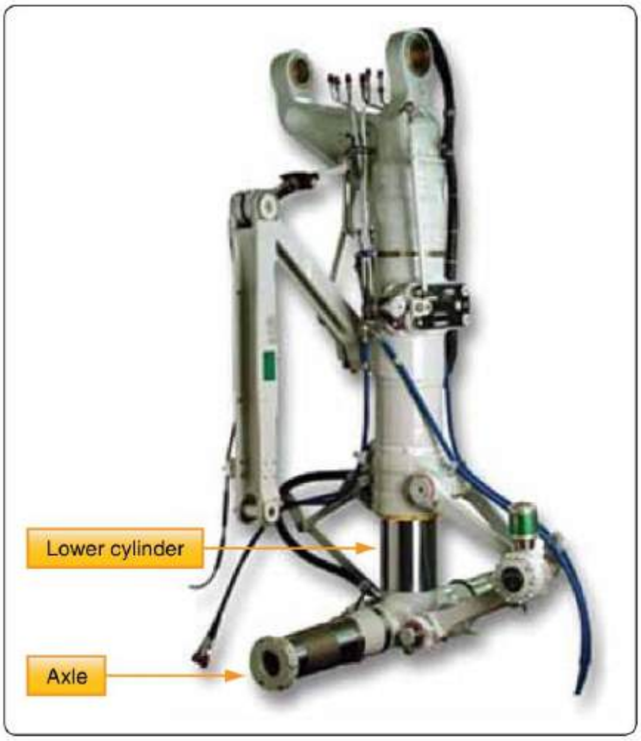


Figure 6.18 – Axles machined out of the same material as the landing gear lower cylinder

Figure 6.19 – Torque links align the landing gear and retain the piston in the upper cylinder when the strut is extended

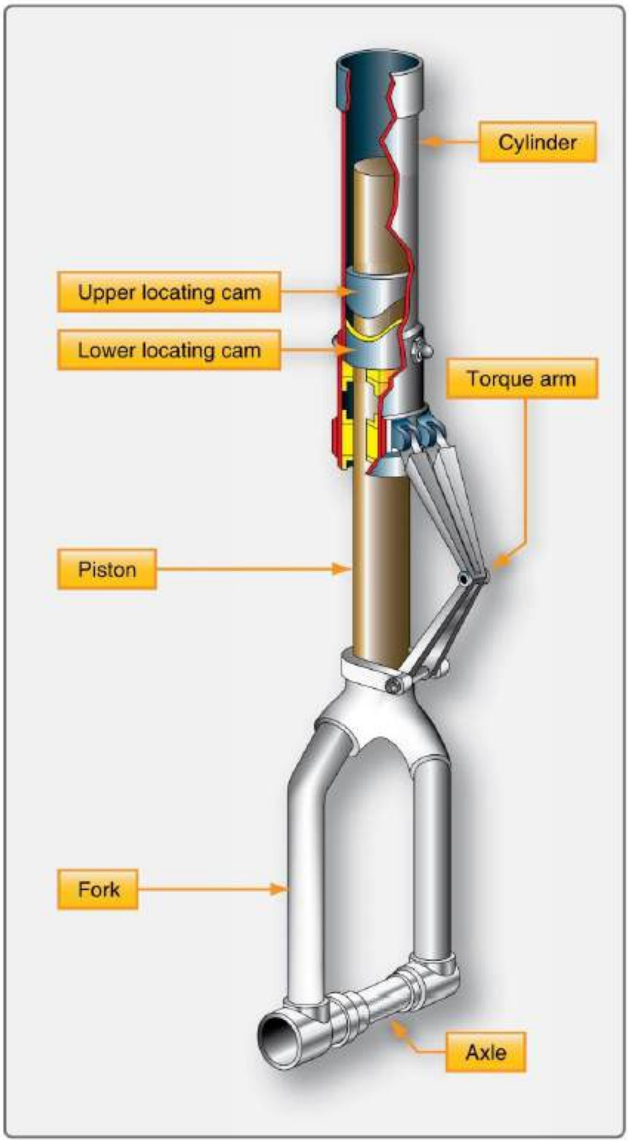


Figure 6.20 – An upper locating cam mates into a lower cam recess when the nose landing gear shock strut is extended before landing
and before the gear is retracted into the wheel well

Shock struts contain an instruction plate that gives directions for filling the strut with fluid and for inflating the strut. The instruction plate is usually attached near filler inlet and air valve assembly. It specifies the correct type of hydraulic fluid to use in the strut and the pressure to which the strut should be inflated. It is of utmost importance to become familiar with these instructions prior to filling a shock strut with hydraulic fluid or inflating it with air or nitrogen.

6.11 Shock Strut Operation

Figure 6.23 illustrates the inner construction of a shock strut. Arrows show the movement of the fluid during compression and extension of the strut. The compression stroke of the shock strut begins as the aircraft wheels touch the ground. As the center of mass of the aircraft moves downward, the strut compresses, and the lower cylinder or piston is forced upward into the upper cylinder. The metering pin is therefore moved up through the orifice. The taper of the pin controls the rate of fluid flow from the bottom cylinder to the top cylinder at all points during the compression stroke. In this manner, the greatest amount of heat is dissipated through the walls of the strut. At the end of the downward stroke, the compressed air in the upper cylinder is further compressed which limits the compression stroke of the strut with minimal impact. During taxi operations, the air in the tires and the strut combine to smooth out bumps.

Figure 6.21 – A shimmy damper helps control oscillations of the nose gear

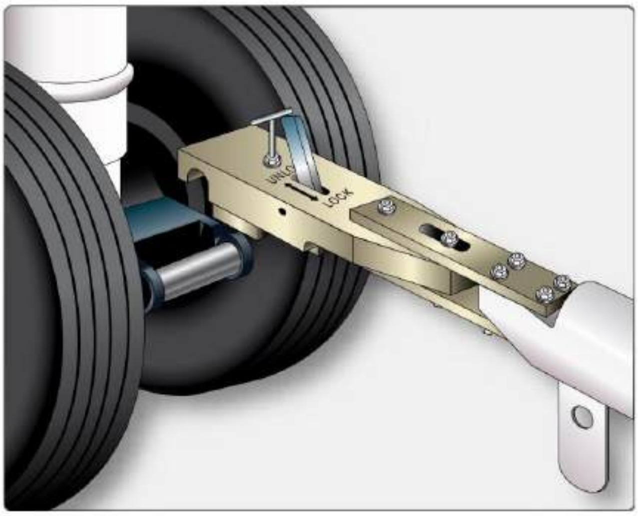


Figure 6.22 – A towing lug on a landing gear is the designed means for attaching a tow bar

