INSTITUTE OF AERONAUTICAL ENGINEERING

(Autonomous)

Dundigal, Hyderabad -500 043

AERONAUTICAL ENGINEERING

COURSE HANDOUT

Course Name	**INTRODUCTION TO AEROSPACE ENGINEERING**
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Course Coordinator	**M.Snigdha**
Course Faculty	**M.Snigdha, Assistant Professor , K. Sai Priyanka Assistant Professor, AE**

UNIT – I
HISTORY OF FLIGHT AND SPACE ENVIRONMENT

- Icarus (s/o Daedalus) – Greek / Roman mythology - flying high and close to sun – wax melted and fell down in the ocean – It is mythology and there is no Engineering or evidence to that ,That was just a story but history says Humans have been fascinated with flight and mimice'd birds.
- Artificial wings and flapped them with their arms. Later mechanical engineering was used to flap wings up and down – Ornithopters. Great Italian artist, architect, scientist, and engineer Leonardo da Vinci (1452–1519) devoted much of his time to flight.
- His manuscripts contained some 160 pages of descriptions and sketches of flying machines. His work includes the world's first known designs for the parachute and helicopter, and it is believed that he made models of both and may have even flown them successfully. While da Vinci's work was brilliant, the concept of an Ornithopter did not lead to sustained flight.
- It was only in the 18th century that humans achieved lighter-than-air flight. Then it took another 120 years to achieve heavier-than-air flight.

Balloons:

- Montgolfier brothers (French), pioneered lighter-than-air flight with their innovative balloon designs. They conceived the idea of using the "lifting power" of hot air to achieve flight.
- On 25 April 1783, they launched the first true hot-air balloon in Annonay, France. The balloon rose 305 m (1,000 ft) before the hot air cooled and it began its descent.
- On 19 September 1783, they launched a sheep, duck, and rooster as the first passengers aboard their balloon.
- The first human to be carried aloft was in 15 Oct 1783, drifted 25.6 m (84 ft). A month later Rozier, accompanied by Marquis d'Arlandes, made the first free flight in a balloon, remaining airborne for 25 min during which they traveled 8.5 km (5.5 mi).
- Hot air balloon replaced by hydrogen
- Professor Jacques Alexander César Charles was the first to successfully demonstrate a hydrogen balloon on 27 August 1783 - 43 km (27 mi) free flight from the garden of the Tuilleries, Paris, on 1 December 1783. This balloon was so well designed that it is essentially the same as the gas-filled balloons used today.
- Benjamin Franklin witnessed this event in Paris and was so impressed that he immediately wrote to scientists in the United States, stressing the military importance of this new invention.
- The Blanchards were other notable hydrogen balloonists.
- Jean-Pierre Blanchard was the first to attempt controlled flight with sails and rudders, first to cross the English Channel, and first to fly in the United States. Sophie Blanchard started flying in 1805 and was probably the first woman pilot.
- She made 59 ascents, flew at night, and put on fireworks displays from her hydrogen-filled balloon. As Science improved further, Ballons started replacing blimps (Dirigibles): Dirigibles

– elongated bags filled with gas, fitted with engine, propeller and rudder (Steam Electric Gasoline).

- Easy to maneuver when gas was completely filled – aerodynamic shape – but difficult to steer when the gas pressure reduced as it lost its shape. So maintaining the shape was challenging.
- By the 19th century, balloons were used for reconnaissance in warfare. France was still leading the way when Charles Renard and Arthur Krebs, officers in the French Corps of Engineers, flew the first fully controllable and powered dirigible on 9 August 1884.
- The vehicle, named La France, flew a circular course of 7.6 km (5 mi). It was powered by a 9 hp electric motor, which drove a 7 m (23 ft) diameter propeller.
- A maximum speed of 22.5 km/h (14 mph) was achieved during the 23 min flight.

Zeppelin -

- The German Count Ferdinand von Zeppelin (1838–1917) was the first to realize that maintaining a rigid shape was essential to making the vehicle steerable, and hence he designed a rigid but light frame containing the gas bags, which led to the development of dirigibles.
- The townspeople of Friedrichshafen, Germany, thought his ideas were ridiculous and nicknamed him "Crazy Count." On 2 July 1900, Count Zeppelin's dreams became reality when his Luftschiff Zeppelin (LZ-1) made its maiden voyage near Friedrichshafen.
- Dirigibles, which soon were called zeppelins, became a practical means of air transportation by 1908. In 1909, the German air transportation company Deutsche Luftschiff arts AG (DELAG) was organized to develop and manufacture air- ships. Until the outbreak of World War I in 1914, more than 1,780 flights had safely carried more than 27,700 passengers. In 1922 the company built the Los Angeles, the U.S. Navy's premier airship.
- In the late 1920s and early 1930s, the LZ-127 Graf Zeppelin was the ultimate airship for passenger air travel. It was used for transatlantic passenger service and flew more than 1.5 million km in commercial service.

Wrist watch story-

- Another notable engineer, inventor, and flyer were the Brazilian-born Alberto Santos-Dumont. At an early age, his dreams were filled with airships and flying machines.
- In the years 1898 through 1905 he built and flew 11 dirigibles. Santos-Dumont's most noteworthy accomplishment took place in Paris on 19 October 1901 when he flew a dirigible from Park Saint Cloud to the Eiffel Tower and back, a distance of 3 km, in under 30 min. After his famous flight, his friend Louis Cartier was among those who celebrated his triumph.
- During the celebration, Santos-Dumont mentioned to Cartier his difficulty in checking his pocket watch to time his performance while keeping both hands on the controls.
- Cartier, in an effort to help his friend, developed a watch with a leather band and buckle to be worn on the wrist. Thus, Santos-Dumont's flight advanced aviation and initiated the wristwatch industry

Heavier than Air Flight:

- We covered the Zeppelin era where mankind had made good progress in flying, but heavier than air flight was still in its infancy.
- However, there were several Aviation Scientists who were contributing to the Aviation field.
- One such Scientist is Sir George Cayley (1773 – 1857).
- Sir George Cayley (Englishman) – He devised the basic configuration of modern airplane that we see today – What it means is that he came up with the idea and in 1799 designed an airplane where he separated the Lift – Propulsion – Controls.
- For Lift - He designed a fixed wing
- For Propulsion - He envisioned paddles
- Stability and Control – He designed a tail unit (vertical & Horizontal units)
- He had good understanding of L, D and Thrust even at that time. He engraved it on a silver disk which is preserved in London Science Museum. In that century also he knew about curved wings, studied engines and propellers
- He is responsible for breaking the thought that flapping of wings and flying (Da-Vinci) is not going to work – Fixed wing is the alternative to that old idea.
- Outside of Aero he was a good person too.
- In 1804 Cayley built a whirling arm apparatus for testing aerofoils – explain the apparatus. He used this to measure aerodynamic forces and CP.
- Competition from peers: Cayley was prompted to document his work in his called "Triple paper" after hearing that Jacob Degan had flown a mechanical machine in Vienna.
- In reality it was only a contraption with lift from Balloon. Cayley was unaware of the details of this flight. This "triple paper" gave the foundation of early flight fundamentals.
- He also mentioned that a lift can be generated by a flat plate inclined to the direction of the movement.
- A cambered surface will also be able to do better than a flat plate – more effective Lower pressure at the top of the wing.
- He built the first human carrying gliders sometime in 1853 exact detail is not known.

Otto Lilienthal (German):

- Built several single wing – bi wing gliders (mono plane and Bi plane). He had more than 2000 gliding flights. He had lot of aerodynamic data of these flights and in 1889 he published his influential book "The flight of birds as the basis of the Act of flying".
- This was the ground work he laid for the Aviation in Europe and US. This book influenced several other Aviation Scientists including the Wright brothers – printing and photography also was industrialized so the timing helped to propagate his work Wilbur (in 1894) actually got lot of interest after reading Lilienthal's work Aug 9, 1896, Lilienthal was gliding – fine summer day – suddenly a gust came and brought his monoplane glider to a standstill; glider stalled and he dropped on the ground– minor damage to the wings but glider was ok.

- He was sent to hospital with a broken spine and the next day he died. There is a belief that if he had lived he could have beaten the Wright brothers. Percy Pilcher (Scottish) – Another Enthusiast who did significant gliding and did some calculations for powered flights

Aeronautics comes to America:

- French – German – English - …America Octave Channute (1832 - 1910) – Fascinated with Aeronautics and collected all info on flight and compiled a book that was very helpful.
- Samuel Pierpont Langley (1834 – 1906) – Well respected in US and was the Secretary of Smith sonian Institution – No formal education beyond high school but had lot of interest and was self-educated.
- He became Math's Prof, at US Naval Academy, Physics and Astronomy prof at University of Pittsburg. Built several model airplanes but got recognition only in 1896 May 6 when his powered airplane made a free flight of 1006 m and in Nov it made 1207m.
- He called these Aerodromes – refer pictures He was satisfied with this and because this was expensive, he decided not to pursue a man carrying machine.

