Introduction to Aviation Engineering

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An extensive coverage

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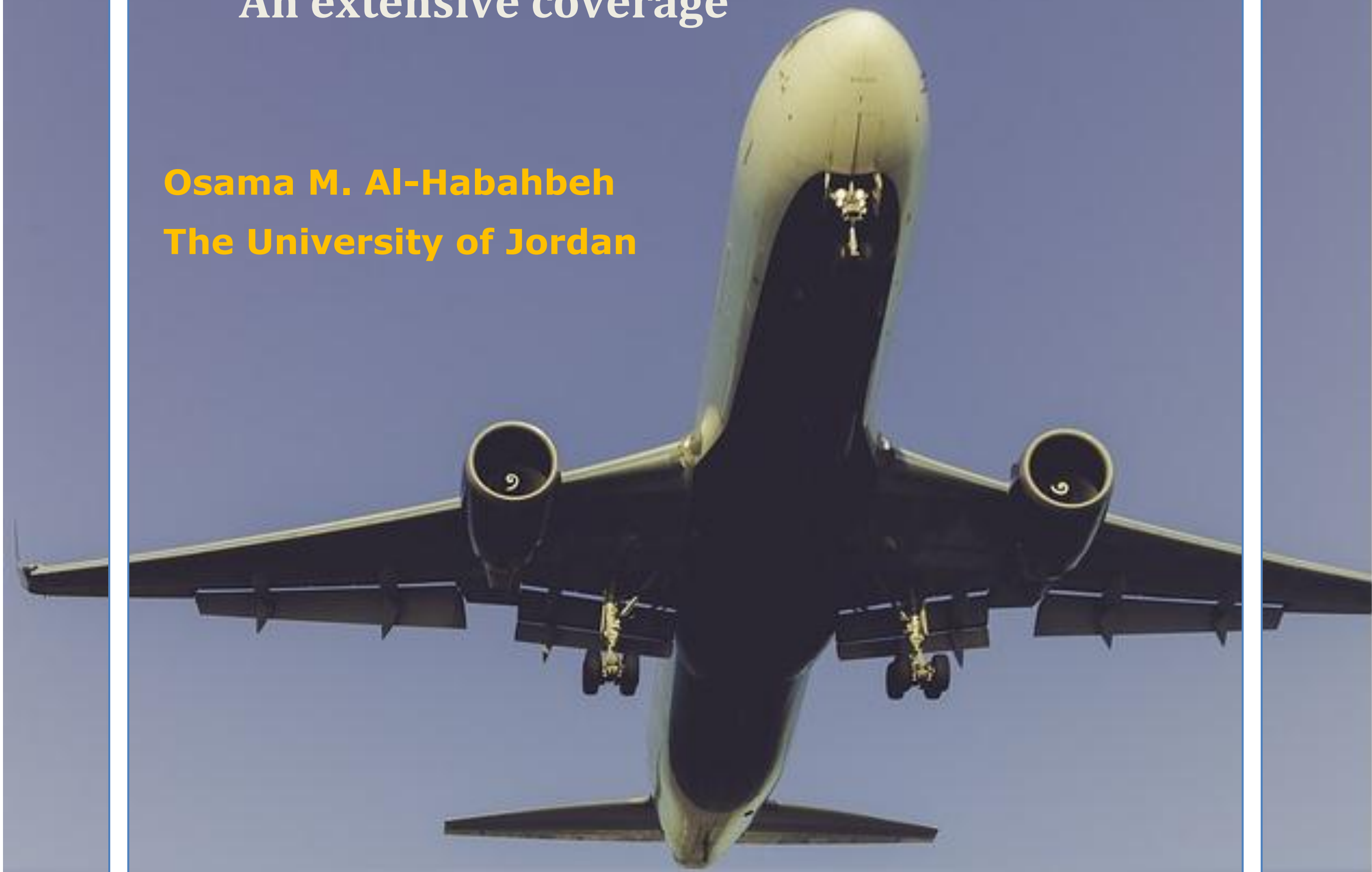

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Introduction

Aviation has become the main passenger transportation method worldwide. Due to this fact, it is considered a pivotal economic activity for all countries. Cargo transportation is another major activity that is growing as well. As the case with every major economic activity, it is desirable to make it more widespread and affordable for more people. Therefore, engineering methods come to play in this regard. From the beginning of aviation, engineering has been the backbone of its development. Today, the field of aviation is too complicated. It has multiple facets ranging from international relations to simple office issues. Airline business could be the most diverse type of business, as the company has to deal with diverse issues in order to run its operations successfully. Due to the rapid expansion and growing complexity, engineers are called upon to play new roles in the airline, in addition to their traditional roles. Universities worldwide have the responsibility to train such engineers to fulfill the needs of the airline industry.

I was asked to teach an introductory course to aviation engineering at the University of Jordan. I started to look for a proper text book for the subject. However, all the existing books were specialized in certain areas of aviation engineering. Such as aeronautics, avionics, engines, etc. Other books talk about the management side of the business or the IT side where it has become much more important during the last few decades. That is when I started thinking about writing a book on the subject. I chose the title "Introduction to aviation engineering" to reflect the fact that the book deals with all aspects of aviation engineering, and not limited to aeronautical engineering. The majority of existing books are written by academics specialized in the subject area, while fewer books are authored by professional experts. Academic authors tend to restrict themselves to their area of specialization, so their books will not go beyond that. Whereas professional authors generally lack the knowledge about students' needs because they don't teach. Therefore, the resulting book would have more value for practicing engineers than for engineering students.

Due to my background as an associate professor with years of research and teaching experience, in addition to my professional experience as an airline senior engineer, I think this book should cover both the academic and the professional dimensions; the academic dimension ensures that the book is scientific and pedagogical enough to be used for teaching, while the professional dimension ensures that the book is fit as a reference for practicing engineers. This capability is supported by the fact that each chapter in the book starts by explaining the theoretical side of the subject and ends with practical examples used in the industry.

In order to cover all areas of aviation engineering, the book does not elaborate on subjects that should have been learnt in other basic courses like fluid mechanics. Nor it goes deep into technical background which is treated in more specialized courses like aerodynamics. As the title implies, the book can be used as an introductory course for new aerospace engineering students or as a familiarization course for other engineering students such as mechanical, electrical, etc., especially those planning an aviation career. In addition, the book is an excellent reference for pilots, dispatchers and other aviation professionals.

The book contains 16 chapters; chapter 1 presents a brief history about aviation in general. Chapter 2 introduces the basic flight fundamentals. Chapter 3 presents the different types of aircraft. Chapter 4 describes the main parts of an aircraft. Chapter 5 describes the structure of the aircraft body. Chapter 6 describes how aircraft is controlled and stabilized in the air and on the ground. Chapter 7 is dedicated to aircraft power plant explaining the different types of aircraft engines. Chapter 8 explains how aircraft operation is planned to be safe and efficient. Chapter 9 introduces the important subject of loading the aircraft while maintaining the essential balance. The main aircraft systems such as hydraulics, pneumatics, environmental control, avionics, electrical, navigation and communications are introduced in chapters 10 to 14. Chapter 15 introduces the main aspects of aircraft maintenance. Finally, chapter 15 covers the airport engineering side of the operation.

The material introduced in this book has been collected from a variety of sources; including years of professional experience, taught university courses, manufacturer training courses, research articles and conferences, as well as reliable references. The mission of this book is to provide basic foundation for all types of engineers starting a career in aviation, as well as students entering any aerospace, aeronautical, or aviation related program.

Osama M. H. Al-Habahbeh, PhD.
Amman, Jordan 18/08/2017

Chapter 1

Aviation History

1.1 Stone age to Renaissance

Flying had always been the dream of man since the dawn of time. Airplanes have been around for more than a century, but aviation started much earlier; The earliest flying vehicles were depicted by Mesopotamians around 7000 B.C. Ideas for flying vehicles were being thought of during the Ramayana period (500 B.C.). Ancient Chinese flew kites and small hot-air lanterns several hundred years BC. Around 200 B.C., Greek mythology depicted Daedalus and Icarus as flying Angles. In 887 A.D., Abbas bin Firnas made the first known attempt of manned flight. He covered his body with feathers and a couple of wings, and then jumped off a tower. He fell down due to the lack of a tail which was necessary to maintain balance. Around 1500 A.D., Leonardo da Vinci drew some simple models similar to Parachute and Helicopter that did not fly. He also suggested lighter-than air flight.

1.2 Industrial revolution era

The first hot-air balloon flight was made in 1782 by Montgolfier Brothers. The same inventors made the first manned hot air balloon flight in 1783. Lighter-than-air vehicles used hot air at first. Later hydrogen was used instead of hot air because it is lighter than air. However, hydrogen is highly explosive and can be triggered by just a spark. Tethered hot-air balloons were used in the first half of the 19th century and saw considerable action in several mid-century wars, most notably during the American Civil War in the 1860s, where observation balloons were used to monitor troops and artillery during the Battle of Petersburg.

Unpowered glider was tried by Otto Lilenthal (1848-1896) and Octave Chanute (1832-1910). During that period, several important developments took place; such as rigid frame aircraft, human controlled flight (weight shifting), wing design, and pitch control surfaces. In addition, the term aviation, noun of action from stem of Latin avis "bird" was coined in 1863 by Guillaume de La Landelle. Aircraft remote operation required the perfection of radio control, a concept proposed and demonstrated in 1895 and 1898, respectively, by Tesla. In addition, aileron control was invented by Glen Curtis (1878-1930). This progress had leaded the Wright brothers to make the first successful powered heavier-than-air flight in 1903, triggering an aviation boom.

1.3 Record-breaking era

The first aircraft to fly across the English Channel in 1909 was invented by Louis Bleriot. The first US coast to coast flight was flown in 1911 by Cal Rogers and took 84 Days and 74 Landings. During that period, several inventions were made; such as aircraft motors, propellers, three axis flight controls, wheeled landing gear, and float planes. As a result, air races became popular and higher performance had been recorded. In World War I (1914-1918), single-engine and multi-engine aircraft were used, as well as airships, while propellers continued to be used to power planes. After the end of World War I, aviation spread rapidly because of surplus aircraft readily available, numerous trained pilots, great interest in aviation from public, and speed and distance records. Airlines started flying passengers and mail. They went from crude airplanes to metal high performance aircraft in a few short years. The ford TIR-Motor (14 passengers) and the Douglas DC-3 (24 passengers) were two of those early airliners.

The first unmanned aircraft was demonstrated in 1916. It was the Hewitt-Sperry Automatic Airplane. This aircraft was made possible by the use of gyroscopic devices to provide directional guidance. However, due to lack of accuracy, interest on automatic planes was lost.

The period from 1918 to 1939 was distinguished with speed and distance records flights, such as New York to Paris flight in 33.5 hours in 1927. In the US, the 1920s and 1930s was a period of rapid growth in the airline industry, which necessitated the creation of an air transport management system of airways, navigation aids, airdromes, weather stations, control centers and Radios. In 1924, for the first time in history, a radio-controlled aircraft was flown remotely through all phases of flight; takeoff, maneuver, and landing. First around the world flight was flown by world cruiser aircraft in the same year. In Britain, experiments with unmanned aircraft took place throughout the 1920s. In 1933, the Royal Navy used the Queen Bee target drone for the first time; a biplane successfully employed for gunnery practice. The first purpose-built rocket plane "Opel RAK.1" was flown in Germany in 1929.

1.4 Lighter-than-air aviation

Lighter-than-air aviation had seen developments in the form of powered balloons. Those balloons were called different names depending on the country; such as Blimps in the US, Airships in the UK, Dirigibles in France, and Zeppelins in Germany. They were successfully used for some time until 1937, when Hindenburg, a German hydrogen airship exploded and crashed on landing in New Jersey. That accident marked the end of the airship commercial transport era. Nowadays, airships use helium which is an inert gas and much safer than Hydrogen. However, it is more expensive than Hydrogen.

1.5 Jet airplanes

One of the major developments that took place in the 1930s was the invention of the turbojet engine. The idea of jet engines dates back to the invention of the aeolipile in the first century AD. The earliest attempts at air-breathing jet engines were hybrid designs in which an external power source first compressed air, which was then mixed with fuel and burned for jet thrust. Examples of this type of design were the Caproni Campini N.1, and the Japanese Tsu-11 engine intended to power Ohka kamikaze planes towards the end of World War II. Even before the start of World War II, engineers were beginning to realize that engines driving propellers were self-limiting in terms of the maximum performance which could be attained; the limit was due to issues related to propeller efficiency, which declines as blade tips approach the speed of sound. This was the motivation behind the development of the gas turbine jet engine in 1937 by Heinkel. The first turbojet aircraft to fly was the He178 of the German Air Force in 1939. The jet engine enables the airplane to fly faster and higher than a propeller-powered airplane.

1.6 World war II era

During World War II, the British introduced the Spitfire fighter, which had new radar technology. While dozens of Japanese fighters and bombers, launched from aircraft carriers, destroyed the U.S Pacific fleet at Pearl Harbor in 1941. The Americans launched long-range bombers, such as the B-17 “Flying Fortress” and the B-29, a large bomber used to drop the atomic bomb on Japan. On the sea front, aircraft carriers were the largest ships used in the war; where a steam device was used to push the airplane for takeoff, and a hock in the back of the plane was used to stop it after landing by catching a wire located on the strip.

1.7 Evolution of civil aviation

The International Air Transport Association (IATA) was established in 1945 as a trade association of the world's airlines. The UN established a specialized agency called the International Civil Aviation Organization (ICAO) in 1947. ICAO codifies the standards of international air navigation and fosters the development of international air transport to ensure safe growth. As a result of the developments introduced during World War II, passenger air transport became faster and more comfortable. Jet planes were introduced; The first commercial jet aircraft was the De Havilland Comet introduced during the early 1950's, followed by the Boeing 707 and the Douglas DC-8. The B707 was the first jet "Air Force One" presidential aircraft. Both military fighters and bombers became capable of supersonic flight in the 1950's. The Federal Aviation Agency (FAA) was created in 1958 to regulate and oversee all aspects of American civil aviation.

The X-15, an experimental aircraft from NASA, flew at Mach 6.7 and altitude of 354,200 feet in 1963. Large commercial jet airliners were developed and put into service during the 1960's. These included the Douglas DC-10, Lockheed L-1011 and Boeing 747. During the 1960's and early 1970's the US was engaged in Vietnam War. Some of the aircraft used in the war were the F-4 Phantom, F-105 and B-52, as well as helicopters such as the UH-1 Huey and CH-47 Chinock.

In the 1960's and 1970's, general aviation grew largely; popular aircraft during that period were the Cessna, Piper, and Beechcraft. Commercial airliners became more economical. These aircraft include Boeing 757, 767, and MD-11. B747 was introduced in 1968 as the largest commercial jet. The Joint Aviation Authorities (JAA) started in 1970 as the joint airworthiness authority in Europe. Airbus A300, a twin-engine airliner that was more economical to operate than its rivals, entered service in 1974. In 1975, the Tu-144 entered service as the fastest supersonic commercial transport jet at Mach 2.35. The Mach 2 Concorde aircraft entered service in 1976, followed by A310 in 1978, and A320 in 1987. A320 family featured fly-by-wire technology and commonality in spare parts which made Airbus a major rival to Boeing, by threatening the status of B737, which managed to maintain its position as the best seller airliner worldwide since 1967. A380, a double-decker aircraft was introduced in 2005 as the largest commercial jet. Later in 2007 Boeing introduced Dreamliner as the first aircraft with composite body.

Chapter 2

Flight Fundamentals

2.1 Introduction

In this chapter, the basics of flight will be explained. Aircraft can be categorized into two broad categories; fixed-wing and rotary-wing. A third -but far less common- category is the flapping-wing aircraft, which is mostly found in small unmanned aerial vehicles (UAVs) or nano drones. Throughout this book, the term "aircraft" will be used to refer to all types of flying vehicles, whereas the term "airplane" will be used to refer to fixed-wing aircraft only. Whether the aircraft is fixed-wing or rotary-wing, it utilizes two wings or more to generate lift. The ability to fly was made possible by the forces created by the atmospheric air on the wing. When the wing moves through the air, the velocity of the air relative to the wing creates aerodynamic forces that lift the wing and consequently the aircraft. We will start by defining the basic aircraft speeds which are normally used in commercial jets:

- Indicated Air Speed (IAS):
  It is the number displayed on the airspeed indicator. It is practically useful because it is directly related to the aerodynamic forces affecting the aircraft. It is corrected for instrument errors.
- Calibrated Air Speed (CAS):
  It is the IAS corrected for the position error of the static port. That position error is greater when flying slow, with flaps down, or when the airplane is in a side slip.
- Equivalent Air Speed (EAS):
  It is the CAS corrected for the error due to the compressibility of the air. The compressibility error is only important when flying at a mach number higher than 0.4.
- True Air Speed (TAS):
  It is the speed in which the aircraft moves relative to the surrounding air. It equals the EAS corrected for the relative density of the air.
- Ground speed (GS)
  It is the horizontal speed in which the aircraft moves relative to a fixed point on the ground.
- Mach number (M)

It is the speed of the aircraft divided by the speed of sound (at a given altitude). It is a dimensionless number.