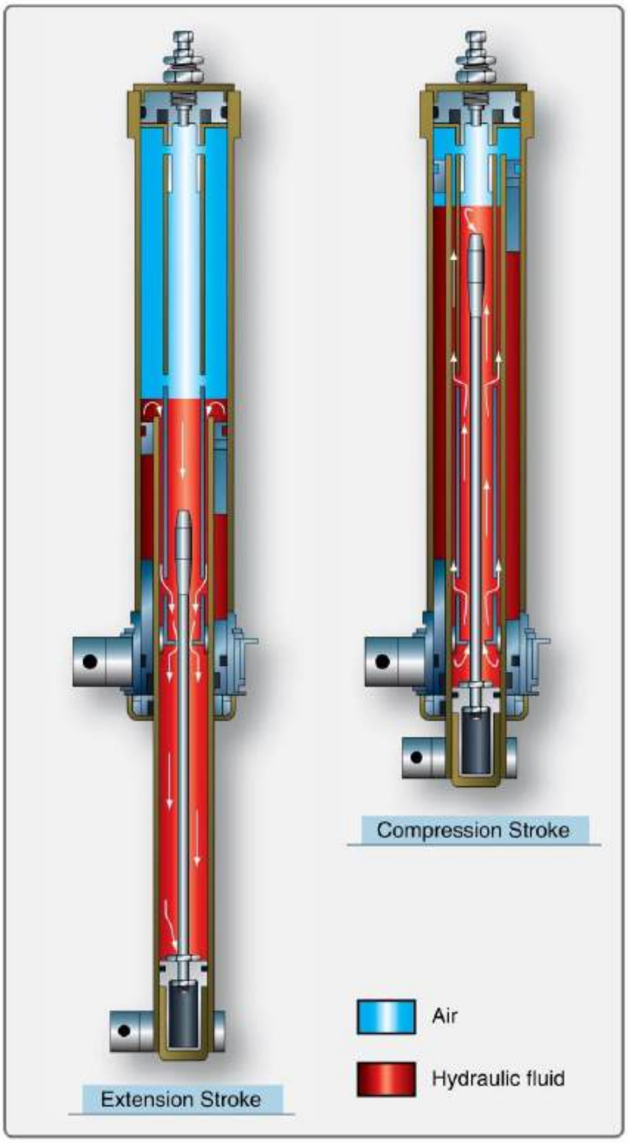


Figure 6.23 – Fluid flow during shock strut operation is controlled by the taper of the metering pin in the shock strut orifice

Insufficient fluid, or air in the strut, cause the compression stroke to not be properly limited. The strut could bottom out, resulting in impact forces to be transferred directly to the airframe through the metallic structure of the strut. In a properly serviced strut, the extension stroke of the shock strut operation occurs at the end of the compression stroke. Energy stored in the compressed air in the upper cylinder causes the aircraft to start moving upward in relation to the ground and lower strut cylinder as the strut tries to rebound to its normal position. Fluid is forced back down into the lower cylinder through restrictions and snubbing orifices. The snubbing of fluid flow during the extension stroke dampens the strut rebound and reduces oscillation caused by the spring action of the compressed air. A sleeve, spacer, or bumper ring incorporated into the strut limits the extension stroke.

Efficient operation of the shock struts requires that proper fluid and air pressure be maintained. To check the fluid level, most struts need to be deflated and compressed into the fully compressed position. Deflating a shock strut can be a dangerous operation. The technician must be thoroughly familiar with the operation of the high-pressure service valve found at the top of the strut's upper cylinder. Refer to the manufacturer's instructions for proper deflating technique of the strut in question and follow all necessary safety precautions.

Two common types of high pressure strut servicing valves are illustrated in Figure 6.24. The AN6287-1 valve in Figure 6.24 *A* has a valve core assembly and is rated to 3,000 pounds per square inch (psi). However, the core itself is only rated to 2,000 psi. The MS28889-1 valve in Figure 6.24 *B* has no valve core. It is rated to 5,000 psi. The swivel nut on the AN6287-1 valve is smaller than the valve body hex. The MS28889-1 swivel nut is the same size as the valve body hex. The swivel nuts on both valves engage threads on an internal stem that loosens or draws tight the valve stem to a metal seat.

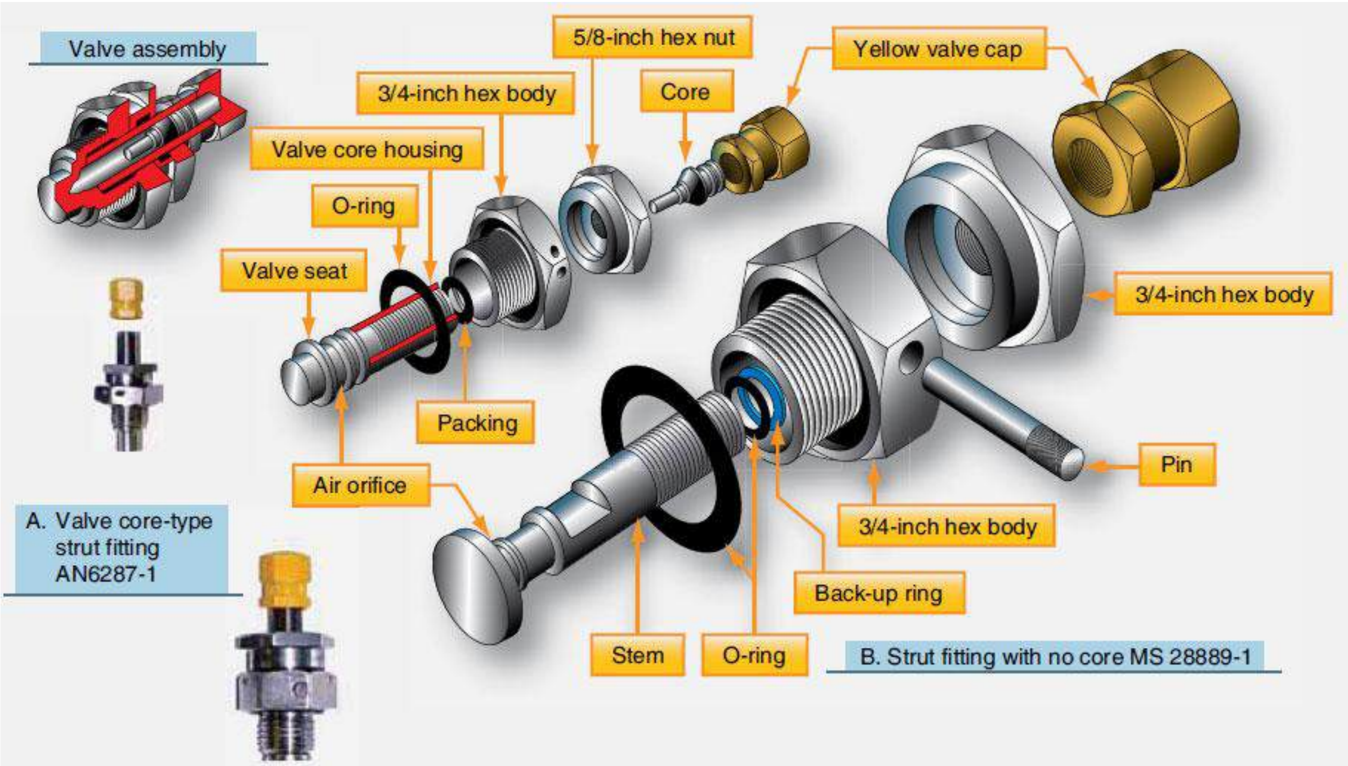


Figure 6.24 – Valve core-type (*A*) and core-free valve fittings (*B*) are used to service landing gear shock struts