Commercial Air Transport:

- Zeppelin: Early decades of 20th century. Flying not more than 100 km/h, but they could do so for thousands of kilometers without having to land. World's largest rigid airship, the LZ-129 Hindenburg, was built in 1936.Length of 245 m, top speed of 135 km/h, and used some 200,000 m3 of hydrogen.
- On 6 May 1937, while landing at Lakehurst, New Jersey, the Hindenburg was completely destroyed in a spectacular explosion attributed to a discharge of atmospheric electricity in the vicinity of a hydrogen gas leak from the airship. This disaster marked the end of the use of rigid airships in commercial air transportation.
- The first scheduled flight of an airline using an aircraft occurred on 1 January 1915 from St. Petersburg, Florida, to Tampa, Florida. The first regular commercial airline with passenger service was Germany's Deutsche Luftreederei, which began service from Berlin to Leipzig and Weimar in February 1919.In October of that year KLM (Royal Dutch Airlines) was founded in the Netherlands and is the world's oldest airline.
- The aircraft of the period could carry between two and eight passengers offered little in comfort Passenger needed to wear warm leather clothes and gloves Earplugs were "strongly recommended, "Emergency landings were very frequent.
- But many refinements in aircraft design were introduced, and significant improvements in performance were achieved during the 1920s. Some of these were made by the National Advisory Committee for Aeronautics and Astronautics (NACA), the predecessor of NASA.
- The U.S. government created NACA in 1915 when it recognized how far it was behind Europe in aircraft production. Boeing - In 1916, William E. Boeing founded the Pacific Aero Products Company, which he renamed in the following year the Boeing Airplane Company.

- In 1933, Boeing 247, an all-metal twin-engine low-wing monoplane, had its maiden flight. Boeing 247 is nowadays regarded as the first "modern" airliner and was sought after by many airlines. However, Boeing restricted the sale of the aircraft until the order for its sister company United Airlines was fulfilled. This prompted competing carrierTrans World Airlines (TWA) to persuade Boeing's biggest rival, Douglas Aircraft Corporation, to launch its own commercial series of aircraft in 1933.
- The DC-1 was an improvement over the Boeing 247 with a better and more spacious cabin. It was refined to become the DC-2 and later evolved into the DC-3. Providing room for 21 passengers and featuring much small technical advancement, the DC-3 became the favorite aircraft among airlines and pilots.
- By 1939, DC-3s were carrying 90 % of all commercial traffic around the world. During the 1930s and 1940s, seaplanes often exceeded the size and range of land planes. The reason was that airfields were fairly limited in size, but this was not so for lakes or coastal waters from which seaplanes could take off and land.

Introduction of Jet Airplanes:

- At the start of World War II, in September of 1939, Germany's aircraft industry was by far the most advanced in the world. Aircraft played a decisive role in the conflict since achieving air superiority became important to winning land and sea battles.
- During the course of the war, aircraft production reached enormous proportions. The United States alone produced over 300,000 military aircraft in the period of 1940 through 1945 shortly before the end of the conflict; the first aircraft powered by jet engines were introduced.
- The jet engine was developed independently by Sir Frank Whittle in Britain and by Hans Joachim Pabst von Ohain in Germany.
- As the speed of propeller aircraft approaches 700 km/h, the efficiency of the propeller drops rapidly and so a different means of propulsion is necessary to fly much faster detailed description of how jet engine aircraft "Aircraft Propulsion."
- Whittle had filed a patent in 1930 which became the basis for the British efforts to develop a jet engine, resulting in the first successful test of a turbojet engine in 1937. However, the German Heinkel He 178 became the first aircraft powered by a jet engine in August 1939.
- The major challenge facing aviation was the so-called sound barrier (a speed of Mach For years it was believed that crossing the sound barrier was impossible, and the numerous casualties among pilots seemed to corroborate that belief.
- The cause of the sudden breakup of the aircraft attempting to fly faster than the speed of sound was a rapid increase in drag as the aircraft approached the speed of sound and a phenomenon known as buffeting (a violent shaking of the aircraft).
- On 14 October 1947, a Bell XS-1 rocket-powered research plane piloted by U.S. Air Force Major Charles "Chuck Yeager became the first aircraft to fly at supersonic speeds. After being dropped from a Boeing B-29 mother ship, the XS-1 (later renamed X-1) reached a maximum

speed of 1,126 km/h, or Mach 1.06. In 1952, the Comet I became the world's first jet airliner, able to carry 36 passengers over a range of 3,200 km at a speed of 720 km/h.

- The aircraft cut the travel time in half and by flying at an altitude of 12,000 m. Once people had flown on the Comet, they had little desire to fly again with propeller-driven aircraft.
- Due to a design error, the aircraft experienced catastrophic failures in flight from metal fatigue problems which led to the grounding of the fleet and the cancellation of the program.
- U.S. manufacturers Boeing and Douglas learned from the design errors of the Comet. In 1966, Pan is ordered 20 Boeing 707 and 25 of the similar Douglas DC-8 jet airliners, which initiated a worldwide jet-buying frenzy.
- In the 1960s, short-haul piston-engine airplanes also began to be replaced by turbine-driven propeller craft. In the commercial aviation sector, the fastest and largest commercial airliners to the present day had their maiden flights. The United States, the Soviet Union, and Britain with France worked on the development of a supersonic airliner. The U.S. effort, the Boeing 2707, did not even reach the prototype stage. The Soviet Tupolev Tu-144 was the first to fly faster than the speed of sound (Mach 1), but it remained in service only briefly.
- Only the British-French Concorde became a successful supersonic transport. The delta-wing Concorde was developed jointly by the British Aircraft Corporation (BAC) and France's Sud Aviation.
- It had its first flight on 1 March 1969 and entered revenue service in January 1976. The aircraft's cruise speed of about Mach 2 reduced the flight time between London and New York to about 3 h. Seventeen aircraft were manufactured for passenger service and remained in use with carriers British Airways and Air France until the summer of 2000, when a tragic crash in Paris took the lives of 113 people.
- After Boeing lost a bid to build a large transporter for the U.S. Air Force, the company and its engine partner, Pratt & Whitney, decided to make good use of their design experience and embarked on an ambitious undertaking to develop a commercial aircraft capable of carrying up to 500 passengers.
- The end product was the first so-called wide-body or twin-aisle passenger jet, the four-engine Boeing 747—affectionately called the Jumbo Jet. Few aircraft are so widely recognized around the world as the 747 with its upper deck.
- The 747 had its maiden flight on 9 February 1969 and entered service in January 1970. The Jumbo Jet consists of some 6 million parts and with a height of 20 m is as tall as a six-story building. Since 1990 the aircraft of the U.S. President Air Force One, is a Boeing 747 (with its military designation VC-25A).
- The Boeing 747 exemplified the U.S. dominance in the airliner industry. By the 1960s, European countries realized that only a close cooperation between them could create a serious and lasting competition to U.S. manufacturers led by Boeing, McDonnell Douglas, and Lockheed. In December 1970, the Airbus Industries consortium was set up to build a European high-capacity short-haul airliner.

- French and German companies had a dual role as both shareholders and industrial participants. They were joined by Spanish and British manufacturers in 1971 and 1979, respectively. Airbus premier model which entered service in May 1974,was the A300B— the world's first twin-engine wide-body jetliner.

Helicopter:

- The German Focke- Wulf Fw 61 became the first practical helicopter when it flew in 1936 as the highlight of an indoor show in Berlin organized by the Nazis. H/c had two rotors mounted on outriggers to the left and right sides of the fuselage and was quite a capable craft outdoors. Reached an altitude of 2,439 m (8,000 ft).
- In 1939, the Russian-born Igor Sikorsky designed, built, and flew the experimental helicopter Vought Sikorsky VS-300 in the United States.
- The VS-300 used a single main rotor for lift and a smaller vertical rotor mounted on the tail to counteract torque.
- During the Vietnam war Bell Helicopter developed the Bell 209 Huey Cobra attack helicopter, which was the first helicopter designed for such a purpose.

Conquest of Space:

- Konstantin Tsiolkovsky (1857-1935) –"Exploration of Cosmic space by means of Reaction Devices"
- Derived a fundamental equation known as Rocket Equation.
- Liquid Hydrogen + Liquid oxygen & gyroscopes for stability.

Herman Oberth (1894-1989):

- "Rockets into Inter planetary Space & Ways to Space Travel "Idea of Rockets for Space Travel, Space craft, Space Suits, Space Station Robert H Goddard (1882-1945)– US Physics Prof – WPI / Clark University1919 book - "A method of Reaching Extreme Altitudes", his ambition to fly to moon16 March, 1926 – Launched the first liquid rocket using gasoline and liquid oxygen as propellant – Height of 12.5m .
- Germany (Society for Space Travel) – Key activity .Built in 1932 – Range of 5km and altitude of 1500m.Peace Treaty after WW-1, Military restriction on Germany.
- Rocket was an excuse - Lot of work started in this and in missile as a private enterprise from a military stand point – missiles Soviet and US also picked up but behind Germany Soviet Union saw Astronautics as Technical superiority.
- Oct 4, 1957 first satellite "Sputnik – 1" into orbit – circling the earth every 96 min .A month later they sent a dog into space – Sputnik -2.31st Jan 1958 – US launched its first satellite – Explorer -12 years in orbit and discovered the Van Allen radiation belt (solar cosmic rays – charged particles – 1000km to 60000km) .
- Sputnik "shock" made US start NASA in 1958 July 28 to counter Soviet competition .April 12, 1961, Yuri Gagarin was orbited into space – The first human being – Vostok -1108 min to orbit

at 200km – 3 weeks later US sent Alan Shepherd into space on a ballistic trajectory that lasted only 15 min1962 - John Glenn was the first US to make the orbital flight President.

- Kennedy declared in the Congress on 25 May 1961 that US would launch and land a moon and bring them safely back by the end of the decade Gemini program initiated Apollo 1 had a terrible setback as all three Astronauts perished as fire broke out during reversal Remaining Apollo missions were successful Apollo 8 was the first with humans t orbit the moon and
- Apollo 11 was the first to land man on the moon – July 16, 1969. Apollo 13 had an accident in oxygen tank but managed to return safely back to earth .
- Apollo 17 – in 1972 – collected large samples of rocks etc from moon Sky lab US had also setup a sky lab in space in May 14 1973.The 75 ton station provided generous quarters for the astronauts and hosted three crews, each with three astronauts for a total 171 days.
- The station had been abandoned for 5 years when it reentered the atmosphere uncontrolled in July 1979.