The unit used for flying speed is called knot (kt), where,

1 kt = 1 nm/h = 1.852 km/h.

Nautical mile (nm) is used in air and marine navigation, where,

1 nm = 1,852 m = 6,076 ft. It is also called air mile or sea mile.

On the other hand, Land mile or statute mile is less than nautical mile and equal to 1,609 m or 5,280 ft.

2.2 Basic flight mechanics

In a straight and level flight, the aircraft is subjected to four balanced forces; engine thrust, air drag, aircraft weight, and lift, mainly generated by the wings (Fig. 2.1). If the plane flies at constant speed, the four forces acting on it are in equilibrium. By controlling the thrust, control surfaces, and high lift devices, the pilot is able to change the speed, direction, and flight level of the airplane.

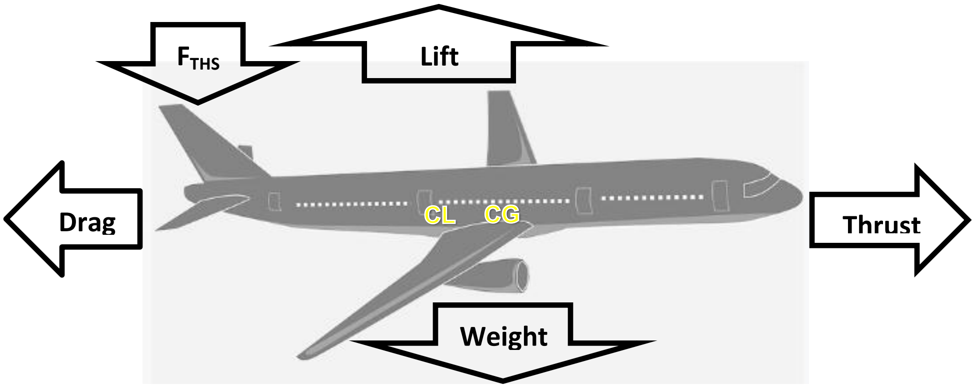


Fig. 2.1: Forces affecting aircraft [94]

Lift is generated mostly by the wings, however, a small part of the lift is generated by the fuselage. The lift acts perpendicular to the wingspan. The theoretical concept that summarizes the direction and magnitude of lift is the center of pressure. During level cruise, lift equals aircraft weight. During climb, lift is greater than weight, and during descent, lift is less than weight. Weight is a body force generated by gravity (g-force) that acts perpendicular to the ground. It is assumed to act through the center of gravity. Thrust is a force generated by the engine(s) that acts parallel to aircraft longitudinal axis. During level cruise at constant speed, thrust equals drag, during acceleration, thrust is greater than drag, while during deceleration, thrust is less than drag. Drag is the air resistance to aircraft while flying. It acts parallel to flight path.

2.3 Wing airfoil

The cross-section of the wing is called wing airfoil. When air flows past a wing from left to right as shown in Fig. 2.2, and due to the lower curvature of the bottom surface, coupled with air viscosity, a higher pressure zone is created below the wing, generating lift. In addition, two stagnation points are formed at the leading and the trailing edges of the wing.

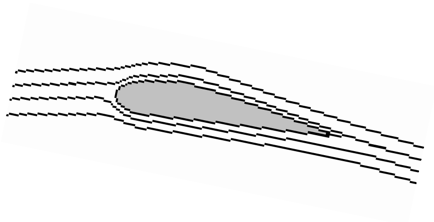


Fig. 2.2: Wing airfoil

A flying aircraft is called "airborne", and its speed is measured relative to the surrounding air, not to the ground. However, the ground speed is calculated by considering the wind speed and direction. The basic fluid motion equation is called Bernoulli's Equation:

$$\frac{1}{2}\rho v^2 + \rho g h + p = \text{constant} \qquad 2.1$$

Where,

ρ : air density
v : air speed
g : gravity acceleration
h : altitude
p : pressure

This equation is important because it relates air pressure to air velocity. Therefore, it can explain the airfoil behavior. Since the upper surface is more curved, the adjacent air stream has to travel faster, producing lower pressure. The pressure difference between the upper and lower surfaces produces upward lift. In addition to lift force, drag force acts on the wing in the backward direction. Lift, drag, angle of attack and center of pressure are shown in Fig. 2.3.

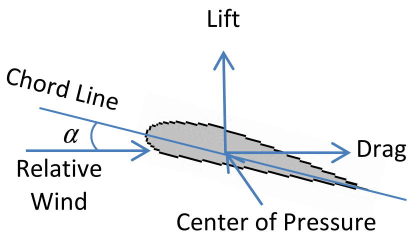


Fig. 2.3: Wing airfoil

The lift force can be calculated using the following equation:

$$Lift = C_L \frac{1}{2} \rho v^2 A \qquad 2.2$$

Where,

C_L : lift coefficient
ρ : air density (kg/m³)
v : flight speed (m/s)
A : wing area (m^2)

The lift coefficient (C_L) depends on the angle of attack (α) and the shape of the wing. The relationship between C_L and α is shown in Fig. 2.4.

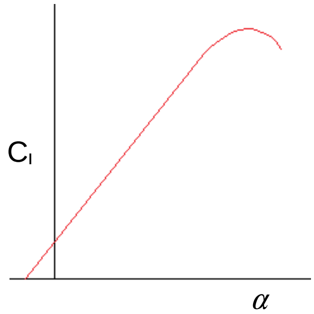


Fig. 2.4: Coefficient of lift vs. angle of attack

The drag force shown in Fig. 2.3 can be calculated using the following equation:

$$Drag = C_D \frac{1}{2} \rho v^2 A \qquad 2.3$$

Where C_D is the drag coefficient.

It can be seen that equation 2.3 is similar to equation 2.2 with the exception that it has C_D instead of C_L. The relationship between C_D and α is nonlinear, i.e., C_D depends on the square of α.

2.4 Aerodynamic forces

As shown in Fig. 2.1, the main forces affecting the aircraft are drag, thrust, lift, and weight. The weight is not constant, as it decreases during flight due to fuel burnt by the engines. The thrust is produced by the engines and generally decreases as the altitude increases. The lift is mainly produced by the wings. The drag is produced in different ways and can be classified as:

- Induced drag: by-product of lift and increases as the angle of attack increases.
- Dynamic drag: caused by the inertia of air.
- Parasite drag: due to friction of air and aircraft skin.

An important aerodynamic parameter indicating the capability of an aircraft is the lift/drag ratio. It is equal to the lift coefficient divided by the drag coefficient and defined as:

$$\text{L/D}\ ratio = C_L/C_D \qquad 2.4$$

The L/D ratio is a measure of aircraft efficiency; The higher the L/D ratio, the lower the glide angle, and the greater the distance that an aircraft can travel across the ground for a given change in height. A high L/D ratio can maximize the range of an aircraft. The relationship between drag and velocity is of special interest; As speed increases, parasitic drag increases exponentially, on the other hand, as speed decreases, induced drag increases exponentially.

The minimum value of the total drag corresponds to the Maximum range cruise (MRC) speed (maximum distance per unit fuel). If speed is decreased from that value, induced drag increases. As a result, fuel consumption would increase. On the other hand, if speed is increased from that value, parasitic drag increases, resulting in higher fuel consumption. Therefore, this point corresponds to the most efficient speed at which the airfoil can generate maximum lift and minimum drag, which is the same as the maximum L/D ratio.

Chapter 3

Aircraft Types

3.1 Introduction

There are different ways to categorize aircrafts, such as size, design, purpose, licensing, speed, etc. For example, according to their design, they can be classified as fixed-wing and rotary-wing. Helicopters are rotary-wing aircrafts ranging in size from single seat to 50 passengers. Some of them carry loads in excess of 10 tons. Another classification by design is "heavier-than-air" versus "lighter-than-air" aircraft; it is based on the lifting principle of the aircraft, whether it is aerodynamic or buoyancy. Aerodynamic lift includes fixed and rotary wings, whereas buoyancy lift includes gas and hot-air balloons as well as airships. However, the most common classification is based on the intended purpose of the aircraft, which is divided into three categories:

- Commercial Aviation
- General Aviation
- Military Aviation

3.5 Commercial Aviation

Commercial aviation is part of civil aviation. It involves operating revenue flights to transport passengers or cargo. This category includes scheduled, non-scheduled, cargo, and firefighting flights. Aircraft in this category normally hold more than 20 passengers. The passenger airplane's baggage hold (the "belly") is used for passenger luggage and cargo. Cargo can also be transported in the passenger cabin as "carry-on" bag that is placed in the overhead compartment. Cargo airplanes are dedicated for the job. They carry freight on the main deck and in the lower compartments (belly), by means of side loading, nose loading, or tail loading. A combi aircraft carries cargo on the main deck behind the passengers' seating zones.

Commercial jets operated by airlines (Airliners) are the most visible type of civil airplanes (Fig. 3.1). Most countries are members of the International civil aviation organization (ICAO), and work together to establish common standards and practices for civil aviation. Most airlines are members of the International air transport association **(**IATA), which supports aviation with global standards for airline safety, security, and efficiency. The two major manufacturers of commercial jets are Boeing and Airbus.

Fig. 3.1: A passenger commercial jet (airliner) [94]

A cargo aircraft is designed for cargo flight and sometimes have features that distinguish them from conventional passenger aircraft, such as a large fuselage cross-section, a high-wing to allow the cargo area to sit near the ground, a large landing gear to allow it to land with heavy weight, and a high-mounted tail to allow cargo to be driven directly into the aircraft.

3.6 General Aviation

General aviation includes airplanes used for training, business and agriculture. Aircraft in this category generally hold less than 12 passengers. This category includes all civil aviation operations other than scheduled and non-scheduled (chartered) flights. General aviation flights range from gliders to corporate jet flights. The majority of the world's air traffic belongs to this category, while most of the world's airports serve general aviation exclusively.

This category includes amphibious aircraft, or amphibian, which is an aircraft that can take off and land on both land and water. Fixed-wing amphibious aircraft are seaplanes that are equipped with retractable wheels. Some amphibians are fitted with reinforced keels which act as skids, allowing them to land on ice with their wheels up. Another subcategory of general aviation is Ultralight aviation; which means flying of lightweight, 1 or 2 seat fixed-wing aircraft or "ultralight aircraft".

An aircraft without engine is called "a Glider" (Fig. 3.2). It is supported in-flight by the aerodynamic reaction of the air against its lifting surfaces. There is a wide variety of types differing in the shape of their wings, location of the pilot, and control method. They exploit meteorological phenomena to gain altitude. Variants of gliding are hang-gliding and paragliding which are all air sports.

Fig. 3.2: Fixed-wing glider [94]

A low-altitude aircraft is called "Ground effect vehicle". It attains level flight close to the surface of the Earth, by means of a cushion of high-pressure air created by the aerodynamic interaction between the wings and the surface. The flight altitude is limited to one half of its wingspan.

3.7 Military Aviation

A military aircraft is an aircraft operated by any armed service. Military aircraft can be either combat or non-combat; Combat aircraft are designed to destroy enemy equipment using their own armament. On the other hand, non-combat aircraft mainly operate in support roles, and may be developed by either military forces or civilian organizations. However, they may carry weapons for self-defense.

Combat aircraft are divided into multi-role, fighters (Fig. 3.3), bombers, and attackers. Fighter aircraft (denoted by the letter "F") has the role of destroying enemy aircraft in air-to-air combat. They should be fast and highly maneuverable. Another task they normally perform is to escort bombers or other aircraft. Bomber aircraft (B) are larger and less maneuverable than fighter aircraft. They are capable of carrying large payloads of bombs or missiles. They are normally used for ground attacks. Some of them have stealth capabilities that keep them from being detected by enemy radar.

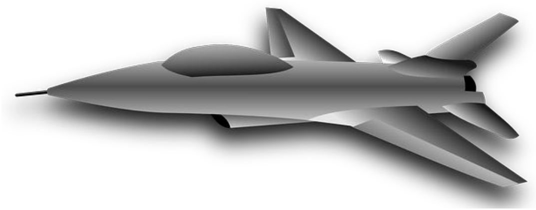


Fig. 3.3: A fighter jet

Non-combat aircraft missions include search and rescue, reconnaissance, surveillance, control, transport, training, electronic warfare, and in-flight refueling. Surveillance aircraft (S) is used for collecting information over time. A newly designed aircraft is called experimental aircraft (X). This implies that new technologies are being tested on the aircraft. One of the latest expanding types of aircrafts is "drones". They have dual use; military and civil. They have other names such as UAS (unpiloted air system) and UAV (unmanned aerial vehicle). Their flight is controlled either autonomously by onboard controllers or by the remote control of a pilot on the ground or in another vehicle.

Chapter 4

Aircraft Parts

4.1 Introduction

The main aircraft parts and components are illustrated in this chapter. A typical fixed-wing aircraft comprises the following main parts (Fig. 4.1):

- Fuselage (Body).
- Wings.
- Empennage (Vertical and Horizontal Tail/Stabilizer).
- Engine(s).
- Under-Carriage (Landing Gear).
- Emergency equipment.

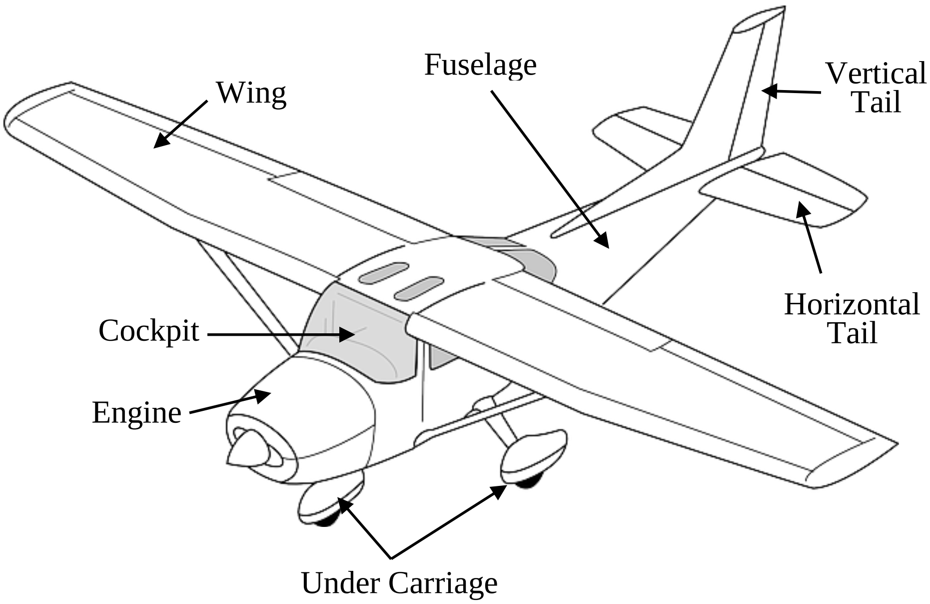


Fig. 4.1: Aircraft main parts

4.2 Fuselage (body)

The body of the airplane is called "fuselage". The fuselage and the wings assembly are called the "airframe". Typically, the fuselage has a long tube shape. In a typical commercial jet, the lower half of the fuselage contains the service compartments; including electronics service center, environmental control systems, electrical service center, and hydraulic service center. The structure of the airframe will be discussed in Chapter 5.