6.12 Aircraft Wheels

Aircraft wheels are an important component of a landing gear system. With tires mounted upon them, they support the entire weight of the aircraft during taxi, takeoff, and landing. The typical aircraft wheel is lightweight, strong, and made from aluminum alloy. Some magnesium alloy wheels also exist. Early aircraft wheels were of single piece construction, much the same as the modem automobile wheel. As aircraft tires were improved for the purpose they serve, they were made stiffer to better absorb the forces of landing without blowing out or separating from the rim. Stretching such a tire over a single piece wheel rim was not possible. A two-piece wheel was developed. Early two-piece aircraft wheels were essentially one-piece wheels with a removable rim to allow mounting access for the tire. These are still found on older aircraft (Figure 6.25). Later, wheels with two nearly symmetrical halves were developed. Nearly all modem aircraft wheels are of this two piece construction (Figures 6.26 and 6.27).

6.13 Wheel Construction

The typical modern two-piece aircraft wheel is cast or forged from aluminum or magnesium alloy. The halves are bolted together and contain a groove at the mating surface for an o-ring, which seals the rim since most modern aircraft utilize tubeless tires. The bead seat area of a wheel is where the tire actually contacts the wheel. It is the critical area that accepts the significant tensile loads from the tire during landing. To strengthen this area during manufacturing, the bead seat area is typically rolled to prestress it with a compressive stress load.

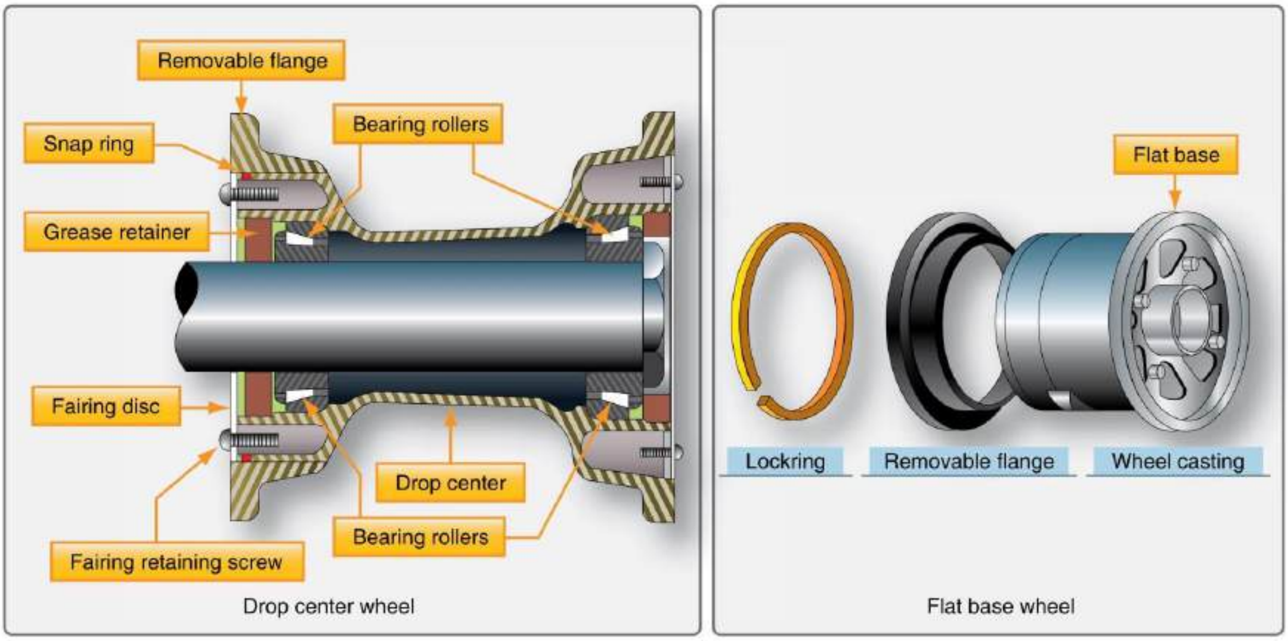


Figure 16.25 – Removable flange wheels found on older aircraft are either drop center or flat base types

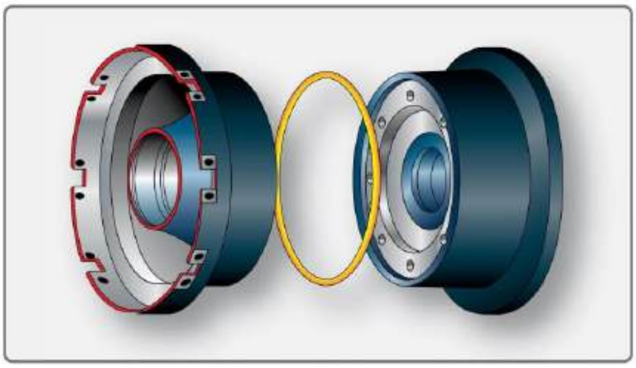


Figure 6.26 – Two-piece split-wheel aircraft wheels found on modern light aircraft

6.14 Inboard Wheel Half

Wheel halves are not identical. The primary reason for this is that the inboard wheel half must have a means for accepting and driving the rotor(s) of the aircraft brakes that are mounted on both main wheels. Tangs on the rotor are fitted into steel reinforced key ways on many wheels. Other wheels have steel keys bolted to the inner wheel halves. These are made to fit slots in the perimeter of the brake rotor. Some small aircraft wheels have provisions for bolting the brake rotor to the inner wheel half. Regardless, the inner wheel half is distinguishable from the outer wheel half by its brake mounting feature (Figure 6.27).

Both wheel halves contain a bearing cavity formed into the center that accepts the polished steel bearing cup, tapered roller bearing, and grease retainer of a typical wheel bearing set-up. A groove may also be machined to accept a retaining clip to hold the bearing assembly in place when the wheel assembly is removed. The wheel bearings are a very important part of the wheel assembly and are discussed in a later section of this chapter.

The inner wheel half of a wheel used on a high performance aircraft is likely to have one or more thermal plugs (Figure 6.28). During heavy braking, temperatures can become so great that tire temperature and pressure rise to a level resulting in explosion of the wheel and tire assembly. The thermal plug core is filled with a low melting point alloy. Before tire and wheel temperatures reach the point of explosion, the core melts and deflates the tire. The tire must be removed from service, and the wheel must be inspected in accordance with the wheel manufacturer's instructions before return to service if a thermal plug melts. Adjacent wheel assemblies should also be inspected for signs of damage. A heat shield is commonly installed under the inserts designed to engage the brake rotor to assist in protecting the wheel and tire assembly from overheating.