Commercial use of space:

- Early satellites were “passive” since they lacked on-board electronics and could therefore be used only as a relay station for communications. Transmission of human voice from space - 1958, U.S.
- Air Force launched the first active communications satellite Weather Observation Satellite - Tiros, launched in April 1960 first time TV Programs - TELSTAR, launched in 1962.
- TV broadcast and communications over large regions of the world - In 1963, SYNCOMM III became the world’s first geostationary satellite. By being placed in an orbit 35,800 km above the earth’s equator, satellites appear stationary from earth and are ideal for television broadcasts and communications over large regions of the world.
- Europeans space Agency – Ariane rockets was the world’s most commercial expendable launch vehicle. The Ariane series of rockets is responsible for placing more than one-half of all commercial satellites into space.

Exploring the Solar system and Beyond:

- In 1962, NASA launched two probes to Venus. The second one, Mariner 2, flew past the planet in December, marking the first successful mission to another planet.
- The Voyager autonomous interplanetary probes were launched by the United States to observe the outer planets of our solar system. Voyager 1, launched in September 1977, flew by Jupiter in 1979 and reached Saturn in 1980.
- It then took up a trajectory to lead it out of the solar system. Voyager 2, launched in August 1977, encountered Jupiter (1979), Saturn (1981), Uranus (1986), and Neptune (1989). Mars Path finder - On 4 July 1997, the Mars Pathfinder spacecraft landed on the Red Planet and released the 10.6 kg (23 lb) micro-rover.
- The mission validated various new technologies for planetary exploration and returned valuable scientific information.

Hubble Space Telescope –

- Hubble was brought into orbit aboard a space shuttle in April 1990.The optics of the telescope had a flaw, resulting in fuzzy pictures but was rectified in orbit in December 1993 with corrective optics which made it possible for Hubble to produce spectacular images.
- Compton Gamma Ray Observatory (GRO) - Since Hubble was designed for observation in the **visible portion of the electromagnetic spectrum**, NASA launched in 1991 the Compton Gamma Ray Observatory (GRO) to capture gamma rays from far distant objects in space. Chandra X-ray Observatory - The observation gap of the spectrum between Hubble and GRO was filled in 1999 with the launch of the Chandra X-ray Observatory.
- A few months later it was joined in orbit by the largest European satellite, the XMM (X-ray multi mirror) telescope.
- Together the two X-ray telescopes are searching the universe for spectacular X-ray sources such as exploding stars.

Earth's Atmosphere:

Atmosphere contains Nitrogen 78% Oxygen – 21% Argon, Co2, water vapor etc. – 1%
Atmosphere protects us from space materials that are directed towards Earth. These Meteors and other space materials directed towards Earth get burnt by the immense friction that is generated by the Earth's atmosphere and thus saves the human beings.

Tropospnere:

- The troposphere begins at sea level and reaches a height of about 18 km. The temperature in this region varies with altitude from about 290 K (17°C) at sea level to 220 K (-53°C) at 11 km. @ 5.6k/km.
- Nearly all weather effects we experience on the surface of Earth, such as rain and snow, occur within the troposphere. As is shown in the temperature gradient, the surface of earth is the warmest part of the troposphere.
- Heat is transferred upward by means of infrared photon diffusion and gaseous convection. Tropopause - Tropopause is an extension of the troposphere where the temperature remains relatively constant, and it extends from 11 to 18 km.

Stratosphere:

- Begins at 18 km till an altitude of 50 km. Temperature gradient reverses and the air actually gets warmer. At 18 km the temperature is about 220 K and rises to about 270 K (-3°C) at 50 km.
- This higher temperature results from heating via solar radiation. At 22 km, aerospace vehicles can no longer, economically, compress air from the environment for cabin pressurization due to low atmospheric density and the threat of ozone poisoning. Human flight above this height requires a sealed environment with independent oxygen and pressure supplies.

- For Human flight after 22km the flight will have to independently carry its own oxygen and pressure supplies. So from human stand point space starts from this. At approximately 45 km, aircraft propulsion requires an independent supply of fuel and oxidizer. So, essentially, for aircraft the space environment begins at 45 km.
- Ozone layer is within the Stratosphere. Ozone is a molecule made of three oxygen atoms. It forms a gossamer-thin layer that screens out ultraviolet radiation. Without ozone, that radiation would kill off our nucleic acids and make life impossible.
- Visible light has only a slightly greater wavelength, but ozone lets it through. And life would also be impossible without that visible light and photosynthesis.
- High-altitude carbon dioxide caps off the atmosphere like a greenhouse window. Visible energy from the sun passes through, and Earth absorbs it.
- When Earth reradiates that energy as long-wavelength infrared energy, the CO_2 will not let it back out. The greenhouse effect is no theory. It is an absolute necessity. It keeps Earth warm enough to sustain life.

Mesosphere:

- Extends from 50 km till 85 km.
- As in the troposphere, the temperature in this region decreases with altitude from about 270 K at 50 km to 190 K (-83°C) at 85 km (this is the coldest region of the atmosphere).
- The mesosphere is essential for human survival on earth .It absorbs primary cosmic radiation and deadly solar ultraviolet and X-ray radiation vaporizes incoming meteorites entering from interplanetary space.
- At 60 km altitude no atmosphere is present to scatter sunlight, making the sky appear black and allowing the curvature of the earth to be discerned.

Thermosphere:

- Extends from 85 to 300 km.
- In Thermosphere the temperature gradient rapidly reverses - rises from 190 K (-83°C) to 1,000 K (773°C).
- During solar flares the temp can exceed 1000 k due to higher number of energetic particles in the region which results in an inflation of the upper atmosphere and an increase in the density at a given altitude.
- At higher altitudes ultraviolet (UV) radiation from the Sun is absorbed .Within the thermosphere lies an imaginary line known as the Von Karmen line.
- Found at 100 km, the Von Karmen line denotes the altitude where aerodynamic forces (drag, viscosity, etc.) are minimal.
- An altitude of 100 km is the height that the U.S. Air Force Office of Aerospace Research defines as the beginning of space.

Exosphere:

- Extends from 300 km and merges with the ionized gases of the interplanetary medium.
- The temperature remains constant at 1,000 K with the exception of solar cycle variations.
- The nature of atomic oxygen is highly reactive due to its high chemical activity, particularly on satellite surfaces in specific orbits.
- Upper atmosphere aerodynamic drag affects spacecraft design and operations. This drag is created by the impact of atmospheric particles on the spacecraft surface.
- Although its magnitude is in no way comparable to aerodynamic drag encountered by aircraft, it is nevertheless present and below ~600 km should be considered.
- Atmospheric drag makes orbiting Earth below 200 km not viable; that is, a satellite at 200 km cannot remain there for more than several days (the orbit duration depends on the ratio of surface area to mass of the satellite, or more technically speaking, on the ballistic coefficient of the spacecraft).
- More than an order of magnitude of variation in atmospheric density is observed between solar minimum and solar maximum. This variation should be considered when designing a space system to be operated below 600 km

Hard Space:

- Above the exosphere is the region known as hard space. While the idea of space is usually accompanied by a thought of emptiness, hard space is by no means empty.
- At 2,000 km altitude, we still see a density of 108 particles per cubic meter. While this number is significantly lower than the density of the surface of Earth, it does indeed show that space is not empty but, rather, is filled with electromagnetic radiation and particles.

The Standard Atmosphere:

- The Earth's atmosphere constantly changes due to changes in pressure, Temperature, location in the globe (latitude/longitude), time of day, season, sunspot activity etc.
- Thus it is difficult to take into account all these variables in the design and performance of flight vehicles. Therefore we have defined a standard atmosphere for all practical purpose.
- We use this in order to relate flight tests, wind tunnel tests etc. Also, this data is used for a std. reference.
- The std atmosphere gives mean values of pressure, temp and density and other properties as a function of altitude.
- To a reasonable extent the std atmospheric data reflects average conditions.
  - Temp & Pressure – SI units
  - Pressure = 101.325KPa (14.696psi or 1 atm).
  - Temperature = 288.16K.
  - Density is 1.22kg/m^3

Temperature Extremes of Space:

- On Earth, heat transfer is carried out in three ways:
- **Conduction**— Direct heat transfer through solids, liquids, and gases. (Ex. Melting of ice on our palms).
- **Convection**—Direct transfer of heat due to fluid movement (Ex. Greenhouse effect) **Radiation**—transfer of heat by a hot source (e.g., electromagnetic radiation).
- There are limits to the temperature range that humans and equipment can endure. The extreme thermal conditions in space require not only shielding and insulation, but heat rejection capabilities as well. In the vacuum of space an isolated body, such as a space suited astronaut during a spacewalk or a planet or a satellite, can transfer heat to or from another body solely by radiation, provided the body is in a state of thermal equilibrium.
- The physical phenomenon of radiation is governed by Kirchhoff's law, which states that a body in thermal equilibrium will radiate an amount of energy equal to that absorbed from the outside universe.
- Energy exchange and balance determines the temperature of an astronaut, planet, or satellite in the space environment. The extent to which a body absorbs solar radiation is determined by the solar absorption coefficient α It is helpful to think of α, or the solar absorption coefficient, as affecting the amount of absorbed power similar to the way the coefficient of lift affects how much lifting force can be generated for a given aerodynamic surface. Likewise, the amount of power a body emits also depends on the emissivity.
- Kirchhoff's law is satisfied when the amount of power absorbed is equal to the amount of power emitted. From Kirchhoff's law, the equilibrium temperature of the body is determined as follows:
    - P emitted = P absorbed

Microgravity:

- Talk of "g" effect and what it is and then come to Weightlessness and Microgravity.
- When we hear astronauts describe the feeling of "weightlessness" while in orbit, what they are actually referring to is the effect of microgravity.
- Microgravity can be simulated either by placing an object in an environment where the force of gravity is naturally small (i.e., placing an object between two gravitationally equal massive bodies) or by placing an object in free fall, such as in low Earth orbit.