4.3 Wings

All airplanes have wings. Wings are shaped with smooth surfaces. The wing design determines how fast and high the plane can fly. Wings are also called "airfoils". Wings may have different shapes and can be classified according to their design; for example; an aircraft wing can be classified as straight, tapered, swept-back, delta, or variable-geometry (Swing-wing). One important wing parameter is the aspect ratio (*A.R.*) (Fig. 4.2), which is defined as the wing span (*S*) divided by the average chord (*C*):

$$A.R. = \frac{Span}{Chord} = \frac{S}{C} = \frac{S^2}{SC} = \frac{S^2}{A} = \frac{(Span)^2}{Area} \qquad 4.1$$

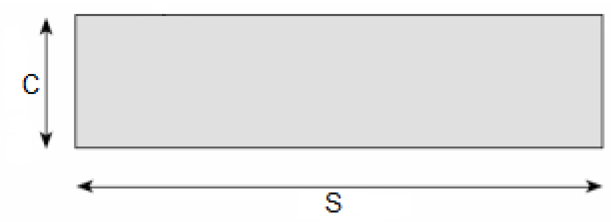


Fig. 4.2: Wing aspect ratio

Aspect ratio is a measure of wing slenderness. Low aspect ratio involves a short wing, which is more efficient structurally and provides higher roll rate. It tends to be used for high-speed aircraft. Moderate aspect ratio is used for general-purpose wing, while high aspect ratio means a long and slender wing, which is more efficient aerodynamically, having less drag. It tends to be used for high-altitude subsonic aircraft. Straight wing (Fig. 4.3) extends at right angles to the line of flight. It is considered the most structurally-efficient wing. It is common for low-speed aircraft.

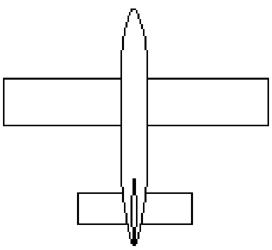


Fig. 4.3: Straight wing

The leading and trailing edges of the elliptical wing (Fig. 4.4) are curved such that the chord length varies elliptically with respect to span. It is the most efficient wing design. However, it is difficult to make. The tapered wing is shown in Fig. 4.5. In this design the wing narrows towards the tip. It is structurally and aerodynamically more efficient than a constant-chord wing. In addition, it is easier to make than the elliptical type. Therefore, it is one of the most common wing designs.

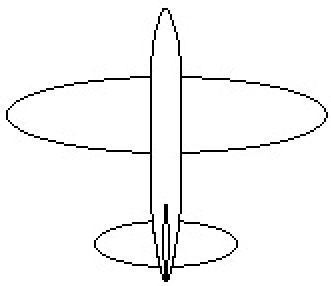


Fig. 4.4: Elliptical wing

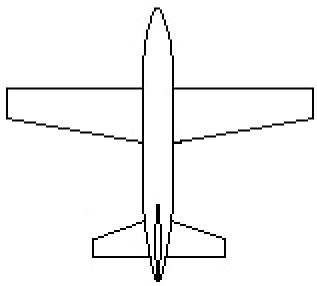


Fig. 4.5: Tapered wing

In a swept-back wing configuration, the wing sweeps rearwards from the root to the tip. At transonic speeds swept wings have lower drag, but may behave badly in or near a stall. This type is used for high-subsonic aircraft. The swing-wing is also called "variable sweep wing". In this configuration, the two wings vary their sweep together, usually backwards.

The delta wing is a triangular design with swept leading edge and straight trailing edge. It offers the advantages of a swept wing, with good structural efficiency. Drawbacks include low wing loading and high wetted area required for aerodynamic stability. Canard wing involves a "canard" which is the fore-plane surface at the front of the aircraft. It was common in the early years. It has been rarely seen since WWI.

In the low-wing configuration, the wing is mounted near or below the bottom of the fuselage. In the mid-wing configuration, the wing is mounted approximately halfway up the fuselage. As for the high-wing configuration, the wing is mounted above the top of the fuselage.

A Biplane is an airplane with two wings of similar size. The wings are stacked one above the other. It was a common configuration until the 1930s, when the monoplane dominated. The Wright Flyer I was a biplane. For a monoplane, angling the wings up or down spanwise from root to tip can help to resolve various issues, such as flight stability and control. Two main configurations are used; Dihedral and Anhedral. In the Dihedral configuration, the wing tips are higher than the root, giving a shallow "V" shape when seen from the front. The advantage of this design is that it improves the lateral stability of the aircraft. In the Anhedral design, the tips are lower than the root, which is opposite to the dihedral. This design is used to reduce stability in order to improve maneuverability. Aircraft may have additional minor aerodynamic surfaces. Some of these are considered part of the overall wing configuration. An example of these surfaces is the Winglets, which are two small vertical fins located at the wingtips. They are usually turned upwards. The winglets help in reducing the size of vortices shed by the wingtips, consequently, reducing drag.

4.4 Empennage (vertical and horizontal tail/stabilizer)

The function of the tail at the rear of the plane is to provide stability (as will be shown in chapter 9). The horizontal part of the tail is called the "horizontal stabilizer", whereas the vertical part is called the "vertical stabilizer" or the "fin". The horizontal tail is also known as the "tailplane". Not all fixed-wing aircraft have tailplanes. For example, canards, tailless, and flying wing aircraft have no separate tailplanes, while in v-tail aircraft, the vertical stabilizer, and the tailplane are combined in a V layout. The tail can be mounted in different ways, such as low, medium, or high (T-tail).

4.5 Engine(s)

The subject of aircraft engines (power plants) will be discussed in chapter 7.

4.6 Under-carriage (Landing gear)

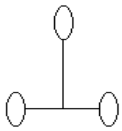
4.6.1 Overview

The wheels of an aircraft are called the "landing gear". There are two main wheels on both sides of the fuselage called the "main landing gear". There is one more wheel near the front of the plane called the "nose landing gear". The landing gear is used for both takeoff and landing, as well as for parking and taxiing on the ground. The landing gear brakes are operated by pedals. Most landing gears can be folded (retracted) into the fuselage after takeoff –to reduce drag-, then opened (extended) before landing. Wheels are used for runways and land strips, skis are used for ice operation, floats are used for water surface operation, and skids are used for vertical takeoff/landing (VTOL) vehicles.

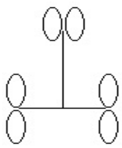
4.6.2 Landing gear configurations

The basic designs were the “single wheel” (one wheel per strut), the “dual wheel” (two wheels side by side on a strut), and the “dual tandem” (two wheels side by side followed by two additional side-by-side wheels). However, with the advent of large commercial jets, it became necessary to increase the number of wheels and struts so that more wheels can share the aircraft weight, thereby reducing the impact of each wheel on the runway pavement. With repetitive usage, if the impact exceeds the limit, it could damage the runway pavement.

Current airplanes in the market have many different landing gear configurations. However, all configurations generally consist of three parts; Main landing gear, which refers to the primary landing gear that is symmetrical on both sides of the aircraft, Nose landing gear and Body landing gear. The latter is used only for some large commercial jets and is located in the center portion of the aircraft between the main gears. Two example configurations are shown in Fig. 4.6.



Single wheel main gear/Single wheel nose gear



Two single wheels in tandem main gear/Dual wheel nose gear

Fig. 4.6: Landing gear configuration examples

Chapter 5

Airframe Structures

5.1 Introduction

An aircraft airframe consists of a fuselage, wings, empennage and undercarriage. These components comprise many structural elements connected together. The elements include:

a. Beams: used to resist bending loads.
b. Webs: used to resist twisting loads.
c. Struts: used to resist compression loads.
d. Ties: used to resist tension loads.

Most early aircraft designs had trusses incorporated into their biplane wing structure. The truss structure was used extensively because it provides strength and light weight. Aluminum used to be the primary aircraft construction material. Nowadays, composite materials such as carbon fibres are increasingly being used for building airframes. The entire airframe and its components are joined by a variety of bonding methods; such as rivets, bolts, welding, and adhesives. The airframe must withstand a variety of loads, such as aerodynamic forces, pressurization, and fatigue due to cycling of pressurization and depressurization at each flight.

5.2 Fuselage

It is the main body of the aircraft. It contains the cockpit, passengers' cabin, and the cargo holds, in addition to openings such as doors and windows. There are three main types of fuselage structure; truss, monocoque, and semi-monocoque. The truss and the semi-monocoque types are shown in Fig. 5.1. The monocoque type looks like the semi-monocoque type except that there are no stringers. This is compensated for by using stressed skin. In large commercial jets, the fuselage is generally made up of six sections or more before being assembled. In addition to Aluminum and carbon fiber composites, magnesium and titanium alloys are used to build fuselage structure.

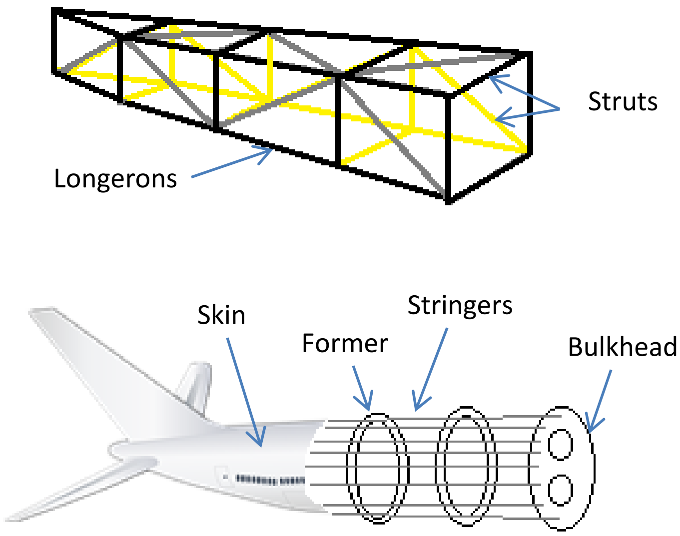


Fig. 5.1: Truss (upper) and Semi-monocoque (lower)

5.2.1 Truss-type structure

A truss is a rigid framework made up of beams, struts, or bars to resist deformation. The truss-type fuselage frame is usually constructed from steel or aluminum alloys. The truss is covered with a metal or composite cover so that less drag will be generated. The structures of most airplanes are thin-walled shells. The structure transmits aerodynamic forces to the longitudinal and transverse supporting members. When the structure is pressurized, longitudinal members resist bending and axial loads while transverse members resist hoop load.

5.2.2 Monocoque-type structure

Monocoque or single shell fuselage relies on the strength of the skin to support the loads. It uses formers, frames, and bulkheads to provide shape to the fuselage. Since no stringers are installed, the skin must support the loads and keep the fuselage rigid.

5.2.3 Semi-monocoque-type structure

Most modern aircraft have this construction. It has a better strength to weight ratio than pure monocoque construction. It consists of frames, bulkheads and formers. In addition, the skin is reinforced by longitudinal elements such as stringers and longerons. These elements prevent tension and compression from bending the fuselage.

5.3 Wing structure

The main structural element of the wing is called wing spar. In general, wing construction is based on one of three fundamental designs: monospar, multispar or box beam. An important feature of the wings is that they house the aircraft fuel tanks, where the tanks are either an integral part of the wing structure, or consist of flexible containers mounted inside the wing. A typical wing structure consists of the following components:

a. Spars:

They run span wise and serve to resist bending and axial loads for stable torsion resistance.

b. Stringers:

They run span wise and serve to resist bending and axial loads, in addition to dividing the skin into small panels and thereby increasing its buckling strength. They also resists axial load caused by pressurization.

c. Webs:

Consist of skin and spar webs. They carry only shear stress.

d. Transverse ribs and formers or bulkheads:

They run chord wise (leading edge to trailing edge), and are used to keep the cross-section unchanged during loading. The ribs transfer loads from the skin to the wing spars.

e. Skin:

It is attached to the wing structure, and carries part of the loads imposed during flight. It transfers the stresses to the wing ribs.

5.3.1 Nacelles

Nacelles or pods are streamlined enclosures used to house the engine and its components. They usually present a round or elliptical profile to the wind thus reducing aerodynamic drag. On single-engine aircraft, the engine and nacelle are at the forward end of the fuselage. On multi-engine aircraft, engine nacelles are built into the wings or attached to the fuselage at the empennage. A nacelle contains the engine, accessories, firewall, and cowling on the exterior to fare the nacelle to the wind. An important part of the nacelle is the engine mount, which is usually made of rubber and metal. The metal portion connects to the engine on one side and to the frame on the other. The rubber is in-between to provide flexibility to isolate engine vibrations.

5.3.2 Other wing features

There are other structures visible on the wings that contribute to performance, such as winglets, vortex generators, stall fences, and gap seals. For example, a winglet is an obvious vertical upturn of the wing's tip resembling a vertical stabilizer. It is an aerodynamic device designed to reduce the drag created by wing tip vortices in flight.

5.4 Empennage

The empennage of an aircraft is also known as the tail section. Most empennage designs consist of a tail cone, fixed aerodynamic surfaces or stabilizers, and movable aerodynamic surfaces, such as elevator and rudder. The tail cone serves to close and streamline the aft end of the fuselage. The cone is made up of structural members like those of the fuselage. The structure of the stabilizers and movable surfaces is similar to that used in wing construction.

5.5 Materials used in airframe construction

The materials used for airframe construction must have the following properties:

- High strength to weight ratio
- Light weight
- Corrosion resistant
- Non-flammable
- High quality

Some common materials used for airframe construction include:

- Steel alloys
- Aluminum alloys
- Titanium alloys
- Magnesium alloys
- Composites

Chapter 6

Control and Stability

6.1 Introduction

Flight control mainly involves changing the direction and attitude of the aircraft. Whereas flight stability involves the aircraft design characteristics that render the airplane stable, or unstable! Stability can be static or dynamic as will be explained later in the chapter. The most basic flight control system is based on mechanical components. This system was used in early aircraft. However, it is still used in some small aircraft where the aerodynamic forces are not excessive. Today’s aircraft employ a variety of flight control systems. For example, some small aircraft rely on weight-shift control, while hot-air balloons use burn technique. Helicopters use rotor tilting to control pitch and anti-torque pedals to control yaw. As for large airplanes, most of them utilize fly-by-wire (FBW) technology for flight control.

6.2 Primary Flight Controls

While the aircraft is taxing on the ground, it can easily be steered using the wheels, similar to a car. However, once the aircraft starts take-off, considerable aerodynamic forces will be present. These forces are used to control the plane, starting from takeoff, and throughout all flight phases, until landing. During the flight, the aircraft may need to move up, down, right, or left. These movements are induced using the so-called "control surfaces", as shown in Fig. 6.1. Control surfaces inputs cause movement about the three axes of rotation; Longitudinal, Lateral, and Vertical.

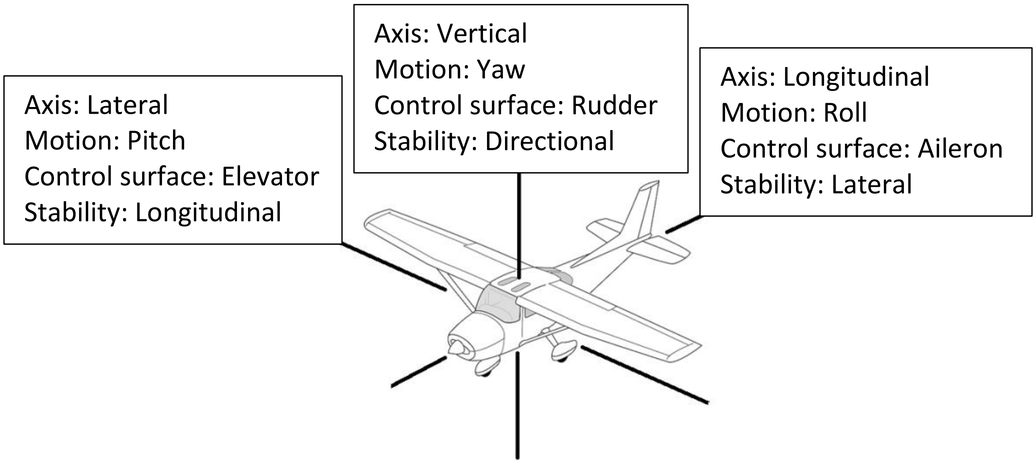


Fig. 6.1: Airplane basic axes

As depicted in Fig. 6.1, Roll is the rotation about the longitudinal axis, Yaw is the rotation about the vertical axis, while Pitch is the rotation about the lateral axis. These three movements are produced by three different control surfaces; where the Roll is produced by the Aileron, the Yaw is produced by the Rudder, and the Pitch is produced by the Elevator, as shown in Fig. 6.2. Usually the Elevator is activated alone to produce pitch rotation (nose-up or nose-down), whereas the rudder and the aileron are coupled together to produce change of heading.