An overinflation safety plug may also be installed in the inner wheel half. This is designed to rupture and release all of the air in the tire should it be over inflated. The fill valve is also often installed in the inner wheel half with the stem extending through holes in the outer wheel half to permit access for inflation and deflation.

Figure 16.27 – Keys on the inner wheel half of an aircraft wheel used to engage and rotate the rotors of a disc brake

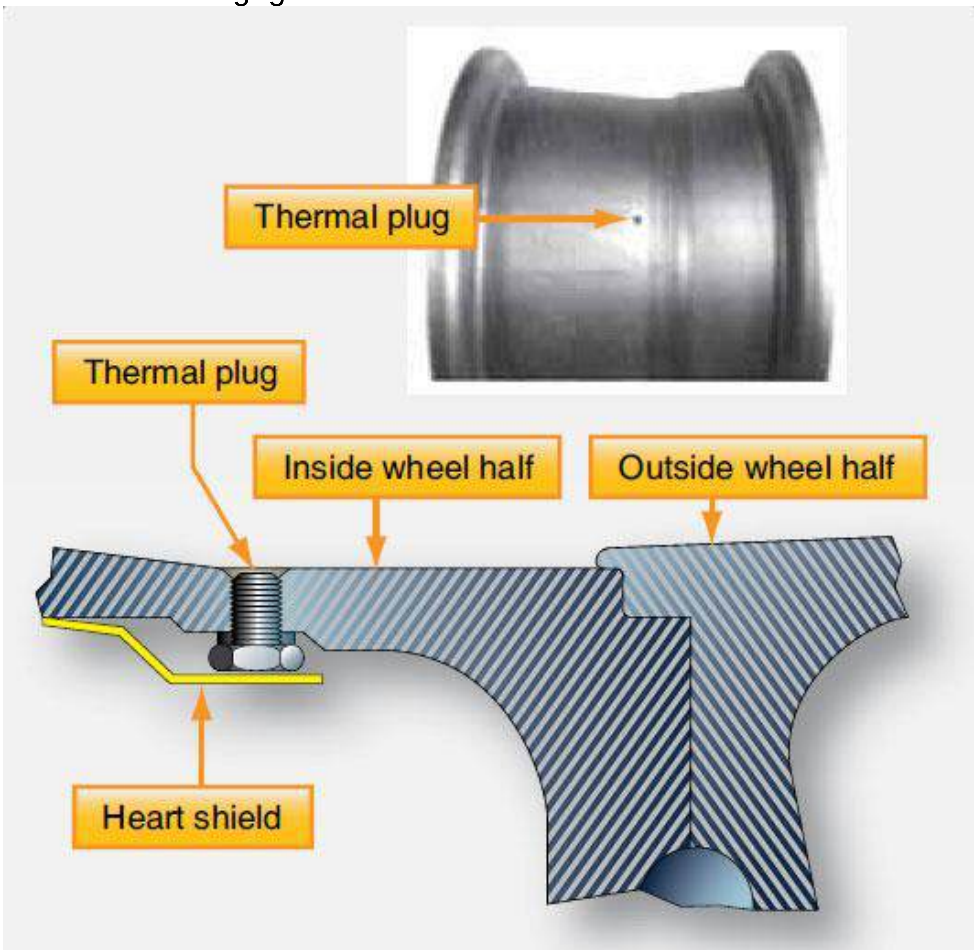


Figure 16.28 – Heavy use of the aircraft brakes can cause tire air temperature and pressure to rise to a level resulting in explosion of the wheel assembly. To alleviate this, thermal plug(s) mounted in the inner wheel half of a high performance aircraft wheels are made with a fusible core that melts and releases the air from the tire before explosion

6.15 Outboard Wheel Half

The outboard wheel half bolts to the inboard wheel half to make up the wheel assembly upon which the tire is mounted. The center boss is constructed to receive a bearing cup and bearing assembly as it does on the inboard wheel half. The outer bearing and end of the axle is capped to prevent contaminants from entering this area. Aircraft with anti-skid brake systems typically mount the wheel-spin transducer here. It is sealed and may also serve as a hub cap. The 737 outer wheel half illustrated in Figure 6.29 also has a hub cap fairing over the entire wheel half. This is to fair it with the wind since the outer wheel half does not close behind a gear door on this aircraft. Hub caps may also be found on fixed gear aircraft.

The outboard wheel half provides a convenient location of the valve stem used to inflate and deflate tubeless tires. Alternately, it may contain a hole through which a valve stem extension may pass from the inner wheel half or the valve stem itself may fit through such a hole if a tube-type tire is used.