What is Micro gravity?

- Contrary to what many believe, astronauts on the Space Shuttle do not experience a zero gravity (0 G) environment that lacks the gravitational pull of Earth. Rather, in a low Earth orbit, a spacecraft (and the astronauts inside) experiences a radial gravity effect that is only one-tenth less than the standard 9.8 m/s2 (1 G) environment.
- While orbiting Earth, the spacecraft and astronauts experience a constant state of free fall; and thus, they are considered to be in a microgravity environment where the centripetal acceleration of the spacecraft (acting tangentially)is responsible for the resulting microgravity environment

(10^{-6} G) on board. The term microgravity (or mG) is used to describe this very low-acceleration environment.

Benefits of Microgravity:

- Working in a microgravity environment allows researchers to investigate essential questions of
  - Fundamental physics
  - Life science
  - Materials science
  - Space science
  - Earth observation
  - Medicine
  - Gravitational biology
  - Engineering technology.
- Microgravity allows scientists to observe phenomena usually overshadowed by the effect of gravity on the surface of Earth.
- Engineers explore new technologies and develop devices specifically designed to function in microgravity.
- Medical professionals today use medicines developed in orbit. Work planned in microgravity:
- There are four areas that are targeted for future exploration and microgravity investigations:
  The Space Science to
  - Solve mysteries of the universe
  - Explore the solar system
  - Discover planets around other stars
  - Search for life beyond Earth
  - Study evolution of universe and understand its galaxies, stars, planets, and life.
  - Creating an international capability to forecast and assess the health of the Earth system; disseminate information about the Earth system; and enable the productive use of Mission to Planet Earth science and technology in the public and private sectors.

The Human Exploration and Development of Space (HEDS) Enterprise:

- Prepare for the conduct of human missions of exploration to planetary and other bodies in the solar system.
- Use the environment of space to expand scientific knowledge
- Provide safe and affordable human access to space
- Establish a human presence in space and share the human experience of being in space
- Enable commercial development of space and share HEDS knowledge, technologies, and assets that promise to enhance the quality of life on Earth.

What happens in ISS?

- The International Space Station promises to provide a permanent presence in space laboratory for long-duration microgravity experiments in the life and physical sciences. ISS offers major capability in the following areas:
    - Biomedical research and countermeasures development.
    - Gravitational biology and ecology (under variable gravity).
    - Materials science.
    - Bio technology.
    - Fluids and combustion.
    - Human-machine interfaces and advanced life support.
    - Low-temperature physics.
    - Earth observation and space science.

Microgravity calculation:

- Let us calculate how far away we would need to be from Earth to achieve this microgravity, for near-weightless, condition. Recall that force is proportional to 1/r 2 and that the distance r is measured as the distance between the centers of the two objects.
- Therefore, for a laboratory on the surface of Earth, r is Earth's radius, or 6,370 km.
- Where the radius of Earth is r, the force at the surface of Earth is Fg, the force in micro gravity is Fμ, and the distance from the center of earth to the microgravity environment is rμ.
- In other words, to achieve one-millionth the force of gravity on the surface of Earth, we would have to move our laboratory a distance equal to the square root of 1 million (1 thousand) units farther away from the center of Earth.
- That is 1,000 Earth radii (or 6,370,000 km)! The moon is only about 60 Earth radii way, or 384,401 km, so this deep space laboratory to attain true micro gravity does not appear very practical.
- International Space Station are nowhere near far enough away to avoid Earth's gravitational field—they are only about 300 km above the surface of Earth

Law of Gravitation:

- Two of the most colorful personalities in the field of astronautics were Johannes Kepler and Sir Isaac Newton, who defined the laws of orbital motion and the law of gravitation, respectively.
- A full historical account and a derivation of their contribution in "Orbital Mechanics," but need mention in this chapter to introduce Newton's sweeping generalization about bodies in motion. Specifically, Newton based his law of gravitation on his axioms of mechanics (often referred to as Newton's three laws, detailed in Section9.3, "Newton's Laws of Motion and Gravitation") and Kepler's law of equal areas of an orbit being covered in equal time intervals ("Kepler's Laws") to state that Every particle in the universe attracts every other particle with the force that is directly proportional to the product of their masses and inversely proportional to the distance between their centers.
- The law of gravitation can be expressed mathematically as

$$F_g = -\frac{GMm}{\mathbf{r}^2}$$

- G is shown as –ve because of the standard that has been adopted which defines attraction as negative and repulsive force as positive.
- Where Fg is the force on mass m due to mass M and r is the vector from M to m. The universal gravitational constant G has the value 6.67 108 dyn (cm2/g2). Newton's first law (or axiom) from his 1687 publication The Mathematical Principles of Natural Philosophy, commonly known as the Principia, states that Every particle persists in a state of rest or of uniform motion in a straight line unless acted on by a force.
- Mathematically, the gravitational force between two objects can be very small [Equation (8.5)], but never becomes exactly zero for bodies with mass at a finite distance from one another. So, the practical question for us is, how small does the gravitational force need to be to carry out meaningful spaceflight studies or microgravity experiments? To scientists and engineers, a microgravity environment is one in which the gravitational acceleration force is one-million that on Earth's surface.
- That is 0.000001 times less than that on Earth, or 1 106 Gs—nearly, but not quite, weightless.

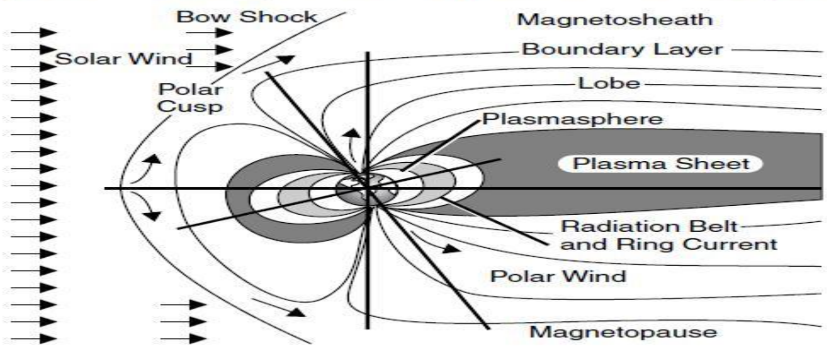
The Magnetosphere:

- The magnetosphere is defined by the interaction of Earth's magnetic field and the solar wind- up to 4 or 5 Earth radii, the Earth's magnetic field resembles that of a simple magnetic dipole (a bar magnet), with field lines originating from the magnetic North pole, curving around in a symmetric arc, and entering at the magnetic South pole.
- Magnetic dipole is tilted at 11 degree and also offset by 500 km toward the west pacific ocean (not at the exact center of earth)
- Weaker magnetic field over the south Atlantic which is called the South Atlantic Anomaly (SAA)
- In SAA radiation particles interfere with satellite and aircraft and space communication.
- Usually trapped particles are repelled by the strong magnetic field of earth. However within the SAA the weaker field strength allows more particles to reach lower altitudes.
- No radio signals are received when space craft passes through SAA region because of this high concentration of charged particles leading to communication black out that lasts for 15-20 min / orbit.
- High doses of radiation – So Astronauts are exposed.
- At an altitude of 500 km, SAA region ranges from -90degrees to +40degrees longitude and -50degree to 0 degree latitude – Home work to find the region.

What are the characteristics of the magnetosphere above 4 earth radii:

- The field lines deviate substantially from those of a simple dipole.
- As the solar wind hits earth's atmosphere the magnetic field is compressed on the day side of the earth.
- Magnetopause – The region where the solar wind is stopped (not exactly). Magnetopause is situated around 10 earth radii on the day side of the equatorial plane.
- During solar flares this boundary could be 6 earth radii exposing satellites to harsh GCRs and solar particles. This is extremely damaging if not lethal to satellites.
- On the dark side the solar wind interaction with the magnetosphere results in its huge elongation. This stretched structure is magneto tail.

Earth's magnetosphere illustrating key energetic particles that respond to variations in solar wind parameters. [41]



Low Earth Orbit:

- LEO is defined as spaceflights orbiting in the near vicinity of earth i.e., within a range of ~300 km to 1000s km. (160km to 2000km).By flying in an orbit close to Earth, astronauts avoid strong doses of radiation that result from flying in high-altitude orbits.
- Even in LEO, satellites pass through the Van Allen belts, which are a source of heavy radiation and a major concern for human spacecraft missions.
- LEO space travel does place some limitations on the mission and the functions of the satellite in orbit.
- To maintain a typical Space Shuttle LEO altitude (~300 km) where the satellite makes one Earth revolution approximately every 90 min, speeds close to 29,000 km/h must be maintained.

What happens if the Shuttle reduces its velocity?

- If the Shuttle were to reduce its velocity, external forces, such as aerodynamic drag, would slow the spacecraft down until it reentered Earth's atmosphere. In fact, the Shuttle uses the atmosphere to slow down for reentry at the end of a mission.
- As orbital altitude increases, the speed necessary to sustain an orbit decreases, not surprisingly, because drag forces diminish as we venture farther from the atmosphere.

- The period of an orbit, increases with altitude until, at about 36,000 km, the orbital period is nearly 24 h long. At this point, satellites are considered to be in a geostationary earth orbit, or GEO, and remain “fixed” above one point on Earth.