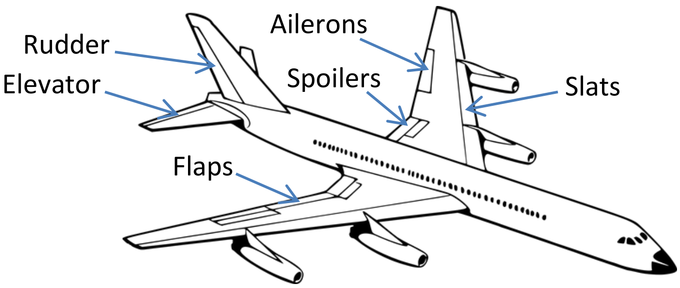


Fig. 6.2: Flight Control Surfaces

6.2.1 Elevator

The elevator controls pitch about the lateral axis. Similar to the ailerons on small aircraft, the elevator is connected to the control column in the cockpit by a series of mechanical linkages, such that aft movement of the control column deflects the trailing edge of the elevator surface up. Consequently, the airplane nose goes up.

Whereas forward movement of the control column deflects the trailing edge of the elevator surface down. Consequently, the airplane nose goes down (dive).

6.2.2 Ailerons and Rudder

Sometimes ailerons are used alone; for example, to avoid an obstacle. One the other hand, the rudder can be used alone to overcome cross wind effect on aircraft direction. However, ailerons and rudder are usually coupled controls. This can be accomplished with a variety of methods depending on the control architecture. For example, in mechanical control, rudder-aileron interconnect springs are used. The coupled ailerons and rudder are used to change the direction of the plane; that is right or left.

6.2.3 Tab Control Systems

Early large aircraft used tab-activated controls, as shown in Fig. 6.3. In a tab control system, the pilot moves a small actuating tab on the larger control surface. The force generated by the tab moves the main control. In addition, the control forces may be excessively high in some modern aircraft. In order to reduce them, balance tabs are used. In this case, both the control surface and the balance tab are moved in the same time.

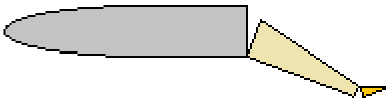


Fig. 6.3: Tab control

6.3 Mechanical flight control

It is the basic method of aircraft control used in early planes. Nowadays, it is being used in small aircraft where the aerodynamic forces are not excessive. It utilizes a collection of mechanical parts such as rods, cables, pulleys, counterweights, and chains to transmit the forces applied from the cockpit controls directly to the control surfaces. The aerodynamic forces required to move control surfaces have increased due to several factors; such as larger control surface areas required by large aircraft, as well as higher loads caused by high speeds in small aircraft. Consequently, complicated mechanical gearing designs were developed to reduce the forces required from the pilots.

6.4 Hydraulic-powered controls

Since the complexity and weight of mechanical control systems continued to increase with size and performance of the aircraft, it became necessary to develop more efficient control systems. Hydraulic control systems were the answer, especially in large airplanes. In these systems, the control surfaces are operated by hydraulic actuators controlled by valves, which are moved by control yoke and rudder pedals. An artificial feel system gives the pilot resistance that is proportional to the flight loads on the control surfaces. In modern aircraft, power-assisted controls are used, where electrical signals are used to control the hydraulic valves.

6.5 Fly-By-Wire

Fly-By-Wire (FBW) is a modern computer-based control system, where the operator communicates with the actuators through electrical signals. FBW was developed for military aviation in 1970s, and started as an analogue technique and later on transformed into digital. The supersonic Concorde is considered the first civil aircraft equipped with an analogue FBW system. In 1980's, digital FBW was introduced into civil aviation by Airbus, with the introduction of the A320. The advantages of FBW system include saving weight due to elimination of mechanical linkages, and improving reliability due to using multiple channels. In addition, FBW system is capable of controlling highly-maneuverable unstable aircraft, as it provides flight envelope protection, such as preventing stalling.

The FBW architecture is based on computer signal processing, where the pilot's command is transduced into electrical signal and sent to a group of independent computers. The computers sample data concerning the flight conditions. The command is then processed and sent to the actuator, properly tailored to the actual flight status. Any computer whose results disagree with the others is ruled to be faulty, and it is either ignored or re-booted. Safety and reliability are further enhanced by redundant transmission; where the signals are transmitted through multiple parallel and independent lanes. Furthermore, FBW is a closed-loop control system where feedback signals are sent from the actuator back to the computer reporting the position of the actuator. When the actuator reaches the desired position it stops moving.

6.6 Secondary Flight Controls

6.6.1 Flaps

Flaps are the most common high-lift devices used on aircraft (Fig. 6.2). These surfaces, which are attached to the wing trailing edge, increase both lift and drag. They are normally extended for landing and takeoff, and retracted for cruise.

6.6.2 Slats

Slats are high-lift devices largely used on aircraft (Fig. 6.2). They are attached to the wing leading-edge, and serve to increase camber and wing surface area, thereby increasing lift. Slats can be operated separately or together with flaps.

6.6.3 Spoilers and Speed Brakes

Spoilers and speed brakes are very similar high-drag devices (Fig. 6.2). The only difference between them is that spoilers may assist the ailerons in turning the aircraft, but they are identical in all other aspects. Spoilers and speed brakes deploy from the wings to spoil the smooth airflow, reducing lift and increasing drag. On gliders, spoilers are used to control rate of descent for accurate landings. On fixed-wing aircraft, deploying spoilers allows the aircraft to descend without gaining speed. Spoilers are also deployed to help reduce landing distance. This is accomplished by increasing the force on the wheels to improve braking effectiveness.

6.7 Aircraft Stability

Stability can be defined as the ability of an aircraft to correct for conditions that act on it. In other words, stability is the ability to damp unwanted disturbances. There are two types of aircraft stability; static and dynamic. For each of these types, the response could be positive, neutral or negative. In addition, aircraft stability can be achieved passively or actively. An aircraft is considered completely stable if it is found stable along each of the three principal axes; pitch, yaw, and roll, namely; longitudinal, directional and lateral stability, respectively.

6.7.1 Static and Dynamic Stability

Assuming an aircraft is disturbed, static stability is the initial tendency of the aircraft to return to its original position, whereas dynamic stability is the long-term tendency of the aircraft to return to its original position.

6.7.2 Positive, Neutral and Negative Stability

Depending on the stability behavior, a disturbance will be affected as follows:

a) If the stability is positive, the disturbance will be reduced.
b) If the stability is neutral, the disturbance will stay put.
c) If the stability is negative, the disturbance will be amplified.

6.7.3 Passive and Active Stability

Passive stability is achieved by the aircraft aerodynamic design. It is an inherent feature in the design of most passenger airplanes. On the other hand, since fighter jets require high maneuverability, they are intentionally designed unstable. For example, the main purpose of the aircraft tail is to provide stability. If tilted by wind shear, a stable airplane tends to recover. The tail has two major parts; vertical and horizontal. The vertical part is called the fin or vertical stabilizer, and the horizontal part is called the horizontal stabilizer. They both provide passive stability to the airplane.

Active stability, on the other hand, is normally achieved by FBW system, which utilizes feedback control to maintain stability. Inertial Navigation Units (INUs) are fitted in the aircraft to sense movement changes in the pitch, roll and yaw axes. Any movement results in signals being sent to the computer which move the relevant control actuators. In addition, trim tabs are used to actively stabilize aircraft on different axes. A trim tab control system is shown in Fig. 6.3.

6.7.4 Longitudinal, Directional and Lateral Stability

Longitudinal stability is the ability to correct pitch disturbances. If the airplane tilts up or down, air pressure increases on one side of the horizontal stabilizer and decreases on the other, pushing it back to its original position. The stabilizer also holds the tail down, countering the tendency of the nose to tilt downward, a result of the aircraft's Center of Gravity (CG) being forward of the wing's Center of Lift (CL). One of the causes of longitudinal disturbances is the shifting CG due to burning fuel. A trim tab position controller is located in the cockpit; placing the trim control in the nose-down position moves the trim tab to its up position. With the trim tab up and into the airstream, the airflow over the horizontal tail surface forces the trailing edge of the elevator down. This causes the tail of the airplane to move up, and the nose to move down.

Directional stability is the ability to correct heading disturbances. The tail fin, or vertical stabilizer, keeps the aircraft lined up with its flight direction. When the aircraft is flying straight ahead, air presses against both fin surfaces with equal forces. However, cross-wind can push the airplane to the right or left, air pressure increases on one side of the stabilizer and decreases on the other. This pressure imbalance pushes the tail back into line.

Lateral Stability is the ability of the aircraft to recover from a roll without intervention. When a dihedral-winged aircraft undergoes a roll, a part of the lift is pointed sideways. Therefore, the aircraft moves laterally, or sideslip. Sideslip affects the high and low wings in opposite directions; upward and downward. The upward force is called up-wash, which increases lift on the low wing, while the downward force is called downwash, which reduces lift on the high wing. As a result, the aircraft recovers from the roll.

Chapter 7

Power Plant

7.1 Introduction

Power plant provides the thrust needed to fly an aircraft. It could be a jet engine in large airplanes or a piston engine in small airplanes. In addition, aircraft engine produces the power needed for other aircraft systems. A typical jet engine can produce 100,000 pounds of thrust. Jet engines operate according to the third law of physics; which states that for every action, there is a reaction, equal in magnitude and opposite in direction. Jet engines are similar to industrial gas turbines, which are used for non-aircraft applications, such as electrical power generation.

7.2 Jet engine

There are three main types of jet engines; turbojet, turbofan, and turboprop. These types are shown in Figures 7.1, 7.2 and 7.3, respectively. Turbojet engines were the first type of turbine engines developed. In these engines, all the thrust comes through the turbine and nozzle, which is called the core of the engine. The main difference between turbojet and turbofan engines is that the latter incorporates a fan to produce additional thrust. Up to 75 percent of the total thrust of the turbofan engine comes from the bypass air. This design provides greater efficiency at high altitudes. It is the most common type of engines used in commercial airliners. As for the turboprop engine, the exhaust gases are used to rotate a propeller attached to the turbine shaft. This configuration results in increased fuel economy at lower altitudes. Turboprops are found on large helicopters and slow cargo planes.

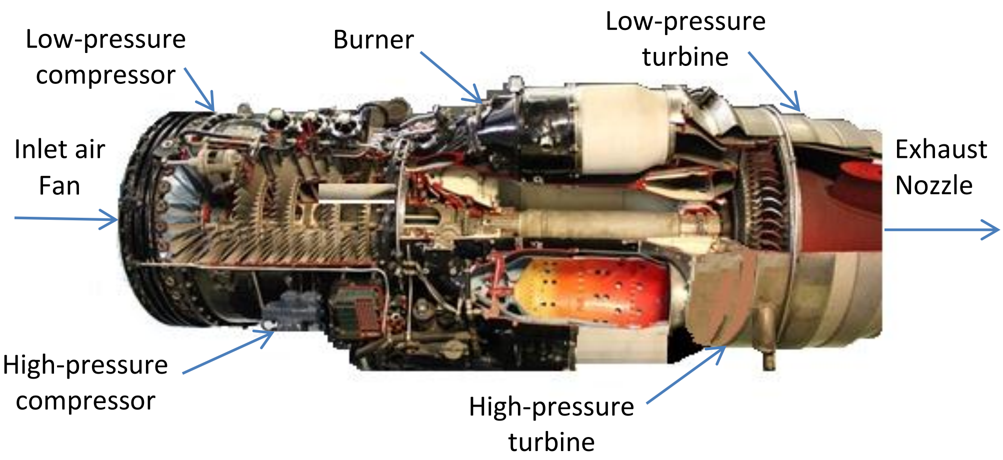


Fig. 7.1: Jet engine

Fig. 7.2: Turbofan Engine

Fig. 7.3: Turboprop engine

7.2.1 Jet engine components

As shown in Fig 7.1, the jet engine consists of the following components:

a. Fan:

It is the first component in a turbofan engine. The fan sucks in large quantities of air. The fan blades are made up of lightweight materials such as titanium. Part of the propelled air goes through the engine core. The rest of the air bypasses the core and goes through a duct that surrounds the core, all the way to the back of the engine.

b. Compressor:

It is the first component in the engine core. It is made up of many blades that squeeze the air into smaller areas, thereby increasing air pressure, before being pushed into the combustion chamber.

c. Burner:

In the burner, air is mixed with fuel, where fuel is sprayed into the airstream, and then ignited. The combustion chamber is often made of ceramic material in order to resist the heat.

d. Turbine:

The hot gases exiting the burner enter the turbine, causing the turbine blades to rotate. The turbines are linked by shafts to turn the compressor and the fan.

e. Nozzle:

It is the exhaust duct of the engine. Thrust is produced when the combustion products expand and blast out through the nozzle. Additional thrust is produced in turbofan engines when the colder air that bypassed the engine core exits the nozzle.

7.2.2 Jet engine performance

One of the main factors that affect the performance of jet engine is the mass of air entering the engine. The higher the air mass, the higher the burned fuel, and the higher the produced thrust. In a straight and level flight with constant speed, a constant volume of air enters the engine. However, changes in air density result in changes in produced power. Since air density is different under different atmospheric conditions, these conditions affect the engine performance. For example, on a cold day, air density is high, so the mass of air entering the engine increases. Consequently, a higher thrust is produced. The reverse happens on a hot day. On the other hand, at high altitude, air density decreases, resulting in a lower thrust, whereas, at low altitudes, the reverse happens.

By design, the turbine material can withstand a maximum given temperature. This temperature limit must not be exceeded. Since additional thrust means higher temperature, this temperature limit imposes thrust limitation, which in turn translates to aircraft payload limitation.

7.2.3 Jet engine design

A typical jet engine consists of at least one spool. The number of spools corresponds to the number of shafts. A single-spool engine has one shaft, on which is installed a compressor on forward portion of the shaft, and a turbine on the aft portion of the shaft. A twin-spool engine has two shafts, each one rotates independently. Each shaft has a compressor in the forward portion and turbine in the aft portion. The two shafts are arranged concentrically, such that one of them is the "inner shaft" and the other is the "outer shaft“. The rotational speed of the inner shaft is usually denoted by N_1, whereas the rotational speed of the outer shaft is denoted by N_2. The inner shaft carries the low-pressure compressor and turbine (spool-1), and the outer shaft carries the high-pressure compressor and turbine (spool-2). Consequently, N_2 is always greater than N_1.

The principle of operation of jet engine is based on Brayton open thermodynamic cycle, as shown in Fig. 7.4. The figure demonstrates four thermodynamic processes; Adiabatic compression in compressor (1-2), isobaric expansion in combustion chamber (2-3), adiabatic expansion in turbine (3-4) and isobaric compression at exhaust (4-1). In process (4-1), it is assumed that the air entering the compressor comes from atmospheric air exhausted from the outlet of the expander.

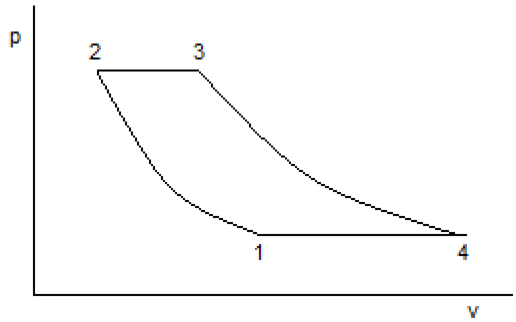


Fig. 7.4: Brayton cycle

A typical design of turbojets is called a twin-spool engine. In this engine, the low-pressure compressor is driven by the low-pressure turbine, and the high-pressure compressor is driven by the high-pressure turbine. These two units rotate at different speeds in order to maintain high efficiency in all stages of compression. The thrust force developed in a jet engine can be determined from the Second law of Physics, where the thrust is equal to the rate of change of the momentum of the fluid flowing through the engine.

7.2.4 Engine Control

Engine control is one of the most complicated control applications. The reason is that the engine involves combustion at different altitudes, pressures, temperatures, and speeds. The engine has to deliver the required thrust under all these conditions, and in a safe manner. The purpose of engine control is to provide guaranteed performance throughout its life. FAA regulations provide a minimum rise time and maximum settling time for thrust from idle to max throttle command.