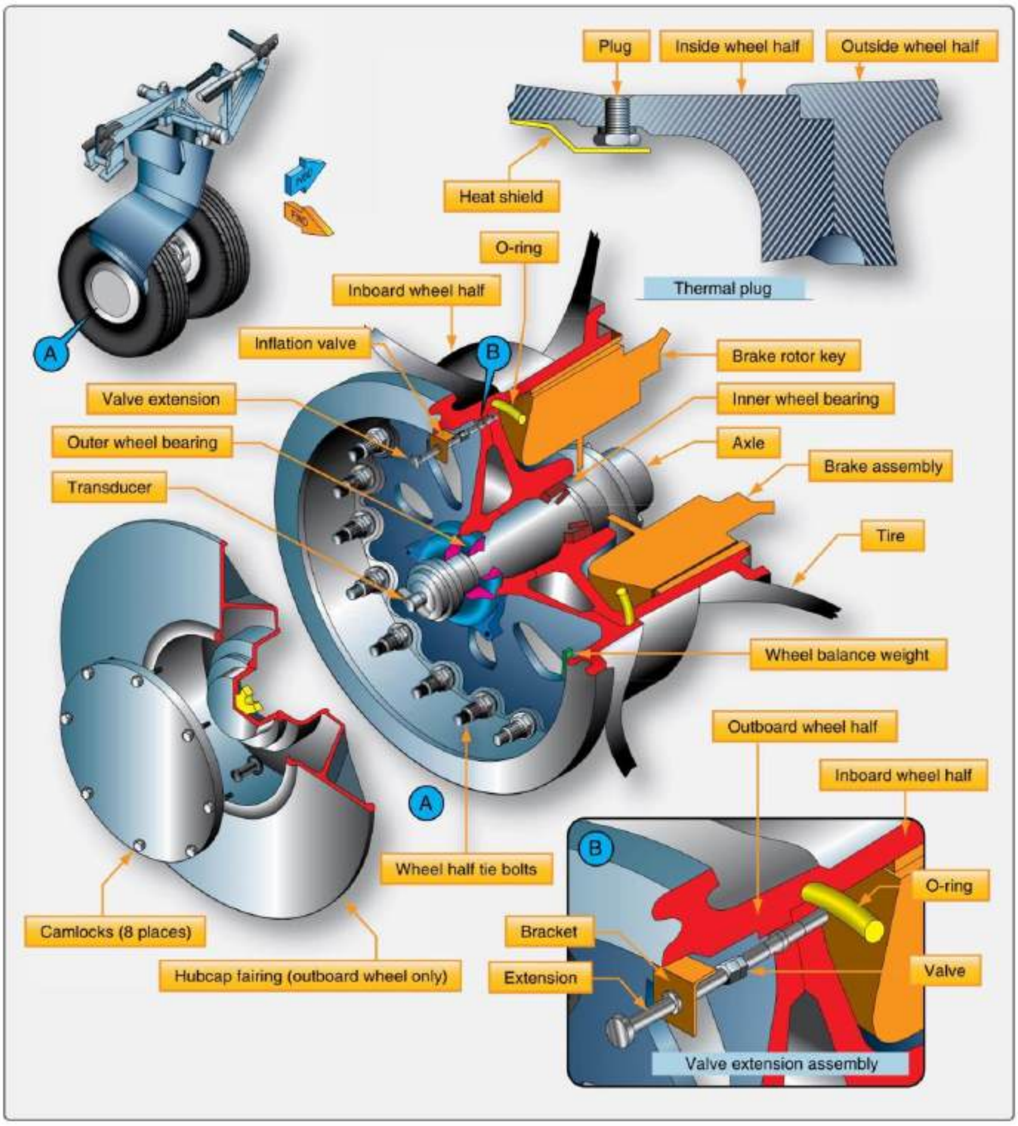


Figure 6.29 – Features of a two piece aircraft wheel found on a modern airliner

6.16 Aircraft Tires and Tubes

Aircraft tires may be tube-type or tubeless. They support the weight of the aircraft while it is on the ground and provide the necessary traction for braking and stopping. The tires also help absorb the shock of landing and cushion the roughness of takeoff, rollout, and taxi operations. Aircraft tires must be carefully maintained to perform as required. They accept a variety of static and dynamic stresses and must do so dependably in a wide range of operating conditions.

6.17 Tire Classification

Aircraft tires are classified in various ways including by: type, ply rating, whether they are tube-type or tubeless, and whether they are bias ply tires or radials. Identifying a tire by its dimensions is also used. Each of these classifications is discussed as follows.

6.18 Types

A common classification of aircraft tires is by type as classified by the United States Tire and Rim Association. While there are nine types of tires, only Types I, III, VII, and VIII, also known as a Three-Part Nomenclature tires, are still in production.

Type I tires are manufactured, but their design is no longer active. They are used on fixed gear aircraft and are designated only by their nominal overall diameter in inches. These are smooth profile tires that are obsolete for use in the modern aviation fleet. They may be found on older aircraft.

Type III tires are common general aviation tires. They are typically used on light aircraft with landing speeds of 160 miles per hour (mph) or less. Type III tires are relatively low- pressure tires that have small rim diameters when compared to the overall width of the tire. They are designed to cushion and provide flotation from a relatively large footprint. Type III tires are designated with a two number system. The first number is the nominal section width of the tire, and the second number is the diameter of the rim the tire is designed to mount upon (Figure 6.30).

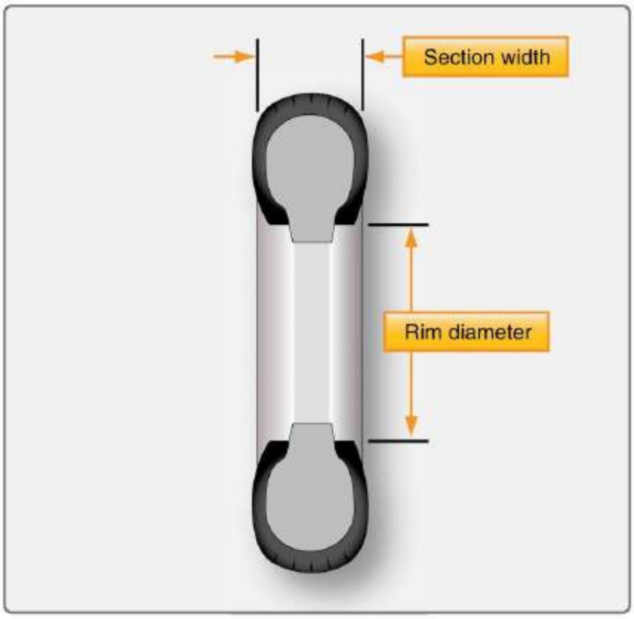


Figure 6.30 – Type III aircraft tires are identified via a two-number system with a (-) separating the numbers. The first number is the tire section width in inches. The second number is the rim diameter in inches. For example: 6.00-6 is a Cessna 172 tire that is 6.00 inches wide and fits on a rim that has a diameter of 6 inches

Type VII tires are high performance tires found on jet aircraft. They are inflated to high-pressure and have exceptional high load carrying capability. The section width of Type VII tires is typically narrower than Type III tires. Identification of Type VII aircraft tires involves a two-number system. An X is used between the two numbers. The first number designates the nominal overall diameter of the tire. The second number designates the section width (Figure 6.31).

Type VIII aircraft tires are also known as three-part nomenclature tires (Figure 6.32). They are inflated to very high-pressure and are used on high-performance jet aircraft. The typical Type VIII tire has relatively low profile and is capable of operating at very high speeds and very high loads. It is the most modern design of all tire types. The three- part nomenclature is a combination of Type III and Type

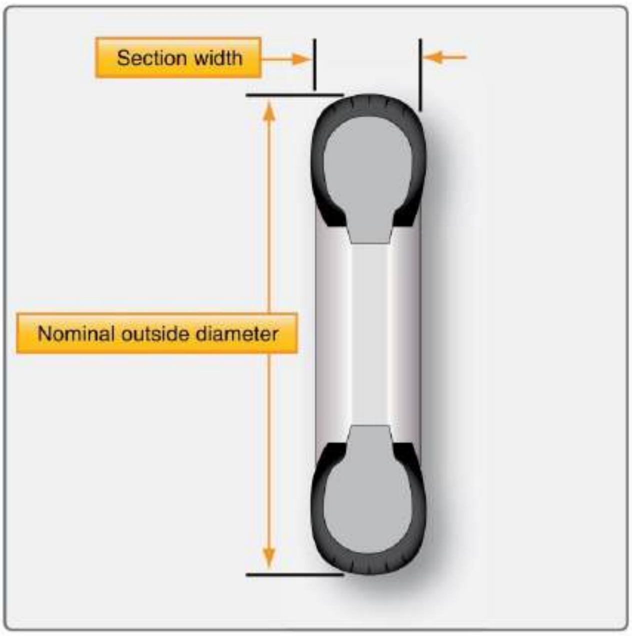


Figure 6.31 – A Type VII aircraft tire is identified by its two- number designation. The first number represents the tire's overall diameter in inches and the second number represents the section width in inches. Type VII designators separate the first and second number an "X. " For example: 26 X 6.6 identifies a tire that is 26 inches in diameter with a 6.6-inch nominal width

VII nomenclature where the overall tire diameter, section width, and rim diameter are used to identify the tire. The X and symbols are used in the same respective positions in the designator.