The Near Earth Radioactive Environment:

- In our study of Magnetosphere we realized how fragile it would be if the Earth’s magnetic field would not have been there to save all living creatures from the wrath of the solar radiation and other harmful rays.

Solar Activity and Emission:

- The Sun is a modest star by stellar standards, and it is one out of more than 100 billion stars that form our galaxy. It provides all the heat input to the solar system and dominates the gravitational field.
- The Sun contains 99.85 percent of the solar system mass. The gravity of the Sun creates extreme pressures and temperatures within itself, which makes it fundamentally a giant thermonuclear fusion reactor, fusing hydrogen nuclei and producing helium. And hence it produces a tremendous amount of energy.
- The Sun has no distinct surface or discrete physical boundary (the apparent surface is merely optical). The sun rotates (differential rotation) on its axis - 24 days at the equator, but more than 30 days near the poles; and second is its cyclic evolution of activity. The source of this differential rotation is an area of current research in solar astronomy.
- The Sun’s rotation axis is tilted by about 7.25º from the axis of Earth’s orbit, so we see more of the Sun’s North Pole in September of each year and more of its south pole in March.
- Activity of Sun is measured by the number of visible sunspots (organized in groups). This activity presents a periodicity of approximately 11 years (7 max solar activity + 4 Min) 7 years of maximums (i.e., high solar activity levels related to an increase in the number of sun spots, and associated with violent emissions of particles), and 4 years of minimums.
- Radius - 6.96×10^5 km, or about 109 times the radius of Earth.
- Distance from Earth to the Sun (referred as astronomical unit, or au). One au is about 1.5×10^6 km.
- Temperature, pressure, and density are highest at the core, or center, of the Sun. At the core, temperatures can reach as high as 16 million K. This high-temperature zone is where fusion reactions occur to produce the energy that the Sun releases through solar activity.
- The temperature decreases farther away from the sun to about 10^6 K at the highest point of the atmosphere. The atmosphere is composed of three regions.
- Photosphere is the visible surface of the Sun. It begins at the surface of the Sun and extends only a short distance to about 330 km. Here, small structures known as granules are observed.
- Granules are zones of bright and dark gases. These granules transport hot gases upward while the cooler gases sink down, creating a stirring or bubbling effect when observed from Earth.

- Beyond the photosphere lies in the chromospheres, where small jets of gas shoot upward as high as 10,000 km at velocities of 20 to 30 m/s.
- These streams, or spicules, exist in regions of stronger magnetic fields and play a role in balancing mass between the chromospheres and higher levels of the atmosphere.

Solar Flare:

- The external gaseous envelope of the Sun, the corona, has an extremely high temperature and thus it continuously ejects particles, mainly electrons and protons. This continuous flux of charged particles constitutes the solar wind.

Properties of Solar flares:

- The solar wind streams off the Sun in all directions at speeds of about 400 km/s (about 1 million mph).
- The temperature of the corona is so high that the Sun's gravity cannot hold onto it. The solar wind–charged particles, under the influence of the solar magnetic field, diffuse in the entire interplanetary space.
- The average speed of charged particles ranges from 400 to 1,000 km/s. These particles originate from two regions, the Sun's equatorial and polar regions.
- The equatorial area where the Sun's magnetic field is weak emits ions at ~400 km/s, which continuously affect the near-Earth environment.
- The Sun's polar region spits particles out at 1,000 km/s, but these only occasionally affect our neighborhood (when these regions extend to lower latitudes).

Sunspots and solar flares:

- Sun's magnetic field, is produced by the flow of electrically charged ions and electrons. Sunspots are places where very intense magnetic lines of force break through the Sun's surface.
- The sunspot cycle results from the recycling of magnetic fields by the flow of material in the interior. Sunspots are found on the photosphere and are colder areas (by as much as1, 500 K) where an intense magnetic field blocks the thermal transport in the Sun.
- The magnetic field of the Sun forms vertical bands from the north magnetic pole to the south magnetic pole. Sunspots occur when the differential rotation of the Sun causes the magnetic field lines to overlap on themselves and to form regions of concentrated polarity. Intense magnetic fields are detected in the center of sunspots and are thought to be the reason for the decreased temperature.
- They often appear in complementary pairs, known as a bipolar spot group. From these active regions stem the solar flares that are associated with a violent release of energy for a short time, from an hour to a few days.
- This burst of energy produces various types of radiation, mainly X-rays and gamma rays, and ejects particles that can have extremely high energy into the interplanetary environment. In a

period of solar maximum, solar flares are often observed, and an active zone can be responsible for several consecutive solar flares.

- Sunspots tend to reside at high solar latitudes and remain at that latitude for the duration of their life.
- Solar flares can be associated with protons or heavy ion ejections or, more plausibly, with various combinations of both.
- The solar phenomena described above, solar wind and flare activity, are often termed solar cosmic rays (SCRs). Two additional types of ionizing radiation are discussed below, namely, galactic cosmic rays and the Van Allen belts.

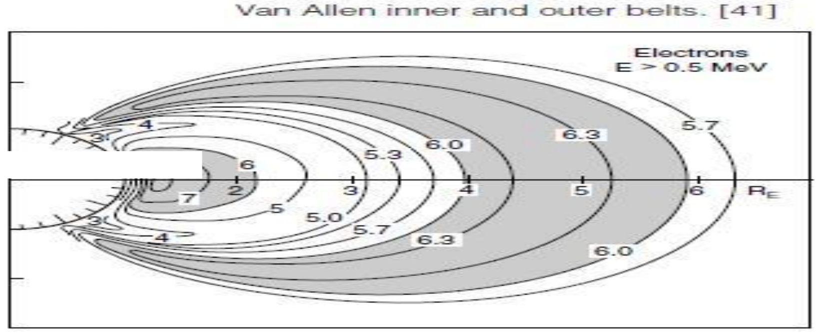
Galactic Cosmic Rays:

- Galactic cosmic rays are mainly protons, heavy ions, and a particle with extremely high energies. As their name indicates, they are of galactic and/or extra galactic origin.
- Emitted by distant stars and even more distant galaxies, GCRs diffuse through space and arrive at Earth from all directions.
- During solar maximums, the GCR fluxes are lower than during solar minimums. One way to imagine this effect is to think about solar maximum periods as a strengthening of the heliosphere, the Sun equivalent of the Earth magnetosphere, that is, the magnetic shield of the Sun that extends throughout the entire solar system, and hence protects the planets from these particles.
- GCRs are a serious danger to spacecraft, and the humans inside, because a single particle, since it is highly energetic, can damage any common electronic component onboard.

Van Allen belt:

- Regions of trapped particles mainly protons and electrons, around Earth discovered on the Explorer 1 satellite mission on January 31, 1958.
- Where do these charged particles come from and how do they get trapped? Comes from the Sun - As the particles hit Earth's magnetosphere, they undergo a velocity modification (charged particle moving in a magnetic field).
- Under certain conditions of incident angles and energy, the velocity modification results in a relatively stable trajectory of the particle around Earth, hence the particle gets trapped. Particles may reside in the Van Allen belts for periods of weeks to several years.

Van Allen inner and outer belts. [41]



Source from Interactive Aerospace Engineering and Design by Newman. D

Environmental Impact on Spacecraft Design:

- Energetic radiation can severely degrade the optical, mechanical, and electrical properties of a spacecraft. Specifically, satellite degradation results from ionization of atoms encountered.
- The important parameters that aerospace engineers design for include (i) cumulative dose of radiation, (ii) transient effects (Single Event Effects) that depend on the instantaneous flux of radiation, and (iii) electrostatic arcing due to the accumulation of electric charges encountered

Cumulative Dose Effect

- A body absorbs radiation and the absorbed "dose" is defined as the ratio of the average energy transferred to a given volume of material by the radiation per mass of the volume – In SI unit the Absorbed dose is defined "Gray" i.e. 1 Joule absorbed in 1 kilogram of material.
- Cumulative dose effect is considered mainly in space craft and its electronic component design because of these radiations. Semi-conductors and bipolar structures undergo a severe degradation of their performance and key parameters with increasing dose - Fails to perform at the desired requirement.
- Specifically in solar cells, an increasing absorbed dose results in reduced efficiency in converting sunlight to electric power. That is why the upper exposed surfaces of solar panels are protected to some extent by the use of cover glass.
- Nevertheless, solar panels degrade on orbit, and satellite manufacturers give the beginning of life (BOL) and end of life (EOL) power available onboard, taking into account the degradation of solar cells.
- Other electronic components are simply hardened enough to survive the expected dose during the operational lifetime of the spacecraft. The expected dose depends primarily on the solar activity and the altitude and inclination of the orbit.