To ensure the safety and efficiency of engine operation, various limits are implemented to control the engine. These limits include fuel flow based on rotor speed, where maximum fuel limit protects against surge, over-temp, over-speed and over-pressure, while minimum fuel limit protects against combustor blowout. A large number of parameters affect engine operation; For example, if N_2 increases, mass flow increases. However, it is shown that hysteresis exists between acceleration and deceleration. High speed combined with high mass flow rate results in over-temperature, over-speed, and over-pressure. Low mass flow rate results in blowout, while high mass flow rate results in surge.

Typical modern engine control involves the use of Full Authority Digital Engine Control (FADEC). The FADEC produces incremental fuel flow commands to control engine speed. Typical working conditions inside an engine involves a flame temperature of 2000 ºC, an ambient temperature of -55 ºC, a rotor speed of 10,000 RPM, a pressure of 40 Bar, and air mass flow of 2 ton/sec. In addition, there is the possibility of foreign object damage, including birds, ice, and stones. This environment results in mean time for service of 20,000 hours.

In early aircraft generations, engine control systems consisted of simple mechanical linkages controlled by the pilot. By moving throttle levers directly connected to the engine, the pilot could control fuel flow and power output. Later, engine control evolved to analog electronics. In this method, electrical signals are used to communicate the desired engine settings. Due to noise and reliability issues in analog control, FADEC was introduced in the 1970s. The first aircraft that adopted the FADEC was F-111.

FADEC receives and analyzes input variables of current flight condition. Based on these variables, engine operating parameters such as fuel flow are computed. The FADEC control results in optimum engine efficiency for a given flight condition. During flight preparations, the flight crew enters the flight plan into the flight management system (FMS). The FMS uses this data to calculate power settings for different phases of the flight. The FADEC applies the calculated thrust settings by sending electronic signals to the engines. The flight crew has no means of manually overriding the FADEC.

Since the FADEC has the full authority for controlling the engine. If it fails, the engine fails. Therefore, the safety and reliability of the engine is enhanced using redundancy, which takes the form of multiple separate identical digital channels. Each channel can provide all engine functions without restriction. FADEC is employed by almost all current generation jet engines, and increasingly in piston engines for fixed-wing airplanes and helicopters.

The FADEC provides automatic engine protection against out-of-tolerance operations. In addition, it gives the ability to use single engine type for wide thrust requirements by just reprogramming the FADEC. It also enables engine long-term health monitoring and diagnostics. As for the flight crew qualifications, it reduces the number of parameters to be monitored by the crew. As an example for enhancing safety, in case of aircraft stall, engines increase thrust automatically. To further enhance safety, redundant FADECs are used.

7.4 Internal combustion engine (ICE)

These are also called piston engines and mainly used in small aircraft. The mechanical efficiency of IC engines is lower than jet engines. For a given developed power, the weight and speed of jet engine is better than IC engine. In addition, ignition and lubricating systems are simpler in jet engine than IC engine. However, the thermal efficiency of jet engine is lower than IC engine. It is also easier to start an IC engine than a jet engine. Moreover, the turbine blades in jet engine need a special cooling system due the high temperature.

Chapter 8

Flight Planning and Performance

8.1 Introduction

Flight planning is a complicated process. Therefore, many airlines outsource it to specialized companies. Some smaller airlines even outsource performance calculations due to economic reasons. The technical capabilities are a matter of hiring the right people, and procuring the needed resources, such as equipment, software, etc. It is the economic feasibility that decides which services are done in-house and which services are outsourced. Even when flight planning and performance are outsourced, coordination with vendors and service providers is still needed. The task of coordination and implementation needs knowledge and training.

8.2 Flight phases

A typical flight starts with push-back, then engine start-up, taxi-out, takeoff, climb, cruise, and descent. Sometimes holding is done before approach for a variety of reasons; it could be due to weather, runway not ready, clearance not obtained, burning of the fuel to avoid heavy landing, or any other emergency situation. The next flight phase is approach, then landing, and taxi-in. At the end of the flight, engine is shut-down. These phases are depicted in Fig. 8.1.

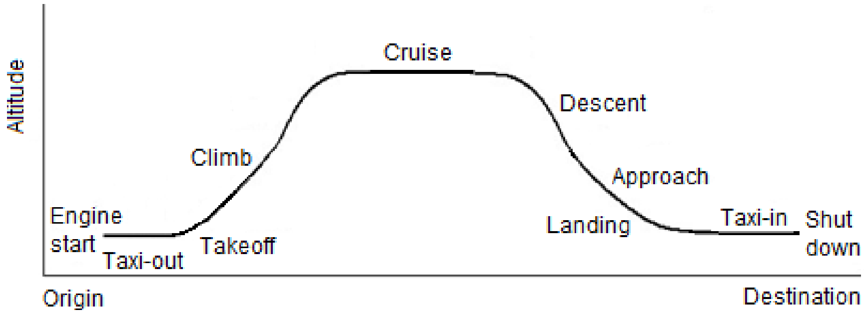


Fig. 8.1: Flight phases

8.3 Takeoff performance

Takeoff is usually the most critical flight phase. There are variables and limitations associated with takeoff; such as runway length and slope, engine thrust, aerodynamics, airport elevation, wind speed and direction, obstacles, outside air temperature, aircraft weight, brake energy, and fuel uplifted. The most important variables will be discussed in the following subsections.

8.3.1 International standard atmosphere (ISA)

ISA is an international model of how the atmospheric temperature changes with altitude. It is commonly used by airlines and civil aviation authorities worldwide. Most civil flights take place within two atmospheric layers; Troposphere and Tropopause. These two layers are divided by flight level (FL) 36,089 ft. In the Troposphere, ISA temperature is 15 °C at sea level, then it decreases 2 °C per 1000 ft altitude, until it reaches -56.5 at the Tropopause. In the Tropopause, the temperature stays constant at -56.5 °C.

8.3.2 Runway

It is a rectangular area on an aerodrome prepared for aircraft takeoff and landing. Some portions of the runway have specific names and definitions, such as Takeoff Run Available (TORA), and Takeoff Distance Available (TODA), which equals TORA plus the length of the Clearway (CWY), where the CWY is an area free of obstacles that is connected to the TORA. Moreover, the Accelerate Stop Distance Available (ASDA) equals the TORA plus the length of the stopway (SWY), where the SWY is an area connected to TORA which the aircraft can use to stop. A runway can be dry, wet, or contaminated. Runway contamination can be due to standing water, slush, snow, or ice. Standing water may cause hydroplaning by the aircraft tires, where a layer of water builds up between the aircraft wheels and the runway surface, leading to a loss of traction and consequently reduction of braking efficiency.

8.3.3 Takeoff profile

The takeoff profile consists of three parts (as shown in Fig. 8.2); Ground acceleration; from brake release to start of rotation. Rotation; from start of rotation to lift-off, and Airborne acceleration, which is the acceleration following lift-off.

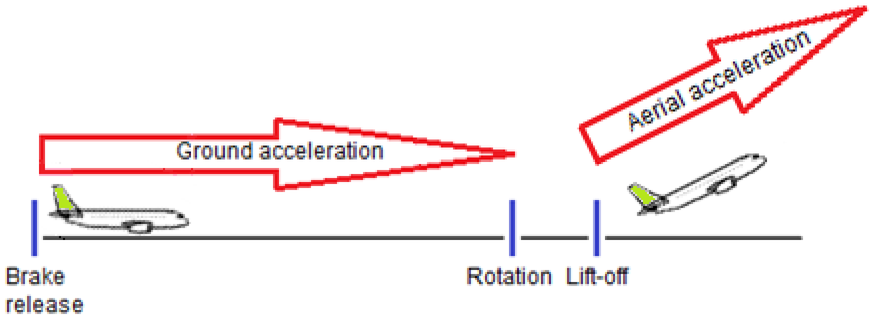


Fig. 8.2: Aircraft takeoff profile

The TORA, TODA, and ASDA defined in subsection 8.3.2 are properties of the runway. They have nothing to do with the type or size of the aircraft, and they all end with the word "available". On the other hand, there is another set of parameters that are properties of the aircraft; these parameters are Takeoff Run (TOR), Takeoff Distance (TOD), and Accelerate Stop Distance (ASD). For an aircraft to operate using a runway, the TOR of the aircraft should be less than or equal to the TORA of the runway, and so forth for the parameters TOD and ASD.

For example, TOD for an aircraft with one engine out on a dry runway is defined as the horizontal distance along the takeoff path from brake release to the point at which the aircraft is at 35 ft above the takeoff surface. The aircraft speed at that moment is called takeoff safety speed V_2, which is the speed at which the aircraft may safely become airborne with one engine inoperative. Takeoff distances are subjected to line-up corrections depending on the angle at which the aircraft enters the runway.

8.3.4 Takeoff weight

The maximum weight at which the aircraft is allowed to takeoff is called the maximum takeoff weight (MTOW). Many factors contribute to the determination of MTOW; such as runway length, runway slope, engine thrust, aircraft aerodynamics, airport elevation, wind speed and direction, obstacles height and distance, air temperature and pressure, maximum brake energy, maximum tire speed, and structural capability.

A critical scenario would be when a long haul flight has full load and is scheduled on a hot day. MTOW will be less than usual because of the high temperature. In the meantime, the flight needs more fuel, which translates to additional weight. Under these circumstances, it may be necessary to offload some cargo in order to takeoff. Another example is when a large aircraft wants to takeoff from a high elevation airport, with a short runway. At high elevation, air density is low, and therefore the thrust and the aerodynamic lift are lower. This means the aircraft needs more distance to accelerate to the required speed. Again, it may be necessary to limit the load in order to takeoff from that runway.

The most important takeoff speed is the takeoff decision speed (V_1). During the takeoff roll, if V_1 is not yet reached, takeoff can be rejected, and the aircraft can stop safely on the runway. However, if V_1 is exceeded, it is not possible to abort the takeoff for any reason, because the aircraft would overshoot the runway. V_1 is determined by the limitations imposed by both the runway and the aircraft; for example, V_1 increases with aircraft TOD, and decreases with aircraft ASD.

MTOW can also be limited due to obstacles existing in the flight path. For that purpose, a certain area beyond the runway should be clear of obstacles. This area is called the "departure sector". The sector must be clear of all obstacles for safe takeoff. Different regulations have different definitions for the departure sector.

One of the most important MTOW limitations is the engine thrust. For a certain range of outside air temperatures, thrust is constant. However, at a certain reference temperature, the thrust starts to decrease with temperature. The main reason for this behavior is that exhaust gas temperature exceeds the allowable value. A reduced thrust takeoff is done using less thrust than the engines capability under the existing conditions. In all cases, the remaining thrust should not be lower than 75% of the maximum thrust. The main purpose of performing reduced thrust takeoff is to save engine life. The takeoff weight and speeds are computed using manufacturer software.

8.3.5 Net takeoff flight path (NTOFP)

The NTOFP is the vertical profile of an aircraft beyond the takeoff point. It represents the minimum altitude that is attained by an aircraft following failure of the critical engine. The aircraft must clear all obstacles by at least 35 ft. The critical engine is the one whose failure would result in the most adverse effect on the aircraft operation.

The NTOFP consists of four segments; in the 1st segment, the landing gear is retracted. In the 2nd segment, the aircraft climbs to the appropriate height for flap retraction. In the 3rd segment, the flaps are fully retracted (clean configuration) and the aircraft accelerates to the fourth segment climb speed. In the fourth segment, the aircraft climbs to 1500 ft. The aircraft must reach the end of the 3rd segment within 10 minutes. The Gross takeoff flight path comes above the NTOFP.

8.4 Cruise performance

After the aircraft reaches 1500 ft, it joins the enroute flight path. As mentioned in chapter 14, there is an international network of VORs and waypoints. These points are connected by flight routes. Aircraft can fly these routes at specified flight levels. The optimum flight level with all engines operating is dependent on aircraft weight and air temperature. As the aircraft becomes lighter due to burning fuel, she can climb to a higher flight level, and saves fuel. However, prior permission should be granted by the air traffic control (ATC) in charge of the area. In addition, wind speed and direction play a role; For example, if tail wind exists at a lower level, it can make it more favorable than the higher level.

A good flight planning system should calculate the optimum combination of flight level and wind speed and direction. The optimum combination does not necessary means minimum fuel burn, because time may be considered more important. More advanced navigation systems such as Area navigation (RNAV) and Global navigation satellite systems (GNSS) are changing the landscape of flight navigation.

8.4.1 Drift down

It is an abnormal procedure performed only in certain cases; such engine failure or loss of cabin pressurization. In the first case, the aircraft cannot sustain the original flight level due to the lower thrust. Therefore she has to descent to a lower flight level that can be sustained using the remaining engine(s). In the second case, pressurization is important to keep enough oxygen in the cabin. Therefore, when it is totally or partially lost, emergency oxygen masks are deployed immediately for passengers use. Since the quantity of oxygen is limited, the flight cannot proceed at the same flight level. It should descend to a lower level so as to get enough air naturally. The new flight level (aka the ceiling) is usually 10,000 ft. At this level, it is possible to breath normally without pressurization or supplemental oxygen.

Drift down procedure could happen during cruise or climb. The procedure is performed at maximum continuous thrust (MCT). Several strategies can be used to perform drift down; such as standard strategy, obstacle strategy, and fixed-speed strategy. During drift down procedure, the net flight path clears the en-route obstacles by a minimum of 1000 ft., while the gross flight path should be above the net flight path.

8.4.2 Ground Speed and Drift Angle

During cruise, the aircraft may drift sideways due to cross wind. The heading of the aircraft is the bearing of the next waypoint. It is represented by ground speed (GS). The track of the aircraft is the actual bearing flown. It is represented by true air speed (TAS). Due to cross wind component, there is a difference between the heading and the track as shown in Fig. 8.3. This difference is called drift angle (DA).

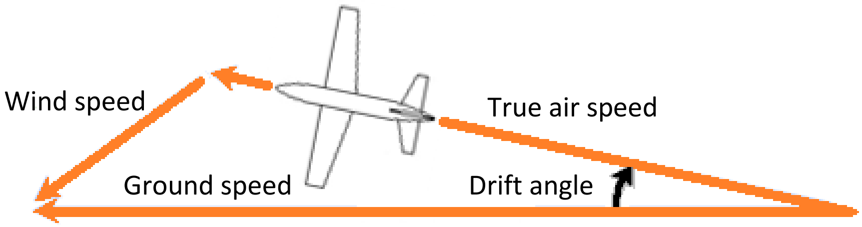


Fig. 8.3: Drift angle

8.4.3 Flight optimization

The optimum flight level is chosen based on the aircraft weight and air temperature; the higher the weight, the lower the optimum level. At a given weight, the higher temperature decreases air density, and consequently, the lift decreases. Therefore, a lower level is mandated. It should be emphasized that the weight is continuously decreasing during the flight due to fuel consumption. As a result, the optimum flight level is continuously getting higher. Generally, the higher flight level saves fuel because of the lower air density, where drag is lower, as well as the air quantity entering the engine. This means less fuel will be burnt.

For a given weight and flight level, it is desirable to determine the best speed or the optimum speed. The optimum speed is determined by many factors, such as fuel price, increase in maintenance cost, and cost of time or delayed flights. Fixed costs (aka overhead costs) have no effect on speed. As speed increases, flight time decreases and the cost of time decreases. However, speed cannot increase beyond the maximum operating speed (VMO).

Generally, a higher speed is associated with higher altitude, as well as low speed is linked to low altitude. The reason behind that is the mechanism of air/fuel combustion inside the engine. If there is too much fuel, the mixture is called "rich". If there is too little fuel, the mixture is called "lean". In the meantime, for maximum engine efficiency, there is an optimum air/fuel ratio. At low altitude, air has high density, and a corresponding large fuel quantity is needed. Even at low speed, this results in high fuel consumption. At high speed, large air volume enters the engine. A corresponding quantity of fuel is needed, which increases fuel consumption. Between these two extremes, there is an optimum altitude where speed is moderate, air quantity is minimum, and corresponding fuel burn is minimum. This leads to lowest fuel cost. The speed at that point is called maximum range speed (M_{MR}), where M stands for Mach number.

It is worth noting that at low altitudes (below 24000 ft), the speed unit used is knots, whereas at high altitudes (above 24000 ft), the unit used is Mach number. The reason for this is that Mach number is based on the density of air, and since it is large at lower altitudes, the Mach number would be exaggerated. On the other hand, at high altitudes, Mach number is more convenient, as it is a smaller figure, in addition to being linked to speed of sound, and the boundary between subsonic, sonic, and supersonic speeds.