When three part nomenclature is used on a Type VIII tire, dimensions may be represented in inches or in millimeters. Bias tires follow the designation nomenclature and radial tires replace the with the letter R. For example, 30 X 8.8 R 15 designates a Type VIII radial aircraft tire with a 30-inch tire diameter, an 8.8-inch section width to be mounted on a 15-inch wheel rim.

A few special designators may also be found for aircraft tires. When a B appears before the identifier, the tire has a wheel rim to section width ratio of 60 to 70 percent with a bead taper of 15 degrees. When an H appears before the identifier, the tire has a 60 to 70 percent wheel rim to section width ratio but a bead taper of only 5 degrees.

6.19 Ply Rating

Tire plies are reinforcing layers of fabric encased in rubber that are laid into the tire to provide strength. In early tires, the number of plies used was directly related to the load the tire could carry. Nowadays, refinements to tire construction techniques and the use of modern materials to build up aircraft tires makes the exact number of plies somewhat irrelevant when determining the strength of a tire. However, a ply rating is used to convey the relative strength of an aircraft tire. A tire with a high ply rating is a tire with high strength able to carry heavy loads regardless of the actual number of plies used in its construction.

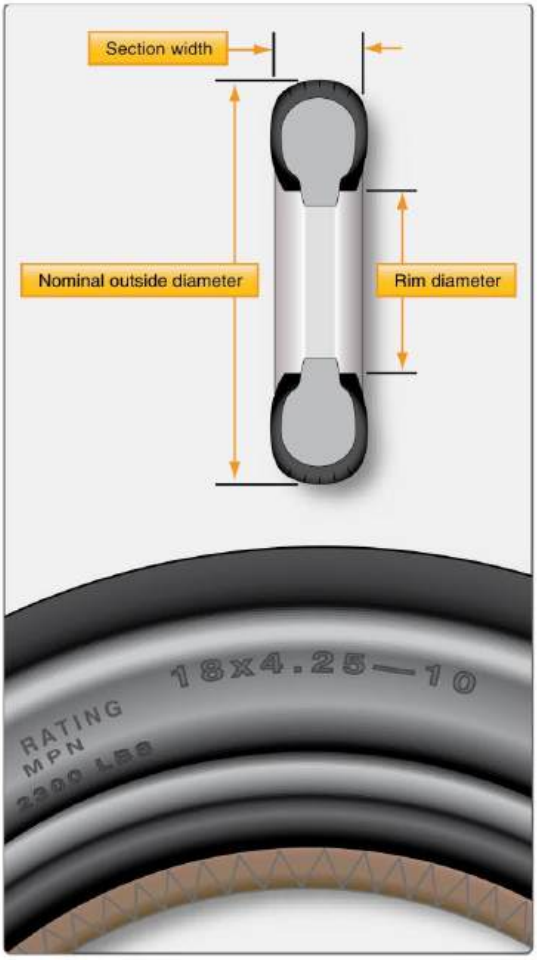


Figure 6.32 – A Type VIII or three-part nomenclature tire is identified by 3 parameters: overall diameter, section width, and rim diameter. They are arranged in that order with the first two separated by an "X" and the second two separated by "–".
For example: 18 X 4.25–10 designates a tire that is 18 inches in diameter with a 4.25-inch section width to be mounted on a 10- inch wheel rim

6.20 Tube-Type or Tubeless

As stated, aircraft tires can be tube-type or tubeless. This is often used as a means of tire classification. Tires that are made to be used without a tube inserted inside have an inner liner specifically designed to hold air. Tube-type tires do not contain this inner liner since the tube holds the air from leaking out of the tire. Tires that are meant to be used without a tube have the word tubeless on the sidewall. If this designation is absent, the tire requires a tube. Consult the aircraft manufacturer's maintenance information for any allowable tire damage and the use of a tube in a tubeless tire.

6.21 Bias Ply or Radial

Another means of classifying an aircraft tire is by the direction of the plies used in construction of the tire, either bias or radial. Traditional aircraft tires are bias ply tires. The plies are wrapped to form the tire and give it strength. The angle of the plies in relation to the direction of rotation of the tire varies between 30° and 60°. In this manner, the plies have the bias of the fabric from which they are constructed facing the direction of rotation and across the tire. Hence, they are called bias tires. The result is flexibility as the sidewall can flex with the fabric plies laid on the bias (Figure 6.33).

Figure 6.33 – A bias ply tire has the fabric bias oriented with and across the direction of rotation and the sidewall. Since fabric can stretch on the bias, the tire is flexible, and can absorb loads. Strength is obtained by adding plies

Some modern aircraft tires are radial tires. The plies in radial tires are laid at a 90° angle to the direction of rotation of the tire. This configuration puts the non-stretchable fiber of the plies perpendicular to the sidewall and direction of rotation. This creates strength in the tire allowing it to carry high loads with less deformation (Figure 6.34).

6.22 Tire Construction

An aircraft tire is constructed for the purpose it serves. Unlike an automobile or truck tire, it does not have to carry a load for a long period of continuous operation. However, an aircraft tire must absorb the high impact loads of landing and be able to operate at high speeds even if only for a short time. The deflection built into an aircraft tire is more than twice that of an automobile tire. This enables it to handle the forces during landings without being damaged. Only tires designed for an aircraft as specified by the manufacturer should be used.

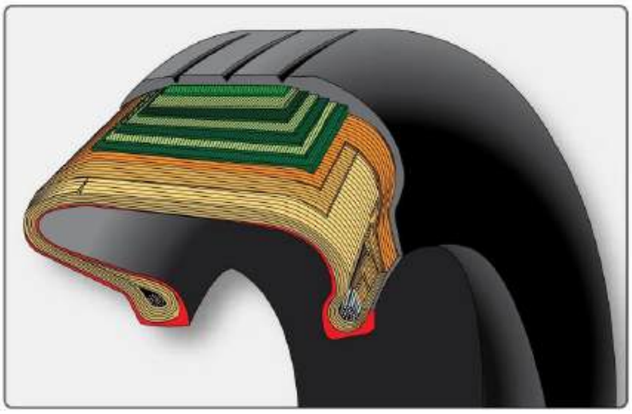


Figure 6.34 – A radial tire has the fiber strands of the ply fabric oriented with and at 90° to the direction of rotation and the tire sidewall. This restricts flexibility directionally and the flexibility of the sidewall while it strengthens the tire to carry heavy loads

It is useful to the understanding of tire construction to identify the various components of a tire and the functions contributed to the overall characteristics of a tire. Refer to Figure 6.35 for tire nomenclature used in this discussion.

6.23 Bead

The tire bead is an important part of an aircraft tire. It anchors the tire carcass and provides a dimensioned, firm mounting surface for the tire on the wheel rim. Tire beads are strong. They are typically made from high-strength carbon steel wire bundles encased in rubber. One, two, or three bead bundles may be found on each side of the tire depending on its size and the load it is designed to handle. Radial tires have a single bead bundle on each side of the tire. The bead transfers the impact loads and deflection forces to the wheel rim. The bead toe is closest to the tire centerline and the bead heel fit against the flange of the wheel rim.