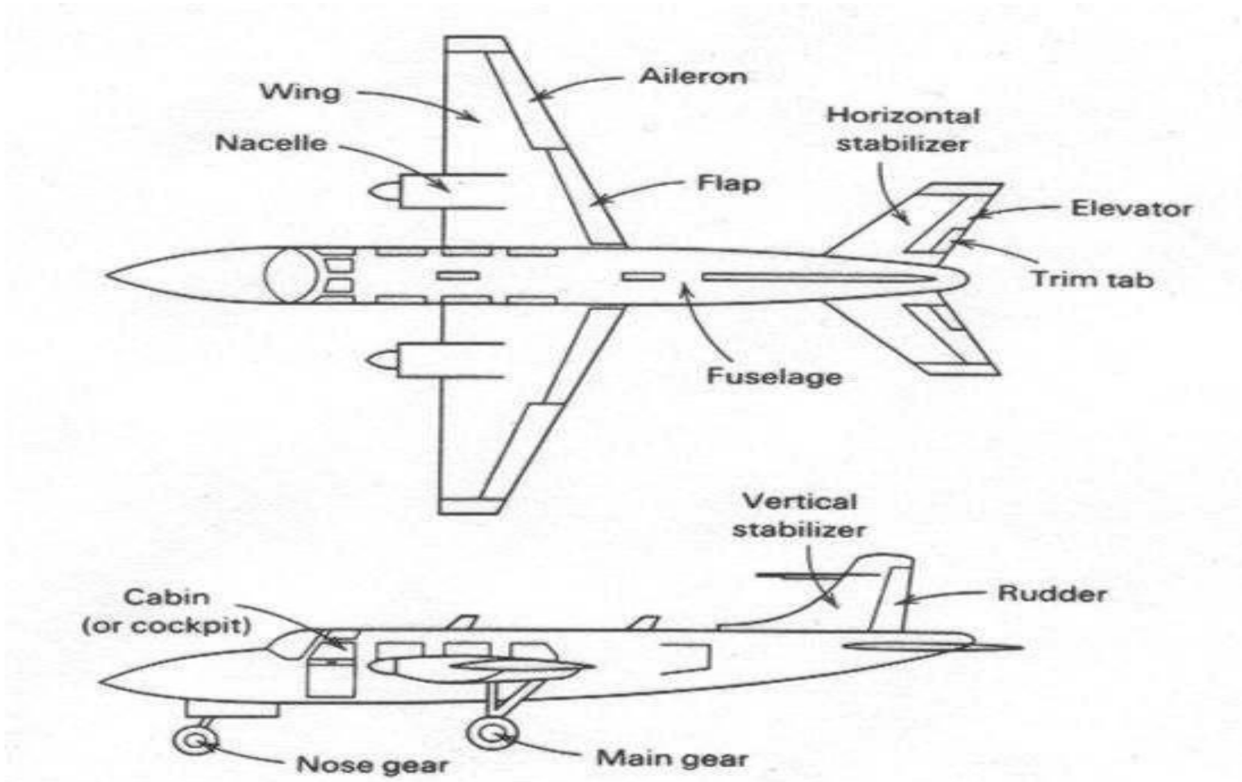
Planetary Environments

- The environments of the planets within our solar system vary greatly. In addition, the gravitational forces on the planets depend on their mass; therefore, the 1 G environment in which we humans have evolved is unique within our solar system.
- All the larger planets have atmospheres. The atmospheres of planets are held in place only by the force of gravity and do not have distinct boundaries in space. Therefore, a spacecraft operating in the vicinity of a planet with an atmosphere must be designed to tolerate the effects of that atmosphere, particularly if humans are aboard the vehicle.
- Chemical composition of a planetary atmosphere varies greatly among planets depending on the distance from the Sun, its size, and its unique large scale chemical reactions. The inner Earth-like planets (Mercury to Mars) are believed to have formed without extensive atmospheres.

- One theory as to how atmospheres came about is that gases once chemically combined in the crust have since escaped, and that additional gases from comet impacts became trapped under the gravity of the planet.
- In the case of Earth, research has shown that the presence of uncombined oxygen in noticeably large quantities is a direct result of the presence of life and suggests that the current atmosphere has evolved significantly over time (the past 4 billion years). Conversely, studies of the outer planets (Jupiter to Pluto) suggest that the atmospheres present today are nearly identical to those present when the planets formed.
- Evolution of an atmosphere is greatly determined by the selective loss of gases by evaporation. For a given atmospheric temperature, lighter gas molecules will travel faster than heavier molecules.
- If the speed of a molecule exceeds the escape velocity of the planet, it will eventually be lost to space. This escape velocity is determined by the mass of the planet. Atmospheric temperature is determined by the planet's proximity to the Sun.
- Thus, as we move closer to the Sun and examine planets that are progressively less massive, we expect to see a greater loss of atmospheric gas until, finally, we see a loss of atmosphere all together.
- Maritain Atmosphere has a typical surface pressure of about 0.01 of Earth's atmosphere (i.e., Earth's atmospheric pressure at an altitude of 30,000 km). The Martian day, is 24 h, 37 min, 23 s long.
- Composed mainly of carbon dioxide (95.3 %), the atmosphere also has trace amounts of other gases, including nitrogen (2.7 %) and argon (1.6 percent). Oxygen makes up only 0.13 percent of the Martian atmosphere.
- Clouds are rarely seen in Mars' sky, as the amount of water vapor is 25 % that of Earth. It is thought that this amount, however, is enough to result in water ice beneath the surface.
- Mars sees winds blowing from all directions, with the highest turbulence in the morning. The greatest wind speeds are seen in the early morning and around mid-day. Numerous dust devils have been recorded on a daily basis. The Martian soil, ranges from particles of 40 mm to large boulders several meters in diameter. The regolith is harder than aluminum, but softer than nickel.
- A design consideration from the constantly blowing regolith is abrasion to equipment, solar panels, and spacesuits. The dust is magnetic and sticks to most surfaces. It also has the potential to charge equipment and produce electrical discharge, which could greatly interfere with mission operations.
- Finally, new measurements show dust adhering to solar panels Temperatures vary from - 133°C during the winter to 25°C at the equator during the summer. In comparison to an average Earth temperature of 15°C, Mars is -55°C. Interesting new data from the Mars Observer mission shows that the variation in vertical temperature from the Martian surface varies greatly over only a few meters.

- There are significant implications for spacesuit design. The average temperature of a suited astronaut on Mars might include a temperature differential of 10°C between the knee and the shoulders (over 0.75 m in height).
- The design solution is a spacesuit with automatic thermal control to account for the temperature variation in altitude as well as the extreme temperature changes from day to night.
- The Martian temperature variations will subject materials to continuous expansion and contraction, resulting in great stresses that must be accounted for in equipment designs. The South polar cap looks like a promising place that might have preserved organic material – From the latest images from Mars-Observer High Resolution camera.

UNIT – II
INTRODUCTION TO AERODYNAMICS



- Aircrafts may be designed for different purposes but the main components of the aircrafts which are common to all most all aircrafts are
  - Fuselage
  - Empennage
  - Wings
  - Control surfaces

Fuselage:

- The fuselage includes the cabin and/or cockpit, which contains seats for the occupants and the controls for the airplane. In addition, the fuselage may also provide room for cargo and attachment points for the other major airplane components.
- Most fuselages are long, cylindrical tubes or sometimes rectangular box shapes. All of the other major components of the aircraft are attached to the fuselage

Empennage:

- The empennage (also called tail) is the rear part of the aircraft. In commercial aircrafts the empennage is built from the cabin pressure-cone and may contain the Flight Data Recorder ("black box"). It comprises of horizontal and vertical stabilizers.

Horizontal stabilizer:

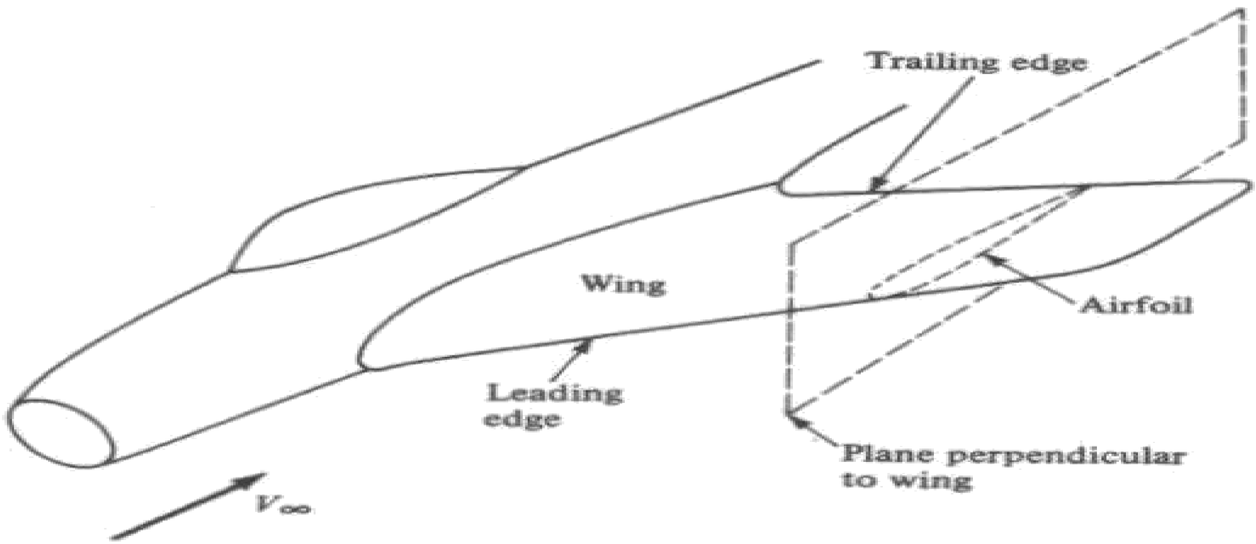
- If an aircraft consists of only a wing or a wing and fuselage, it is inherently unstable. Stability is defined as the tendency of an aircraft to return to its initial state following a disturbance from that state.
- The horizontal stabilizer, also known as the horizontal tail, performs this function when an aircraft is disturbed in pitch. In other words, if some disturbance forces the nose up or down, the horizontal stabilizer produces a counteracting force to push the nose in the opposite direction and restore equilibrium.
- When in equilibrium, we say that an aircraft is in its trim condition. The horizontal tail is essentially a miniature wing since it is also made up of an airfoil cross-section.
- The tail produces a force similar to lift that balances out the lift of the wing to keep the plane in equilibrium. To do so, the tail usually needs to produce a force pointed downward, a quantity called down force.