Direct operating cost (DOC) is obtained by summation of fixed costs, cost of time, and cost of fuel. Therefore, airlines are interested in minimizing all of these costs together. The minimum value of the DOC corresponds to the optimum speed, which is the most economic speed, taking in consideration not only fuel, but also the cost of time, as well as other time dependent costs. The optimum speed is expressed in terms of a quantity called "cost index", where there is a special procedure, and sometimes dedicated software to calculate it.

Some airlines avoid the elaborate process of computing the optimum speed and use a speed called long range cruise (M_{LRC}), where it is calculated simply by allowing an increase of 1% in fuel burn over the M_{MR} speed. It is worth noting that for the same aircraft and destination, there is a different cost index that needs to be calculated prior to each flight. That is due to constant changes in fuel price, as well as other time-dependent costs.

8.5 Flight planning

Flight planning involves the main variables that affect the flight; weight, distance, time, speed, and fuel. At any point during the flight, these four elements should be known and recorded. The flight plan contains this information based on approximation. The flight planning provider obtains aircraft performance data from the manufacturer, and uses the data to calculate the expected performance during the flight. The aircraft data is interfaced with meteorological data, navigational database, and national aeronautical information to predict the actual course of the flight.

The predicted flight plan is sent to the airline ahead of the flight. It contains information about fuel consumption during the flight, distance covered, VORs and waypoints, recommended speeds, and estimated times including arrival time. The aircraft payload is determined by considering the takeoff, landing, and structural limitations. Before pulling a flight plan, MTOW should be known, so that the system can compute the other weights.

8.5.1 Fuel planning

The total amount of fuel needed for a flight includes taxi-out fuel, trip fuel, which covers origin to destination, alternate fuel in case of diversion to alternate airport, and reserve fuel in case of contingency.

8.5.2 Meteorological reports

Air temperature affects the efficiency of the aircraft. Wind may provide a head or tail wind component which in turn will increase or decrease the fuel consumption. Storms and bad weather should be avoided which can alter the planned flight route. Therefore, a meteorological (met) report is briefed to the operating crew by the dispatcher as part of flight preparation.

8.6 Landing distance

It is the horizontal distance traversed by the aircraft from a point on the runway threshold at 50 ft. height, to a complete stop. The landing distance required (LDR) is usually greater than the actual landing distance. The LDR is calculated by taking into account the effects of various factors, including flaps/slats configuration, aircraft landing weight, surface wind and temperature, runway elevation and slope, runway surface condition (dry/wet), and aircraft braking. It also depends on the type of landing performed, whether it is manual or automatic.

In order to minimize the required landing distance, landing is done at the lowest possible speed. However, landing speed should always be greater than the stall speed (V_s), which is the minimum steady flight speed for which the aircraft is still controllable. Unlike small aircraft, large commercial jets must flare prior to touch-down in order to reduce the landing speed.

Chapter 9

Weight and Balance

9.1 Introduction

Aircraft weight and balance is one of the important aspects in airline operations. Normally the task of taking care of weight and balance is done within several departments, such as flight operations, engineering and maintenance, and flight services. The process starts with designing the aircraft, where weight and balance base line is laid out. Engineering and maintenance department within the airline is responsible for weighing in-service aircraft, especially when it enters service. The aircraft must be weighed using a system of three jacks, where the purpose is to find both the weight as well as the center of gravity (CG). The weight is found by adding the reactions of the three jacks, while the CG is found using a formula that depends on the reactions at the three jacks. The wind load should be isolated so as not to affect the result of aircraft weighing. Therefore, it is preferred that the aircraft is weighed inside a hanger.

The result of the weight and CG obtained by weighing is sent to the operations department for further processing. Weight and balance engineers at the operations department build upon the figures obtained from the engineering department. They add operating items to the basic figures and come up with the operating weight and CG. They also design the documents and the automatic system that calculates the effect of passengers and cargo on the weight and CG of the aircraft. This data is provided to the passenger services department that uses the data to prepare for each flight. Prior to the flight, the weights and CGs of the passengers, cargo, and fuel are added to the operating weights. The final weight and CG is used by the flight crew to calculate critical parameters such as engine thrust, takeoff speeds, and aircraft trim setting, and that is to guarantee a safe and efficient flight. When loading an aircraft, the priority is given to passengers, then luggage, then cargo.

9.2 Longitudinal stability

Due to aircraft design, the lateral CG is usually at the center, therefore, the longitudinal CG is the value of interest. Figure 2.1 shows aircraft weight acting downward through the CG. The weight produces pitch-down moment about the center of lift (CL). The aerodynamic lift acts upward through the CL, producing zero moment. In addition, a pitch-up moment is produced by the downward force acting on the trimmable horizontal stabilizer (F_{THS}). The two moments (due to weight and F_{THS}) balance each other.

As a result of aircraft loading, aft CG is usually preferred, as it creates small pitch down moment. This leads to small F_{THS} counter moment, which means the needed lift force is reduced. That leads to smaller stall speed. On the other hand, a forward CG creates high pitch down moment, which needs high F_{THS} counter moment. Therefore, the needed life as well as the stall speed increase.

9.3 Aircraft operational weights

The standard aircraft weights used in weight and balance calculations are shown in Fig. 9.1. These weights range from aircraft structural weight to aircraft taxi weight.

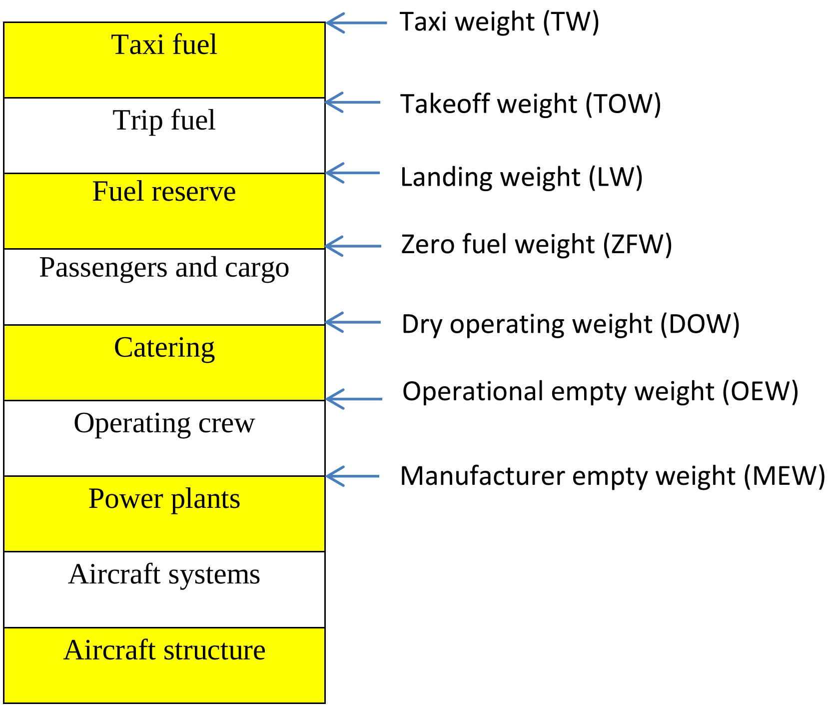


Fig. 9.1: Aircraft weights

One of the major aircraft loads is the trip fuel. The fuel is loaded into different fuel tanks. Depending on the design of the aircraft, fuel tanks can be located in the wings such as inboard and outboard wing tanks or in the fuselage, such as wing center tank, center tanks, and trim tanks. The wing bending is relieved by loading of fuel in the wings. Therefore, the wing tanks are loaded first and consumed last.

9.4 Weight and balance documents

Most of the weight and balance work is done using computerized system. However, if the system is not available, the work should be done manually. Several documents are used to manually prepare weight and balance calculations. These documents include the Load-sheet, which enables the calculation of all the weights shown in Fig. 9.1. Another important document is the Balance chart or the trim sheet. Sometimes it is combined with load-sheet. The trim sheet is used to calculate the CG position after loading the aircraft, while the trim sheet envelope is used to guarantee that the loading complies with aircraft limits.

The passengers are usually seated into three different zones; forward, center, and aft. Cargo is loaded into lower compartments. The moments due to the loaded items are calculated by multiplying the weight of the item by the arm of the item, which is the distance between the item and the CG. The weights and arms of the fuel tanks are used to calculate the fuel moments. Since the moment figures are high, they are difficult to deal with, which may lead to making errors. Therefore, these numbers are converted into smaller numbers using a conversion equation called the Index equation.

9.5 Electronic Data Processing (EDP)

The same documents described in 9.4 are produced automatically using the EDP. This includes the Load sheet and trim sheet. All operating aircraft data should be kept updated on the system so that the correct documents can be obtained for each flight.

9.6 Weight and balance basic concepts

9.6.1 Aircraft datum line

Aircraft datum line is an imaginary vertical line in front of the aircraft intersecting the longitudinal axis of the aircraft. It is used as the reference/origin for measuring the coordinates of all items on the aircraft. If this line was located within the aircraft, some items on the aircraft will have negative coordinates, which is not desirable in weight and balance calculations because it increases the chance for errors. The line is located few meters a head of aircraft so as to allow for any future elongation of the aircraft. Another reason is to avoid having any zero coordinates for items in the aircraft nose, which may become a source of error.

9.6.2 Mean Aerodynamic Chord (MAC)

It is an imaginary line located on the wing parallel to the aircraft longitudinal axis. The location of this line is decided during aircraft design. It can be located using a simple graphical method that depends on the wing tip and the wing root.

9.6.3 Load factor due to flight maneuver

When the aircraft rolls, pitches or yaws, it is subjected to a load factor proportional to the extent of motion. For example, an aircraft during a roll makes a bank angle of θ as shown in Fig. 9.2.

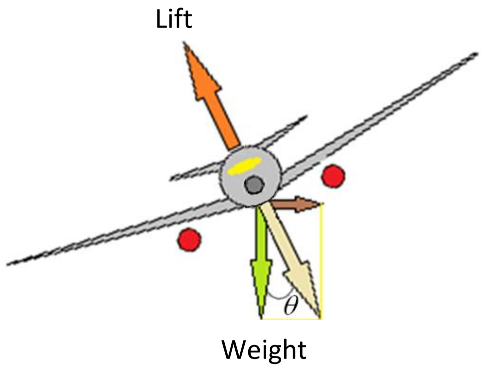


Fig. 9.2: Aircraft during a roll

The bank angle (θ) increases as the turn radius decreases. The weight acts downward, equals mass times acceleration of gravity. During a turn, the load factor (n) is defined as the apparent weight divided by the real weight (kg). The load factor is related to the bank angle by the formula:

$$n = \frac{1}{\cos\theta} \qquad 9.1$$

From equation 9.1, as the bank angle increases, the load factor (n) increases. Similar definitions for the load factor can be shown for the pitch and yaw maneuvers. From eq. (1), since the cosine is bounded between -1 and 1, the load factor (n) is either greater than 1 or less than -1. Typical n limits for a commercial jet in clean configuration (no high-lift devices extended) are in the range -1 g to

+2.5 g. For slats and flaps extended, values are in the range 0 g to +2 g.

9.7 Aircraft cargo

In cargo aircraft, both the main (upper) deck and lower deck are used for cargo loading. Whereas, in passenger aircraft, the lower deck is used for cargo, mail, and luggage loading, while the main deck is used for boarding passengers.

9.7.1 Service compartments

In a typical commercial jet, the lower half of the fuselage is used for cargo loading. However, certain portions are reserved for housing aircraft systems, such as forward electronic service center which is located underneath the cockpit. Environmental control system is located somewhere above nose landing gear. The hydraulic service center is located somewhere above the main landing gear. According to Fig. 9.1, the weights of these systems are included in the manufacturer's empty weight (MEW). The moment effects due to these systems are also included in the manufacturer's empty index, where the moment is converted to index as explained in section 9.4.

9.7.2 Cargo loading

Cargo is loaded into the aircraft in different ways; it can be using containers, pallets, or in bulk. Containers and pallets - also called "unit load devices (ULDs)"- come in two major sizes; full fuselage width (LD6) and half fuselage width (LD3), as shown in Fig. 9.3. Each ULD has its own packing manifest so that its contents can be tracked. ULDs are usually contoured (curved to fit in the plane's body) to provide as much cargo volume as possible. The same types of ULDs can be used in both main and lower decks.

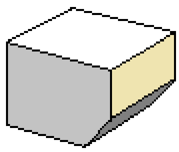


Fig. 9.3: LD3 ULD

Chapter 10

Aircraft Hydraulic Systems

10.1 Introduction

Hydraulic systems involve using a fluid under pressure to transmit power. It is based on the fact that liquids are almost incompressible. A basic hydraulic system comprises a hydraulic pump and actuating cylinder. Mechanical power is converted to hydraulic power using the pump. At the other end, the cylinder converts hydraulic power to mechanical power. Many aircraft systems utilize hydraulic power; such as flaps, speed brakes, doors, landing gear, as well as flight control surfaces.

10.2 Hydraulic system components

A typical hydraulic system consists of the following components:

a. Hydraulic pump:
   It converts mechanical power to hydraulic power. There are different types such as gear pumps and piston pumps.

b. Reservoir:
   It is a tank used to store reserve supply of fluid to account for leakage or thermal contraction of the fluid. It also provides pressure head on the pump, as well as provides space for fluid expansion due to high temperature. In addition, the reservoir provides a place for the fluid to purge itself of air bubbles. In many aircraft the reservoir is pressurized using engine bleed.

c. Directional valve:
   It is used to switch devices between two states, such as extension and retraction of landing gear or flaps.

d. Check valve:
   It is used to prevent back flow of the working fluid.

e. Pressure relief valve:
   It is a backup safety device that prevents over pressurization of the system. It opens at a preset pressure value.

f. Actuation cylinder:
   It takes the fluid pressure and converts it into linear motion.

g. Accumulator:
   It is used to absorb rapid pressure shocks in the system, as well as an emergency source of power.

h. Filter:
   As fluid flow through line filters, any foreign particles found in the system are separated from the fluid.

i. Hydraulic fluid:
   It is used to transmit pressure to units to be actuated. The type of fluid to be used is recommended by the manufacturer. It depends on the working conditions, such as temperature and pressure. Some of the most important properties of hydraulic fluid are viscosity and flash point. One of the most common types of hydraulic fluid is Phosphate ester-based fluid (Skydrol).

10.3 Hydraulic system operation

Hydraulic systems operate based on Pascal's law, where the working fluid is usually oil. The fluid is kept in contact with both sides of the piston head, but at different pressures; high and low. A directional valve determines to which side of the actuating cylinder the high pressure oil is sent.

10.4 Hydraulic power packs

These units are used in many modern airplanes. As a result of their compact size, they can save weight and volume. A hydraulic power pack unit consists of a pump, filter, reservoir, and valves. The advantage of this unit is that it eliminates the need for a centralized hydraulic system and long hydraulic lines. Using these units increases the reliability of the system due to reduced possibility of leakage. If the unit has an integrated actuator, it can be used to control the flight control surfaces directly.

Chapter 11

Pneumatic Systems

11.1 Introduction

Aircraft pneumatic system or vacuum pressure system employs air for transmitting power. In some airplanes, pneumatic systems are used to power brakes, hydraulic pumps, starters, landing gears, flaps, air-conditioning, windows, doors, as well as emergency devices. Some small aircraft instruments such as gyro compass, artificial horizon, and heading indicator use pneumatic systems as their power source.

11.4 Pneumatic system components

The basic pneumatic system components are:

1- Compressor (Air pump).
2- Check valve.
3- Accumulator.
4- Directional valve.
5- Actuator.

The system also includes other components such as:

- Air filter.
- Pneumatic pressure regulator.

11.5 Pneumatic system operation

The compressor pulls the air through the filter in order to prevent contamination. Air passes through the check valve which prevents air backflow. The accumulator soothes the flow and reduces disturbances. After that the directional valve channels the air flow to the desired direction. Finally, the actuator produces the desired motion. Over pressurization could damage the system. Therefore, it is prevented using a pressure regulator.

Different aircraft types use different sources of power such as hydraulic, electric, and pneumatic systems. Many aircraft types use a mix of these systems. One of the major factors that determine which systems to use is the size of the aircraft. Therefore, the detailed description of pneumatic systems is beyond the scope of this book.