An apex strip is additional rubber formed around the bead to give a contour for anchoring the ply turn-ups. Layers of fabric and rubber called flippers are placed around the beads to insulate the carcass from the beads and improve tire durability. Chafers are also used in this area. Chafer strips made of fabric or rubber are laid over the outer carcass plies after the plies are wrapped around the beads. The chafers protect the carcass from damage during mounting and demounting of the tire. They also help reduce the effects of wear and chafing between the wheel rim and the tire bead especially during dynamic operations.

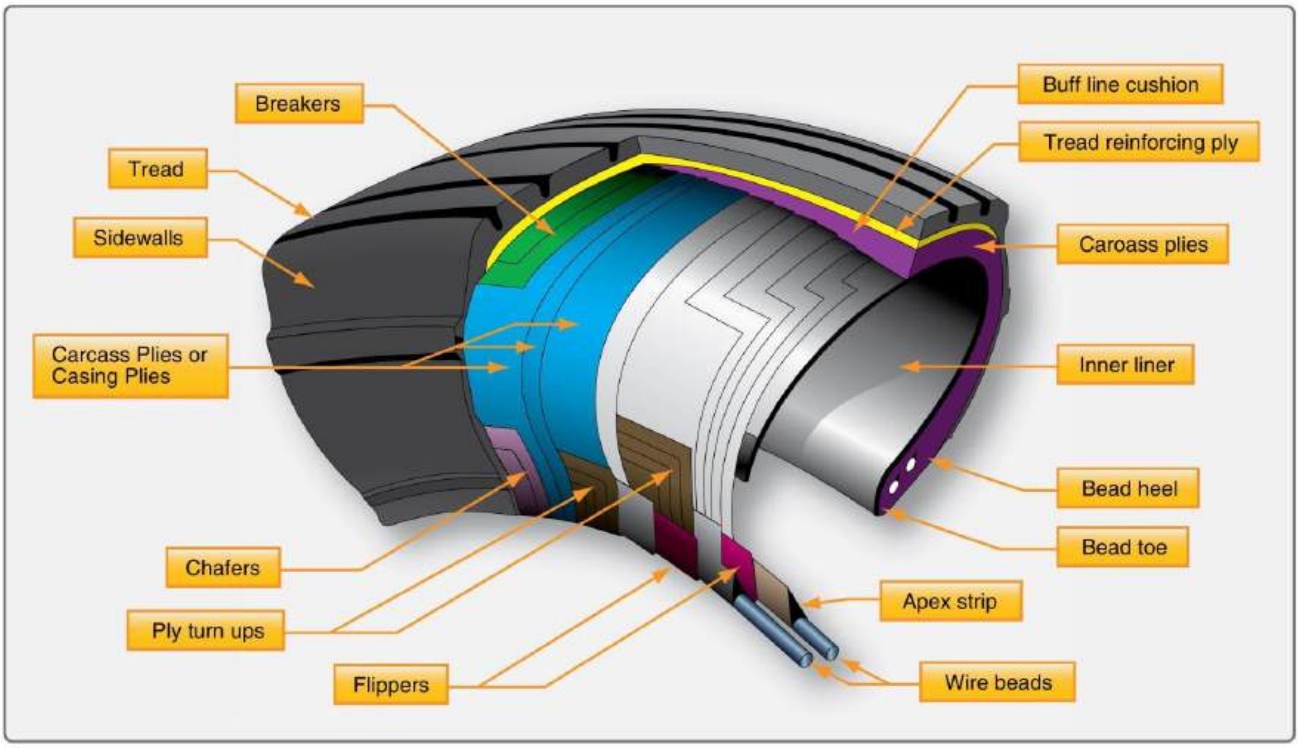


Figure 6.35 – Construction nomenclature of an aircraft tire.

6.24 Carcass Plies

Carcass plies, or casing plies as they are sometimes called, are used to form the tire. Each ply consists of fabric, usually nylon, sandwiched between two layers of rubber. The plies are applied in layers to give the tire strength and form the carcass body of the tire. The ends of each ply are anchored by wrapping them around the bead on both sides of the tire to form the ply turn-ups. As mentioned, the angle of the fiber in the ply is manipulated to create a bias tire or radial tire as desired. Typically, radial tires require fewer plies than bias tires.

Once the plies are in place, bias tires and radial tires each have their own type of protective layers on top of the plies but under the tread of the running surface of the tire. On bias tires, these single or multiple layers of nylon and rubbers are called tread reinforcing plies. On radial tires, an undertread and a protector ply do the same job. These additional plies stabilize and strengthen the crown area of the tire. They reduce tread distortion under load and increase stability of the tire at high speeds. The reinforcing plies and protector plies also help resist puncture and cutting while protecting the carcass body of the tire.

6.25 Tread

The tread is the crown area of the tire designed to come in contact with the ground. It is a rubber compound formulated to resist wear, abrasion, cutting, and cracking. It also is made to resist heat build-up. Most modern aircraft tire tread is formed with circumferential grooves that create tire ribs. The grooves provide cooling and help channel water from under the tire in wet conditions to increase adhesion to the ground surface. Tires designed for aircraft frequently operated from unpaved surfaces may have some type of cross-tread pattern. Older aircraft without brakes or brakes designed only to aid in taxi may not have any grooves in the tread. An all-weather tread may be found on some aircraft tires. This tread has typical circumferential ribs in the center of the tire with a diamond patterned cross tread at the edge of the tire (Figure 6.36).

The tread is designed to stabilize the aircraft on the operating surface and wears with use. Many aircraft tires are designed with protective undertread layers as described above. Extra tread reinforcement is sometimes accomplished with breakers. These are layers of nylon cord fabric under the tread that strengthen the tread while protecting the carcass plies. Tires with reinforced tread are often designed to be re-treaded and used again once the tread has worn beyond limits. Consult the tire manufacturer’s data for acceptable tread wear and re-tread capability for a particular tire.

Figure 6.36 – Aircraft tire treads are designed for different uses. A is a rib tread designed for use on paved surfaces. It is the most common aircraft tire tread design. B is a diamond tread designed for unpaved runways. C is an all-weather tread that combines a ribbed center tread with a diamond tread pattern of the edges. D is a smooth tread tire found on older, slow aircraft without brakes designed for stopping. E is a chine tire used on the nose gear of aircraft with fuselage mounted jet engines to deflect runway water away from the engine intake(s)

6.26 Sidewall

The sidewall of an aircraft tire is a layer of rubber designed to protect the carcass plies. It may contain compounds designed to resist the negative effects of ozone on the tire. It also is the area where information about the tire is contained. The tire sidewall imparts little strength to the cord body. Its main function is protection.

The inner sidewall of a tire is covered by the tire inner liner. A tube-type tire has a thin rubber liner adhered to the inner surface to prevent the tube from chafing on the carcass plies. Tubeless tires are lined with a thicker, less permeable rubber. This replaces the tube and contains the nitrogen or inflation air within the tire and keeps from seeping through the carcass plies.