Vertical stabilizer:

- The vertical stabilizer, or vertical tail, functions in the same way as the horizontal tail, except that it provides stability for a disturbance in yaw. Yaw is the side-to-side motion of the nose, so if a disturbance causes the nose to deflect to one side, the vertical tail produces a counteracting force that pushes the nose in the opposite direction to restore equilibrium.
- The vertical tail is also made of an airfoil cross-section and produces forces just like a wing or horizontal tail. The difference is that a wing or horizontal tail produces lift or down force, forces that are pointed up or down from the aircraft. Meanwhile the vertical tail produces a force pointed to one side of the aircraft. This force is called side-force.

Wings:

- Wings are the main lift generating components of an aircraft. For different purposes different wing plan forms are used. The wing is made up of two halves, left and right, when viewed from behind.
- These halves are connected to each other by means of the fuselage. A wing produces lift because of its special shape, a shape called an airfoil. If we were to cut through a wing and look at its cross -section, as illustrated below, we would see that a traditional airfoil has a rounded leading edge and a sharp trailing edge. The control surfaces which are attached to the wings are flaps and ailerons.



Engine:

- The other key component that makes an airplane go is its engine, or engines. Aircraft use several different kinds of engines, but they can all be classified in two major categories. Early aircraft from the Wright Flyer until World War II used propeller-driven piston engines, and these are still common today on light general aviation planes.
- But most modern aircraft now use some form of a jet engine. Many aircraft house the engine(s) within the fuselage itself. Most larger planes, however, have their engines mounted in separate pods hanging below the wing or sometimes attached to the fuselage. These pods are called nacelles.

Control surfaces:

- In addition to the wing and tail surfaces, aircraft need some additional components that give the pilot the ability to control the direction of the plane. We call these items control surfaces.

Elevator:

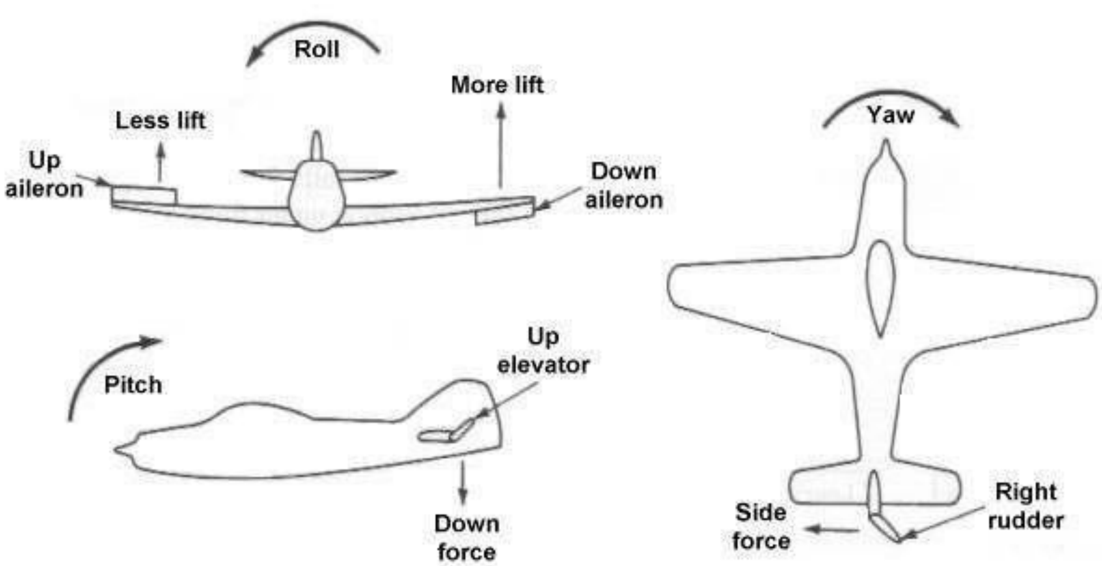
- The elevator is located on the horizontal stabilizer. It can be deflected up or down to produce a change in the down force produced by the horizontal tail.
- The angle of deflection is considered positive when the trailing edge of the elevator is deflected upward. Such a deflection increases the down force produced by the horizontal tail causing the nose to pitch upward.

Rudder:

- The rudder is located on the vertical stabilizer. It can be deflected to either side to produce a change in the side-force produced by the vertical tail.
- The angle of deflection is usually considered positive when the trailing edge of the rudder is deflected towards the right wing. Such a deflection creates a side-force to the left which causes the nose to yaw to the right.

Aileron:

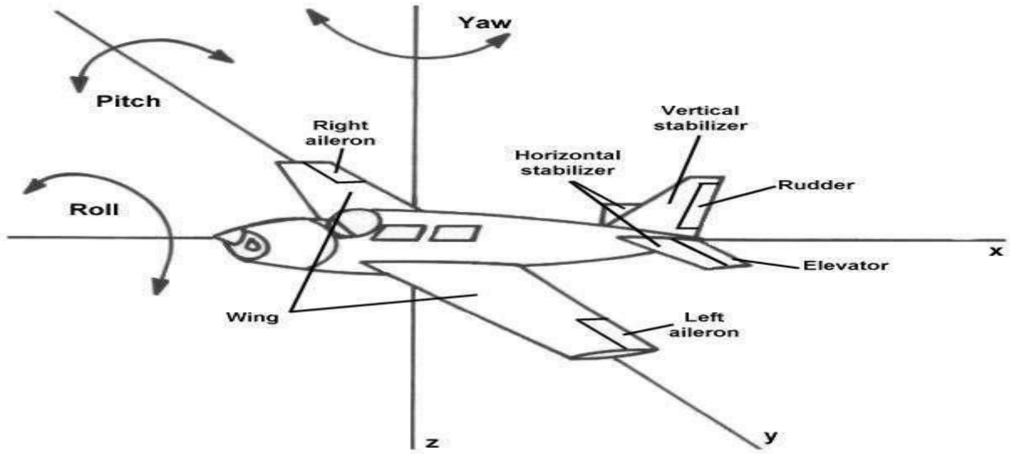
- Ailerons are located on the tips of each wing. They are deflected in opposite directions(one goes trailing edge up, the other trailing edge down) to produce a change in the lift produced by each wing.
- On the wing with the aileron deflected downward, the lift increases whereas the lift decreases on the other wing whose aileron is deflected upward. The wing with more lift rolls upward causing the aircraft to go into a bank.
- The angle of deflection is usually considered positive when the aileron on the left wing deflects downward and that on the right wing deflects upward. The greater lift generated on the left wing causes the aircraft to roll to the right.
- Aircraft motions like Pitching, Yawing and Rolling are caused by deflection of Elevator, Rudder and Ailerons Respectively.
- The effects of these control surfaces and the conventions for positive deflection angles are summarized in the following diagram.



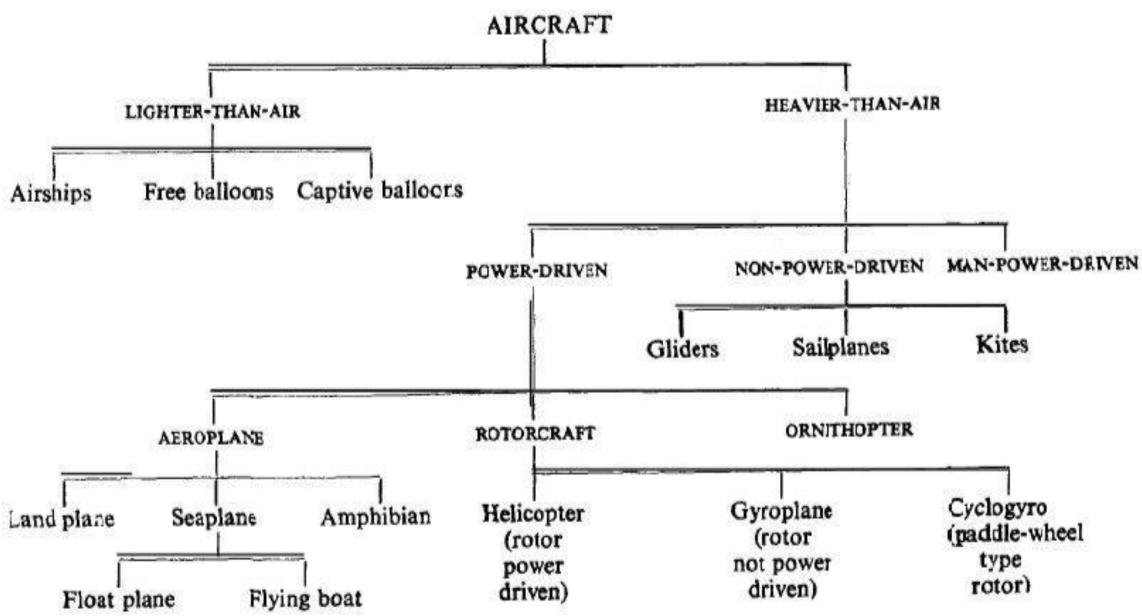
Flaps:

- Flaps are usually located along the trailing edge of both the left and right wing, typically inboard of the ailerons and close to the fuselage. Flaps are similar to ailerons in that they affect the amount of lift created by the wings.
- However, flaps only deflect downward to increase the lift produced by both wings simultaneously. Flaps are most often used during takeoff and landing to increase the lift the wings generate at a given speed.
- This effect allows a plane to takeoff or land at a slower speed than would be possible without the flaps.
- In addition to flaps on the trailing edge of a wing, a second major category is flaps on the leading edge. These leading-edge flaps, more often called slats, are also used to increase lift

Aircraft Axis system



X-axis: Longitudinal axis; Y-axis: Lateral axis; Z-axis-Directional axis



- There are two types of aircraft.
  - Lighter-than-air aircraft
  - Heavier-than-air aircraft

Lighter-than-air aircraft:

- The Lighter-than-air aircraft (aerostats) depend for their lift on a well-known scientific fact usually called Archimedes' principle. When a body is immersed in a fluid, a force acts upward upon it, helping to support its weight, and this upward force is equal to the weight of the fluid which is displaced by the body.