Chapter 12

Environmental Control Systems (ECS)

12.1 Introduction

During the flight, the crew and passengers must be kept in a comfortable environment. In addition, the amount of oxygen onboard should be sufficient. At high altitudes, the temperature outside the aircraft could reach -56.5 °C, while atmospheric pressure loses more than 80% of its sea-level value. The job of the environmental control system (ECS) of the aircraft is to maintain acceptable environment inside the aircraft under these harsh conditions. In addition to passengers and crew, the ECS provides suitable conditions for the avionic, fuel and hydraulic fluids by transferring heat from the engines. ECS also controls humidity levels in the supplied air, while the hot air is used as anti-icing for the moving surfaces of the wings as well.

Oxygen and potable water are stored in the aircraft prior to the flight where the electrical system helps to supply them where needed. It is worth noting that aircraft air-conditioning is fundamentally different from ordinary air-conditioning systems, as no condensation or evaporation of a refrigerant is involved. Instead, air is mixed and heat is exchanged between cold outside ram air and engine bleed, which is hot compressed air extracted from the high-pressure compressor in the engine.

12.2 System description

Air-Conditioning takes air from the engine bleed and cools it using ram air (air from outside). Air is then filtered through purification system. It is used either to heat or to cool the cabin and the cockpit. In the case of cooling (at low altitudes), heat sinks such as outside air and fuel tanks are used to expel heat. During takeoff and landing, outside air temperature could be hot, therefore, heat pump is used in these cases. On the other hand, at high altitudes, ram air is utilized for air-conditioning and ventilation. Heat exchangers are used to increase the temperature of the ram air using engine bleed. As for the hot air, engine bleed is the main source, where it is also used to provide cabin pressurization.

There are two types of bleed air system; open loop and closed loop. The open loop system extracts large amount of air from the engines, refrigerate it using the outside air, and then use it to cool the cabin and equipment. The closed loop system recirculates some of the air and mixes it with fresh air, for the sake of saving engine bleed. Consequently, this leads to saving engine thrust, and avoiding weakening of the engine. However, the closed-loop system is more expensive than open-loop system because it needs more equipment. The mixing of ram air and bleed takes place inside the conditioning pack, where pack stands for "Pneumatic Air-Conditioning Kit".

Bleed air will pass through a catalytic ozone converter before it enters the air-conditioning packs, then enters the mixing manifold, where outside air and filtered re-circulated air are mixed. The resulting air is supplied to cabin through overhead outlets. The second hand air is fully exhausted from the airplane in open-loop systems, or partially re-circulated in closed-loop systems. As outside air enters the aircraft, an equal amount of air from the cabin is exhausted from the aircraft.

12.3 System functions

ECS is used for cabin pressurization, air-conditioning, emergency oxygen, as well as fire and ice protection.

12.3.1 Aircraft interior environment

The growing use of avionics equipment has increased their heat loads. Therefore, air is ducted to these areas to cool down the equipment. On the other hand, air-conditioning is needed to preserve a comfortable environment in the aircraft cabin, where air enters the cabin using overhead ducts and is extracted at the floor level. The movement of air from top to bottom is designed so as to avoid horizontal movement of air, which could spread disease between passengers. Cabin air is refreshed every few minutes, while the air is filtered in order to remove any contaminants.

12.3.2 Cabin pressurization

Cabin is pressurized in order to create a safe and comfortable environment for passengers and crew. Pressurization is needed at altitudes over 10,000 ft. above sea level. It is accomplished by pumping conditioned air into the cabin. The air is bled off from the engines after the compression stage. The bleed air is then cooled and mixed with re-circulated air (in closed-loop systems only) and delivered to the cabin. If pressurization was not provided, crew and passengers health will be adversely affected by the low pressure, which in extreme conditions, may lead to death. An acceptable cabin pressure (or cabin altitude) generally means a cabin-to-outside pressure differential of 0.6 Bar.

12.3.3 Humidity control

Passengers and crew comfort is achieved not only by controlling temperature and pressure, but also by controlling humidity in the cabin. Furthermore, control of humidity helps to prevent damage to electrical and electronic equipment.

12.3.4 Emergency Oxygen

Commercial jets are pressurized at a cabin altitude of around 2400 m, where it is possible to breathe normally. However, if cabin pressure is lost when the cabin altitude is above 4200 m, oxygen masks will drop automatically in front of the passenger. Pressure drop leads to lower air density. Consequently, the amount of air decreases as well. In this case, it is necessary to provide emergency oxygen by any means to the passengers and crew. Emergency oxygen can be provided in different forms; gaseous for crew, chemical for passengers, or liquid for military. The passengers' emergency oxygen consists of a number of oxygen masks stored in compartments near passenger seats.

12.3.5 Fire protection

Fire protection systems are installed onboard to detect and protect against fire. These systems are found in and near the engine and the fuselage. They consist of smoke detectors, infrared sensors, heat sensors, alarms, and fire extinguishers. Fire extinguisher bottles containing pressurized gas are installed in the aircraft. In the event of fire or crash, gas is released automatically and routed through tubes to nozzles, where it is sprayed onto the fire location. Among the extinguishing agents commonly used are CO_2, Methyl bromide, and dry powder.

12.3.6 Ice protection

Due to extremely low temperatures at high altitudes, ice can build up on airfoils, air inlets, and leading edge surfaces. Engine bleed is used to prevent the occurrence of ice on these aircraft surfaces, and consequently keep them operational.

12.4 Emergency equipment

Typical emergency equipment consist of crash ax, megaphone, flashlights, first aid kit, life vests, escape ropes, and life rafts. A crash ax is usually located in the cockpit. The megaphone provides an alternate means of communicating emergency instructions. Flashlights are located by the doors and are self-powered. One life vest is supplied per seat, usually located underneath the seat in front of the passenger. Life rafts can be installed in various places near exits. Some aircraft use the evacuation slide as a life raft. Life rafts have survival kits that contain a canopy to put over the raft, signal flares, and knives.

Chapter 13

Avionics and Electrical Systems

13.1 Onboard electrical system

Electricity is a non-dispensable resource in the aircraft. It is used to power the control computers of the airplane, to power indication systems in the cockpit and the cabin, and to power navigation systems and communications. In addition, it is used for the lights inside and outside the aircraft, for heating the meals for the passengers and crew, and for the entertainment systems in the cabin. During flight, electricity is produced by generators driven by the aircraft engines. On the ground, usually an onboard auxiliary power unit (APU) is used to generate electricity. If this is not used, ground power provided by the airport can be utilized. There is also an emergency battery that can be used when needed.

Most aircraft operate using AC system. Where the voltage is 115/200 V at a frequency of 400 Hz. However, some equipment use DC system at 28 V. Electrical power is normally divided into buses that are equal to the number of engines. The buses are paralleled to share the load. AC is converted to DC when needed using a converter. Both 115 V and 240 V can be supplied similar to demostic power. Common passenger usage include the shaver and thoothbrush. Emergency batteries are installed to supply power to communications and navigation. Emergency generators are installed on the engines. Ram air turbine (RAT) can be deployed in case of electric power loss.

13.2 Avionics

Avionics are the aviation electronics systems that provide the functions and capabilities required for safe and efficient operation of aircraft. Avionics encompass the ground, aircraft, and space assets required for control of all flight phases. Air traffic control system is a global network of national air traffic control systems that seamlessly pass the control of international flights as they cross borders between countries. Air traffic control globally coordinates the use of airspace. Airspace capacity is influenced by weather conditions which may cause delay or cancellation of flights.

The avionics onboard an aircraft provide the operating crew with the capability to manually or automatically control the flight. Flight is controlled based on flight plans and air traffic control clearances. In addition, avionics provide passenger in-flight entertainment. Avionics systems integrate hardware and software to implement control of flight functions, navigation, guidance, communications, and monitoring. Avionics technologies such as global positioning system (GPS) had been used for air navigation before having been extended to other industrial sectors.

Due to the deployment of advanced avionics, pilots nowadays have an unprecedented amount of data available; For example, electronic flight instruments use innovative technologies to provide aircraft attitude, altitude, and speed. A suite of cockpit information systems provide pilots with aircraft position, route, engine status, as well as information on weather, traffic, and terrains. Many tasks can be automatically performed using advanced avionics systems, thereby freeing the hands of the pilot to focus on optimizing the flight, as well as reducing onboard manpower such as flight engineers and navigators. For example, a flight management system (FMS) stores a list of points that define a flight route, and automatically performs most of the flight calculations, in terms of track, distance, time, and fuel. The autopilot is capable of steering the aircraft along the route that has been entered in the FMS system.

Bearing in mind the possibility of failure in any given system, the pilot-in-command must be able to perform the necessary actions in the event of an equipment failure (Emergency procedure). The pilot's capability to perform during emergency situations requires being proficient in accomplishing manual tasks, such as maintaining control of the aircraft manually (using only standby instrumentation), and adhering to air traffic control (ATC) clearances. Risk management requires the flight and cabin crews to always have a backup plan.

13.3 Control and data entry

The pilot is able to control the information being displayed, as well as enter data into the various avionic systems such as navigation way points. Waypoints and flight routes are preloaded into the FMS by maintenance personnel. During preflight preparations, the flight checks that the routes are correct. The pilot then can change any route due to any reason such as bad weather. The flight plan that the pilot receives prior to the flight is more updated than the FMS data. Therefore, the pilot does any necessary modifications to the flight routes according to the flight plan so that both the flight plan and the FMS are synchronized. The data on the FMS is updated every 28 days according to Aeronautical information regulation and control

(AIRAC) cycle, whereas the flight plan is continuously updated and printed about an hour ahead of departure time.

13.4 Avionics systems

- RADOME (Abbreviated from RAdar DOME): an aerodynamic faring (Fig. 13.1) that houses weather radar, ILS localizer, and glide-slope antennas. Unlike the rest of the fuselage it is made of fiberglass to allow radio frequency (RF) signals to pass through.

Fig. 13.1: Aircraft RADOME

- Nav Radio (Navigation radio): used to tune VORs, ILS, and GLS.

- Marker Beacons: pre-tuned to given frequency and illuminate when over-flown (more details are given in chapter 14).

- SELCAL: can alert the crew that a ground radio station needs to communicate with the aircraft.

- Cockpit voice recorder: records crew conversations in the cockpit during flight.

- Service interphone: used by the crew to call ground maintenance.

- Transponder (Transmitter-responder): responds when receiving a radio-frequency interrogation. It is used for aircraft identification by ATC radar.
- Emergency locator transmitter (ELT): used to locate the aircraft after a crash.
- Glare-shield panel: used to house several displays and controls as well as to protect against glare.

- Flight management system (FMS): It automates control of engine thrust (auto-throttle) and compute optimum flight level for best fuel economy. It contains a performance database and functions, and an interactive navigation database that is updated regularly, while optimizing performance to achieve the most economical flight possible. It is fed by load weight data to give gross weight and optimum speeds for all flight phases. It can also compute aircraft position based on inertial navigation system, GPS, and radio position updating.

- Many other avionics systems are available such as screens to display weather and navigation data as well as control and monitoring computers for all aircraft systems which are discussed throughout the book.

13.5 Intelligent displays management

Intelligent knowledge-based systems (IKBS) or "expert systems" are futuristic exploitation in military applications. They are mainly used to assist the pilot in performing the mission, thereby replacing the copilot. A subset of expert systems is the intelligent displays management system, which helps the pilot to deal with unexpected events that lead to an excessive work load, such as bird strike or engine failure.

Chapter 14

Navigation and Communication

14.1 Introduction

Navigation and communication systems are essential to safe and successful flight. These systems increase situational awareness on the flight deck. Navigational radio and radio voice communication were among the first developments in avionics. Today, numerous navigational aids exist, as well avionics to assist with weather, collision avoidance, flight control, public address, and instrument landing. Generally, there are two methods to fly an aircraft; visual flight rules (VFR) and instrument flight rules (IFR). The latter is used mainly at night and during low visibility.

In aviation, communications should be clear, for the sake of safety. Ambiguity should be avoided. For example, in radio communications, short words like "yes" and "no" are replaced with "affirmative" and "negative", respectively. In addition, the letters of sensitive information are replaced with well-known words to clarify the meaning. Where A is alpha, B is bravo, C is Charlie, D is delta, E is echo, F is foxtrot, G is golf, H is hotel, I is India, J is Juliette, K is kilo, L is lima, M is mike, N is November, O is Oscar, P is papa, Q is Quebec, R is Romeo, S is sierra, T is tango, U is uniform, V is victor, W is water, X is x-ray, Y is Yankee, and Z is Zulu. In this chapter, the most used navigation and communication systems will be presented.

14.2 Instrument Landing System (ILS)

It is a ground-based instrument system that provides guidance to an aircraft landing on a runway (Fig. 14.1). It uses a combination of radio signals and lighting arrays to enable a safe landing during reduced visibility. The ILS uses a radio beam transmitter that provides a direction for approaching aircraft, where the aircraft tune their receiver to the ILS frequency. The ILS is the most accurate landing navigation aid that is used today. However, possible problems with ILS include interference due to large reflecting objects, which can reduce the strength of the signals. An ILS consists of two sub-systems; the localizer (LOC), which provides lateral guidance, and the glide slope (GS), which provides vertical guidance. Both the LOC and the GS consist of several directional antennas located near the runway. The aircraft descends along the ILS glide path to the decision height, where the pilot must decide whether to continue the descent to a landing, or perform a missed approach procedure.

Fig. 14.1: ILS installations near runway threshold

There are three ILS categories, CAT I, CAT II, and CAT III, where CAT III is further classified into A, B, and C. CAT I is the most manual procedure while CAT III-C is the most automated procedure. The classification of an aircraft depends on the type of installed equipment onboard, whereas the classification of a runway depends on the ground navigation aids. Operation using a given category requires that both aircraft and runway are rated at that category or higher. ILS alternatives include Microwave Landing System (MLS), Transponder Landing System (TLS), Localizer Performance with Vertical guidance (LPV), and Ground-Based Augmentation System (GBAS). The Global Positioning System (GPS) is expected to provide a source of approach guidance for aircraft in the future.

14.3 VOR/DME

14.3.1 VHF Omni Directional Radio Range (VOR)

It is a short-range radio navigation system that enables aircraft to determine their position. Aircraft receive radio signals transmitted by a network of ground radio beacons. VOR is the standard worldwide air navigation system. It provides for accurate and precise flying, day and night. VOR routes are like invisible highways, where the aircraft can navigate to and away from any location. However, signals cannot be received at altitudes below 1000 ft, as well as being sensitive to interference of terrains.

14.3.2 Distance Measuring Equipment (DME)

It is an en-route navigational system that is often installed near VOR stations. That's why the combined system is referred to as VOR/DME. The DME provides the distance from the aircraft to the ground, expressed in nautical miles (NM). It also calculates the ground speed and the time needed to reach the station. The DME system consists of an onboard antenna and display as well as a transmitter/receiver on the ground. The DME is an accurate system that is capable of handling 200 aircraft simultaneously, over a range of 200 NM. However, the system is restricted to line-of-sight transmission.

14.4 Radar beacon transponder

It is a system used in air traffic control (ATC) to enhance radar monitoring and separation of air traffic. The system assists ATC surveillance radars by acquiring information about the aircraft being monitored. The information is provided to the radar controllers to identify the aircraft.

14.5 Doppler navigation system

This system uses the Doppler principle to measure aircraft speed and drift. The Doppler radar continuously measures Doppler shift and converts the measured values to groundspeed and drift angle. The system is completely self-contained and requires no ground installations. In addition, the system is utilized in VOR and some radar equipment. However, one of the drawbacks is that it is less accurate for over-sea flights.

14.6 Inertial navigation unit

Inertial navigation unit (INU) is an independent tool that operates using dead- reckoning principle; where the status of the aircraft is determined based on a known starting point, which is altered by subsequent movements. The change of acceleration is determined using measurements provided by the accelerometers. The kinematic equations yield the inertial velocities of the system by integrating the acceleration. Integration again using the original position as the initial condition yields the inertial position. As for the change in orientation, it is determined by processing gyroscopic signals. These status parameters are tracked continuously relative to the original point.

14.7 Weather radar

Weather radar is an airborne system used to locate potential hazardous weather. It collects and analyzes data to determine the structure of storms that could affect the flight path, and then presents the graphical data to the flight crew.