The inner liner does not contain 100 percent of the inflation gas. Small amounts of nitrogen or air seep through the liner into the carcass plies. This seepage is released through vent holes in the lower outer sidewall of the tires. These are typically marked with a green or white dot of paint and must be kept unobstructed. Gas trapped in the plies could expand with temperature changes and cause separation of the plies, thus weakening the tire leading to tire failure. Tube-type tires also have seepage holes in the sidewall to allow air trapped between the tube and the tire to escape (Figure 6.37).

6.27 Chine

Some tire sidewalls are mounded to form a chine. A chine is a special built-in deflector used on nose wheels of certain aircraft, usually those with fuselage mounted engines. The chine diverts runway water to the side and away from the intake of the engines (Figure 6.36 *E*). Tires with a chine on both sidewalls are produced for aircraft with a single nose wheel.

Figure 6.37 – A sidewall vent marked by a colored dot must be kept free from obstruction to allow trapped air or nitrogen to escape from the carcass plies of the tire

CONCLUSION

1. Air transport is one of the youngest forms of transport and undoubtedly continues to make a major contribution to the exploitation of world resources. The bulk of international passenger travel today moves by air, and in air freight valuation terms a significant proportion of world trade.

The development of civil aviation was particularly fostered during the Second World War (1939-45), which aided very considerably the advancement of this mode of transport in technical terms.

2. Most of the advances in air transportation will materialize within the next few years. The largest airplane ever designed for commercial service, capable of seating nearly 500 passengers, is already being built.

Supersonic transport prototypes now in development are forerunners of a new generation of 1,800 miles per hour passenger jet-liners.

The “ideal” short-haul air transport is a vertical or short take-off and landing aircraft that can fly 30 to 45 passengers right into the heart of a city or its suburbs trips up to 260 miles.

3. Mankind has entered an age of high speeds, pressures, and temperatures which could be generated and withstood only with the help of new and hitherto unknown materials.

In the 1920s the top speed of an airplane was not more than 200 kilometres per hour, the load per square metre of the wing area was about 50 kilograms. The main construction material was wood. In our day, the speed of aircraft, even passenger planes, is approaching 3,000 kilometres per hour, loads may be as high as 600 kilograms per square metre of wing. The turbine that drives such an aircraft is not only a miracle of design, it is also a miracle of materials strength. Its blades, for example, rotate at a tremendous speed and at the temperature greater than 1,000 Centigrade.

The given examples are sufficient to indicate the complexity of materials studies today and the extent to which progress in the near or more distant future depends on them.

4. Of tremendous importance is the creation of new materials. Chemists engaged in polymer research have produced the world’s best synthetic materials.

Metallurgists studying a new class of aluminium alloys have produced a very durable alloy which is being used in aircraft and rocket engineering. The alloy helps reduce the weight of apparatus substantially, thereby effecting a considerable saving of materials.

Plastics are employed in a number of aircraft engine applications and have successfully displaced metals in jet turbine impellers where the high fatigue resistance of the material is of great importance. If suitable higher temperature plastics were developed, it is quite feasible that turbines will one day be all of plastic construction.

At present a great deal of research and development is being carried out to produce special grades of plastics for space vehicles.

For space travel, resistance to cosmic radiation is an important consideration. Many plastic materials possess this property, and also offer the advantage of light weight. Astronaut couches, space capsules, missile fuel cases are manufactured of plastic materials.

5. Some ideas of rapid air transportation are on the drawing boards, some may never get off. Some are already under way and operational, while others may not take shape until the next decade. But changes are taking place, and there are more to come.

THE BIBLIOGRAPHY

1. Болховитинов, В. Ф. Пути развития летательных аппаратов [Текст] / В. Ф. Болховитинов. – М. : ОБОРОНГИЗ, 1962. – 132 с.

2. Петров, К. П. О достижениях аэродинамики летательных аппаратов. Время, события, люди [Текст] / К. П. Петров.– М. : Едиториал УРСС, 2009. – 224 с.

3. Байдаков, В. Б. Аэродинамика и динамика полета летательных аппаратов [Текст] : учеб. для учащихся авиационных техникумов / В. Б. Байдаков, А. С. Клумов. – М. : Машиностроение, 1979. – 344 с.

4. Airplane Flying Handbook: handbook – America: United States Department of Transportation, Federal Aviation Administration, Airman Testing Standards Branch, AFS-630, P.O. Box 25082, Oklahoma City, OK 73125, 2016. – 348 p.

5. Aeronautics Guide [Электронный ресурс] / Wing Configurations, Flight Control Surfaces, Landing Gear, History of Aircraft Structures – Электрон. дан. – Режим доступа: http://okigihan.blogspot.com, свободный. – Загл. с экрана. – Яз. англ.

6. National Aeronautics and Space Administration [Электронный ресурс] / NASA’s and Boeing’s Programs – Электрон. дан. – NASA Official: Brian Dunbar – Режим доступа: http:// https://www.nasa.gov, свободный. – Загл. с экрана. – Яз. англ.

7. Aircraft Spruce and Specialty Co [Электронный ресурс] / Characteristics and specifications of instruments, aircraft engines, aviation headsets, landing gear components, and composite materials – Электрон. дан. – East-West-Canada, 1995–2018. – Режим доступа: http://www.aircraftspruce.com, свободный. – Загл. с экрана. – Яз. англ.

8. Flight Mechanic [Электронный ресурс] / Basic Aviation Maintenance, Powerplants, Airframes rials – Электрон. дан. – 2017. – Режим доступа: http://www.flight-mechanic.com, свободный. – Загл. с экрана. – Яз. англ.

9. U.S. Department of Transportation, Federal Aviation Administration [Электронный ресурс] / Aircraft Handbooks & Manuals – Электрон. дан. – Washington – Режим доступа: https://www.faa.gov, свободный. – Загл. с экрана. – Яз. англ.

10. История явлений и событий [Электронный ресурс] / Авиация – Электрон. дан. – М.: Летопись – исторический проект – Режим доступа: http://www.letopis.info/themes/aviation/, свободный. – Загл. с экрана. – Яз. рус.

CONTENTS

Навчальне видання

Брега Дмитро Андрійович,

Воронько Віталій Володимирович,

Тіняков Дмитро Васильович,

Воронько Ірина Олексіївна

ВВЕДЕННЯ В АЕРОКОСМІЧНУ ТЕХНІКУ

(Англійською мовою)

Редактор С. В. Опаріна

Технічний редактор Л. О. Кузьменко

Зв. план, 2018
Підписано до друку 13.07.2018
Ум. друк. арк. 4,8. Обл.-вид. арк. 5,44. Електронний ресурс

Видавець і виготовлювач
Національний аерокосмічний університет ім. М. Є. Жуковського
«Харківський авіаційний інститут»
61070, Харків-70, вул. Чкалова, 17
http://www.khai.edu
Видавничий центр «ХАІ»
61070, Харків-70, вул. Чкалова, 17
izdat@khai.edu

Свідоцтво про внесення суб'єкта видавничої справи
до Державного реєстру видавців, виготовлювачів і розповсюджувачів
видавничої продукції сер. ДК № 391 від 30.03.2001