14.8 Radio altimeter

It is an airborne avionics device that measures the aircraft altitude above the ground. It operates by measuring the change of phase between transmitted and reflected signal. Radio altimeter calls are usually generated automatically by a synthetic voice.

14.9 Emergency locator transmitter (ELT)

It is a signal broadcasting equipment that is automatically activated by impact. ELT is usually used for search and rescue operations.

14.10 ADF/NDB

Automatic direction finder (ADF)/Non-directional beacon (NDB) is an old radio navigation system that is still in use today. The key feature of this system is its simplicity. It consists of ADF antenna on the aircraft and indicator in the cockpit. NDB consists of ground antenna near the runway. ADF/NDB assists aircraft navigation by providing aircraft heading information to the airport, where NDB transmits a call-sign in Morse code form to the aircraft. The system is used for runway departure, homing, en-route navigation, and holding. NDB signal can be received at low altitudes, as it is based on surface wave propagation. ADF/NDB system is found in small airports and can be used for back-up. However, it is prone to various effects such as interference, thunderstorm, terrain, night, and coastal environment.

14.11 ACARS

ACARS stands for "Aircraft Communications Addressing and Reporting System". It is a digital datalink system for transmission of messages between aircraft and ground stations via satellites. It also uses VHF signals that are exchanged using a network of land-based stations. Transmitted data include weather, flight plans, and technical information, in addition to communications between crew and ground staff.

Chapter 15

Aircraft Maintenance

15.1 Introduction

Aircraft maintenance is an essential part of airline operation. Without proper maintenance, safety and profitability of airlines can be compromized. Maintenace can be conducted wholy by the same company. However, in most cases, many taskes are outsourced to specilaized maintenace companies.

15.2 Airline maintenace structure

The typical structure of an airline maintenace department is described here. The department typically consists of five main units, each unit consists of three or more sections. The structure and role of each unit will be explained hereafter.

15.2.1 Technical services

The technical services unit consists of Engineering, Planning, Training, Publication, and Computer. The Engineering section organizes and coordinates all work done in the workshops, including power plant, structures, avionics, and systems (hydraulic, pneumatic, etc.). This section is also concerned with the development of the maintenance program, including tasks, intervals, and schedules, as well as issuance of engineering orders (EOs). The Planning section is responsible for production planning, including all activities related to maintenance, such as work scheduling, control of hangars and on-airplane maintenance, as well as monitoring of work progress in the shops.

The Training section is responsible for curriculum and course development and administration for all formal training of employees. The Technical publications section is responsible for all technical publications used by the maintenance and engineering (M&E) organization, especially documents and revisions received from manufacturers and vendors. In addition, it maintains the technical library. The Computer or IT section is responsible for the M&E computing requirements.

15.2.2 Aircraft Maintenance

Aircraft maintenance can be done in the hanger or while the aircraft is parked between flights. It depends on the size of the work and the man-hours required. Usually light work is done between flights, while heavy work is done in the hanger. The hanger contains workshop and storage facilities for aircraft maintenance. Tasks performed in the hanger include modifications, engine changes, "C" checks (and higher), and painting. Hanger facilities include support shops, such as welding, interior and composites.

Line maintenance is conducted outside the hanger. Work is performed on the aircraft on the flight line while the aircraft is in service. These tasks include turnaround servicing, daily checks, short interval checks such as A-Checks. Airline fleet is tracked in flight and at outstations by the Maintenance control center (MCC). It coordinates all maintenance needs and downtime with the flight operations department.

15.2.3 Shop maintenance

It includes engine shops that repair the engines and auxiliary power units (APUs), avionics shops that perform all off-aircraft maintenance of electrical and electronics components; such as radio, navigation, communications, and electric motors. Mechanical components shop (Fig. 15.1) is responsible for equipment such as hydraulic and pneumatic systems, flaps, slats, spoilers, and fuel system. Structures shop is responsible for repairing structural components, such as composites and sheet metal.

Fig. 15.1: Heavy maintenance at the hanger

15.2.4 Materials management

Material management is directly related to costs. A good material management strategy can make big savings for the organization. Material management is divided into four main activities; Inventory control, storage, purchasing, and receiving. Inventory control ensures that the available materials are just sufficient, while maintaining balance between too much inventory and too little inventory. Too much inventory means carrying surplus quantities which translate into frozen capital. While too little inventory means running out of stock too soon or too often, which translates to losses due to delays and downtime.

The stored materials need handling and delivery upon request. The store management system involves proper put away, storing, and retrieval practices. A closely related activity is procurement or Purchasing; because the quantity to be ordered is found using the inventory control system. The procurement process is not limited to buying parts and supplies, tracking orders, and handling warranty claims. It also involves selection of suppliers, and coordination with inventory control and storage management systems. Finally, shipping and receiving activities involve packing, waybill, insurance and customs for outgoing items, as well as clearance, inspection, and tagging for incoming items.

15.2.5 Maintenance program evaluation

Program evaluation involves quality assurance, quality control, reliability, and safety. Quality assurance (QA) audits all units against standards so that they adhere to the organization requirements. Quality control (QC) conducts inspections of repair work, and certifies maintenance personnel. In addition QC is responsible for calibration of tools and test equipment, as well as performing nondestructive testing (NDT). The reliability program must ensure that any problems are addressed in timely fashion. It involves data collection and analysis for better maintenance planning. Safety and health related activities are administered as part of this unit, as well as handling all related reports.

15.3 Aircraft inspections

There are four different categories of inspections:

- A-Check: regular aircraft maintenance.
- B-Check: regular maintenance every 3 months.
- C-Check: detailed maintenance every 15 months.

- D-Check: thorough checking every 6 years.

15.4 Maintenance costs

Aircraft maintenance is the largest part of the operating cost after fuel. It represents around 15% of the worldwide airlines direct operating costs, and these costs are growing. Regular maintenance is necessary in order to maintain the aircraft in an airworthy condition. Maintenance manuals and documentation are provided by the manufacturer. Additional tasks are notified by regular Advisory circulars (AC) and Airworthiness directives (AD) issued by civil aviation regulatory authorities. Maintenance costs include direct maintenance costs (DMC) and indirect maintenance costs (IMC) or overhead. Overhead costs are the fixed costs unrelated to a specific job, such as technical support and salaries, while direct costs are variable and depends on the specific job done, such as spare parts.

Maintenance cost is defined as the sum of incurred labour, materials and various overheads, which equals the sum of DMC and IMC. The Airlines overall maintenance costs are categorized as controllable and non-controllable costs. The controllable cost element is further split into contractual and non-contractual costs. The contractual cost elements are either outsourced or accomplished in-house. On the other hand, maintenance can be classified as ON-Aircraft maintenance OFF-Aircraft maintenance. Generally, the difference between engine and airframe maintenance is that engine material costs will exceed 80% of the total maintenance while airframe maintenance will equally share labour and material costs.

15.5 Component repair methods

Components are repaired to restore their serviceable condition. Parts are categorised into rotables, repairable and expendables; multiple repairs are possible to rotables parts. These parts are scrapped when repair cost exceeds the 65% threshold of the unit cost.

Chapter 16

Airport Engineering

16.1 Introduction

The chapter focuses on all engineering-related matters pertaining to airport operation. After defining some basic terms related to airport engineering, various airport engineering subjects are discussed; such as airport visual aids, lightings, runway pavement designations, rescue and firefighting categories, and aircraft noise abatement regulations. Finally, the major airport ground services are described.

16.2 Basic Definitions

16.2.1 Runway

A runway is a rectangular-shaped, paved surface on an airport, designed for the landing or takeoff of aircraft. Runways may be a man-made surface (such as asphalt or concrete) or a natural surface (grass, gravel, ice, or salt).

16.2.2 Runway Designations

Runways are designated using a two digit number between 01 and 36 according to the direction the runway makes relative to the magnetic north. Runways are generally constructed in the direction of the dominant wind. It is often the case that large international airports will have several parallel runways all pointing in the same direction. To avoid this confusion, an airport with two parallel runways will add an R or L to the end of the runway designation to signify right or left. Some airports will have three parallel runways, in that case the middle runway will be designated with a C after the number to signify 'center'.

16.2.3 Runway length

A runway of at least 6,000 ft in length is usually adequate for aircraft weights below 90 ton. For larger aircraft including wide bodies, they will usually require at least 8,000 ft at sea level. International wide body flights, which carry significant amounts of fuel and are therefore heavier, may also have landing requirements of 10,000 ft or more and takeoff requirements of 13,000 ft. At sea level, 10,000 ft can be considered an adequate length to land virtually any aircraft. An aircraft will need a longer runway at a higher altitude due to decreased air density at higher altitudes, which reduces lift and engine power, requiring higher take-off and landing speeds.

16.3 Visual Aides

16.3.1 Runway visual aids

Visual aids support air traffic control system to provide navigational help for approaching and departing aircraft, as well as control of aircraft and vehicles on the surface of the airport. The different types of visual aids for air navigation are classified as:

a. Indicator and signaling devices
b. Markings
c. Lights
d. Signs
e. Markers

16.3.2 Airport markings

Airport markings can be grouped as:

a. Runway marking
b. Taxiway marking
c. Other marking

16.3.3 Runway Markings

Runway markings are white in color. The following marking are used on runways (Fig. 16.1):

a. Designation marking
b. Center-line marking
c. Threshold marking
d. Aiming point marking
e. Touchdown zone marking
f. Side stripe marking
g. Threshold bar
h. Demarcation bar
i. Arrow and arrow heads
j. Chevrons
k. Holding position marking
l. Runway shoulder marking

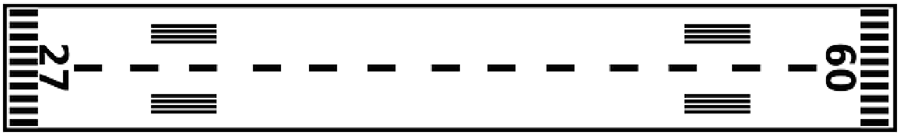


Fig. 16.1: Runway markings

16.3.4 Taxiway Markings

Taxiway is a paved surface designed for the movement of aircraft from one part of the airport to another. The following are the markings used on taxiway:

a. Centerline marking (single continuous yellow line)
b. Edge marking
c. Holding position marking on taxiways
d. Shoulder markings
e. Geographic position markings

16.4 Airport Lightings

The colors and pattern of airport lighting is standardized to provide the needed aeronautical information to the pilot during night time. The light used at an airport can be classified in the following categories:

1. Airport beacon
2. Identification beacon
3. Approach lighting system (Fig. 16.2).
   - For non-instrument and non-precision approach runway
   - For precision approach runway category I
   - For precision approach runway category II and III
4. Circling guidance lights
5. Runway leading lighting system
6. Runway threshold identification lights
7. Runway edge lights
8. Runway threshold and wing bar lights
9. Runway end lights
10. Runway centerline lights
11. Runway touchdown lights
12. Stopway lights
13. Taxiway centerline lights
14. Taxiway edge lights
15. Stop bars
16. Clearance bars

17. Taxi-holding position lights
18. Visual docking guidance system
19. Airport stand maneuvering guidance lights
20. Visual approach slope indicator system

Fig. 16.2: Approach lighting system

16.5 Airport Data

Airport Information Publication (AIP) is the official source of airport data for a given country. However, more detailed information are needed for operational purposes, therefore, a commercial data provider is used by most airlines. As an example for the data involved, Queen Alia International Airport has the following information:

IATA code: AMM
ICAO code: OJAI
Magnetic Variation is 5° East
Operational data:
Airport Communications

AMMAN Approach:	128.90
QUEEN ALIA Tower:	119.80

Nearby Navigation Aids
Runway 08L/26R

Dimensions:	12008 x 200 feet / 3660 x 61 meters	
Surface:	Hard Runway (PCN): 84/F/C/W/T. Asphalt	
	Runway 08L	Runway 26R
Coordinates:	N31°43.60' / E35°58.17'	N31°43.93' / E36°0.45'
Elevation:	2360	2395

Runway Heading: 077° 257°

16.7 Runway Pavements

The design of runway pavements can be compared to highway pavement. However, because of the landing touchdown impact, as well as the high takeoff and landing weights, runway pavements are more critical. The choice of material used to construct the runway depends on the use and the local ground conditions. For a major airport, where the ground conditions permit, the most satisfactory type of pavement for long-term minimum maintenance is concrete.

Runway pavement surface is prepared and maintained to maximize friction for wheel braking. To minimize hydroplaning following rain, the pavement surface is usually grooved so that the surface water film flows into the grooves and the peaks between grooves stay in contact with the aircraft tires. The three most common methods of expressing airport pavement strength are:

a. ICAO Aircraft Classification Number (ACN)/Pavement Classification Number (PCN) system
b. Load Classification Number (LCN)/Load Classification Group (LCG) System
c. Runway weight limits system

16.6.1 ACN/PCN system

Taking AMM airport as an example, where PCN is 84/F/C/W/T, Asphalt. The number in the PCN string (84) relates to the allowable weight of the aircraft. The first letter refers to (F) flexible or (R) rigid pavement. The second letter relates to the bearing strength of the subgrade soil beneath the pavement. The third letter gives a range of allowable tire pressures, and the fourth letter is the evaluation method. If the fourth letter is “T”, that means a technical evaluation of the pavement was conducted. If it is “U”, it indicates that the "Using Aircraft" method of evaluation was used. That means the equivalent ACN of the highest gross weight of the largest airplane currently using the runway is reported as the strength of the pavement. If the ACN for an airplane is lower than or equal to the reported PCN for a runway pavement, the airplane can operate without weight restriction on that pavement.

16.6.2 LCN/LCG system

Some airports use this British pavement rating system for runway strength reporting. It makes no distinction between asphalt (flexible) and concrete (rigid) pavements. Since these two surfaces react to loads differently, LCG type LCNs are not considered to be a highly precise measure of pavement strength particularly for flexible pavements.

16.6.3 Weight limits system

In this system, the weight limits for the runway are expressed in thousands of pounds for each main gear for different wheel configurations, where S/L is the load for a single wheel per leg, T/L is the load for a twin or tandem wheel leg, and TT/L is the load for a twin tandem wheel. Other runway pavement loading formats include Single Isolated Wheel Load (SIWL) and All Up Weight (AUW), which is the maximum weight bearing capacity for any aircraft irrespective of landing gear configuration.

16.7 Airport Rescue & Fire Fighting

Aircraft rescue and firefighting (ARFF) is a special category of firefighting that involves the response, hazard mitigation, evacuation and possible rescue of passengers and crew of an aircraft involved in an airport ground emergency. Aircraft manufacturers provide detailed aircraft rescue and firefighting charts for their products. Airport categories for rescue and firefighting include ICAO airport category (from 1 to 10), and FAA airport category (A, B, C, D, and E). These categories are based on the over-all length and the maximum fuselage width of the airplane.

16.8 Aircraft Noise Abatement

The main sources of transportation noise pollution include rail, road, and air. However, air transport is considered the most annoying among these sources, where sound is mainly produced by aerodynamics, engine and other mechanical noise. Modern high-bypass turbofan engines are quieter than turbojets and low-bypass turbofans. The level of aircraft noise increases as we get closer to the airfield. It can go up to 85 dB or more, while the threshold of human pain due to noise is 140 dB. The most promising form of aircraft noise abatement is through land planning, flight operations restrictions and residential soundproofing.

16.9 Airport Ground Services

Airports are designed to serve departing and arriving airplanes and passengers, as well as other visitors. In order to provide adequate services, various equipment and systems are involved. After an aircraft lands on the runway, it is taxied into the ramp or apron, which is the place where the aircraft is parked for unloading and reloading. Typical ramp services include:

a. Refueling bowser
b. Baggage services (tow tractor, belts, etc.).
c. Push-back, towing, aircraft marshaling and parking.
a. Ground power unit and air-starter.
b. Tracking and auditing of uplift receipts.
c. De-icing.
d. Cabin cleaning and lavatory servicing.
e. Arrival/departure gates for International and domestic flights.
f. Waste management.
g. Flight operations support services, such as landing rights.
h. Customs, Agriculture, and Immigration.
i. Flight planning and Dispatch.
j. Crew transportation.
k. Load Control; Weight and balance.
l. Other ground handling equipment such as Cargo loader (Fig. 16.3), Boarding bridge, Stairs truck and Catering truck.

Fig. 16.3: Cargo loader

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