- A fluid may be either a liquid, such as water, or a gas like air. Thus a ship floats because the water which it displaces is equal to the weight of the ship itself. An airship (or blimp), balloon or kite balloon obtains its lift in precisely the same way.
- The envelope of the airship displaces the air and therefore there is an upward force on the airship which is equal to the weight of the displaced air. If this upward force is equal to the weight of the airship, it will float; if the upward force is greater than the weight, the airship will rise; if it is less, it will fall.
- In order to keep the weight of the aircraft itself as small as possible it must in the first place be made of the lightest materials available, provided of course they are of sufficient strength. Secondly, a very light gas must be used in the envelope.
- Theoretically, the best thing which could be used in the envelope would be nothing, i.e. a vacuum; but in practice this cannot be done, because the pressure of the air outside the envelope would be so great that the sides would cave in unless the skin of the envelope could be made tremendously strong, in which case it would weigh so much that no advantage would be gained.
- However even the lightest gases can exert a pressure from inside which will balance the pressure of the atmosphere from the outside and this means that the skin of the envelope need have very little strength, and therefore very little weight, provided it is gas-proof to prevent leakage in or out.
- The lightest gas in commercial use is hydrogen and for many years this gas was always used in airships and balloons. Unfortunately, however, hydrogen is very inflammable and its use added considerably to the dangers of lighter-than-air flying. So the gas helium came to be used.

Heavier-than-air aircraft:

- An aircraft is a vehicle that is able to fly by gaining support from the air, or, in general, the atmosphere of a planet. It counters the force of gravity by using either static lift or by using the dynamic lift of an airfoil, or in a few cases the downward thrust from jet engines.
- Heavier-than-air aircraft must find some way to push air or gas downwards, so that a reaction occurs (by Newton's laws of motion) to push the aircraft upwards.
- This dynamic movement through the air is the origin of the term aerodyne. There are two ways to produce dynamic up-thrust; aerodynamic lift and powered lift in the form of engine thrust.
- Aerodynamic lift involving wings is the most common, with fixed- wing aircraft being kept in the air by the forward movement of wings, and rotorcraft by spinning wing-shaped rotors sometimes called rotary wings.
- A wing is a flat, horizontal surface, usually shaped in cross-section as an aerofoil. To fly, air must flow over the wing and generate lift. A flexible wing is a wing made of fabric or thin sheet material, often stretched over a rigid frame.
- A kite is tethered to the ground and relies on the speed of the wind over its wings, which may be flexible or rigid, fixed, or rotary. With powered lift, the aircraft directs its engine thrust

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

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

Conventional Design Configurations:

Power plant Locations:

Engine below wing:

- Advantages:
  - Less engine noise
  - Inertial relief (lighter wing structure weight)
  - Easy alternative to solve wing flutter problems by shifting the engine mass enough forward
  - Easy access for engine repair and overhaul
  - Undisturbed inlet flow for the engine inlet
- Disadvantages:
  - May require longer landing gear
  - More chances of ingestion of debris from the runway during Take Off.

Engine above wing:

- Advantages
  - Less engine noise.
  - Easy alternative to solve wing flutter problems by shifting the engine mass enough forward.
  - Less long landing gear required.
  - Can have a positive influence on maximum lift capability in short take off runs (shorter TO distances)
- Disadvantages
  - Less chances of ingestion of debris from the runway during take off
  - Disturbed air flow (shock waves possible and also possible wing boundary layer ingestion) to the inlet possible especially at high angles of attack
  - Less accessible for engine repair and overhaul

Engine at aft fuselage or tail:

- Advantages
  - Less long landing gear required
  - Less chances of ingestion of runway debris during take off
  - Looks more esthetical
- Disadvantages
  - Disturbed air flow to the inlet possible especially at high angles of attack
  - More engine noise.
  - Maybe smaller aircraft W-CG limits constraints.
  - No structure weight saving due to inertial relief

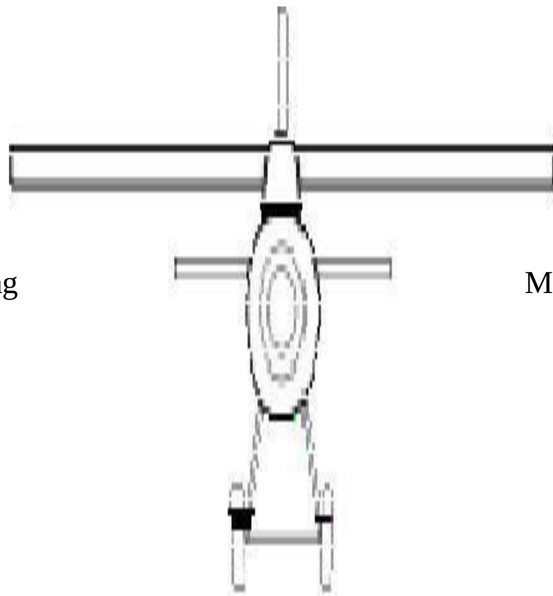
- Usually requires a T-tail which is heavier in construction and has the potential for dangerous stall characteristics (deep stall)

Wing Location:

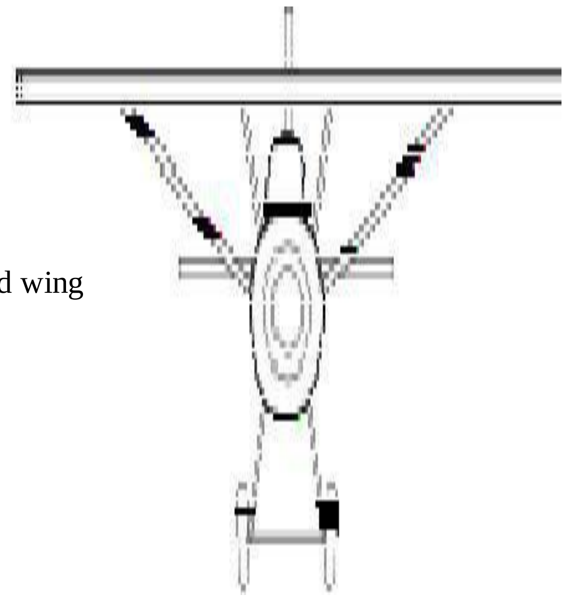
Monoplane:

- Most aero planes have been monoplanes since the 1930s.Thewing may be mounted at various positions relative to the fuselage.
- **Low wing**: mounted near or below the bottom of the fuselage.
- **Mid wing**: mounted approximately half way up the fuselage.
- **High wing:** mounted on the upper fuselage. When contrasted to the shoulder wing, applies to a wing mounted on a projection (such as the cab in roof) above the top of the main fuselage.
- **Parasol wing** - mounted on "cabane" struts above the fuselage with a distinct gap between the wing and the fuselage.

Low wing



Mid wing



Tail Unit arrangement

T-tail:

- The horizontal stabilizer is mounted on top of the fin, creating a "T" shape when viewed from the front.
- T-tails keep the stabilizers out of the engine wake, and give better pitch control. T-tails have a good glide ratio, and are more efficient on low speed aircraft.
- However, T-tails are more likely to enter a deep stall, and are more difficult to recover from a spin.
- T-t ails must be stronger, and therefore heavier than conventional tails. T-tails also have a larger radar cross section.
- Examples include the Gloster Javelin, Boeing 727 and McDonnell Douglas DC-9.

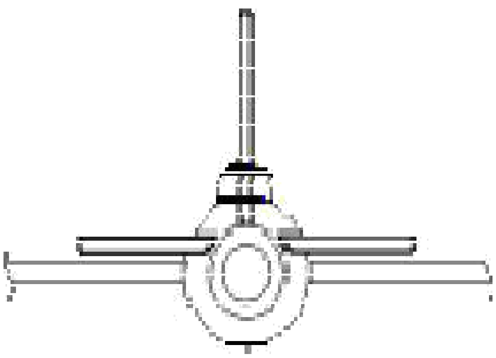
Cruciform tail:

- The horizontal stabilizers are placed midway up the vertical stabilizer, giving the appearance o f a cross when viewed from the front.
- Cruciform tails are often used to keep the horizontal stabilizers out of the engine wake, while voiding many of the disadvantages of a T- tail.
- Examples include the Hawker Sea Hawk and Douglas A-4 Sky hawk.

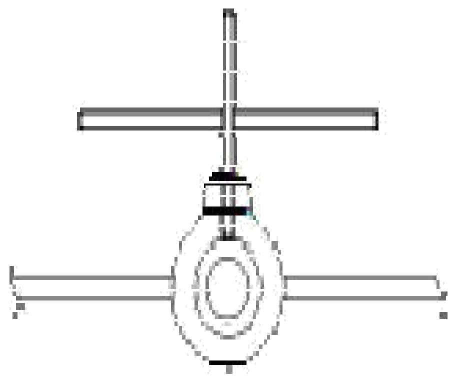
Fuselage Mounted:

- The ho[redacted]anged almost on the axis of the fuselage.

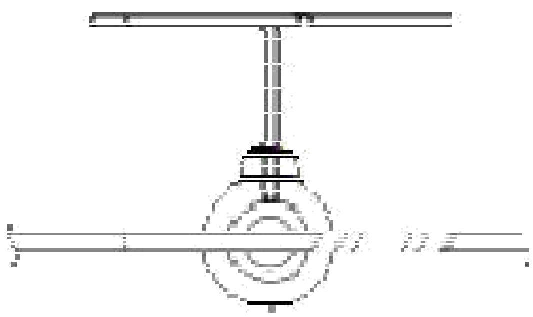
Fuselage mounted



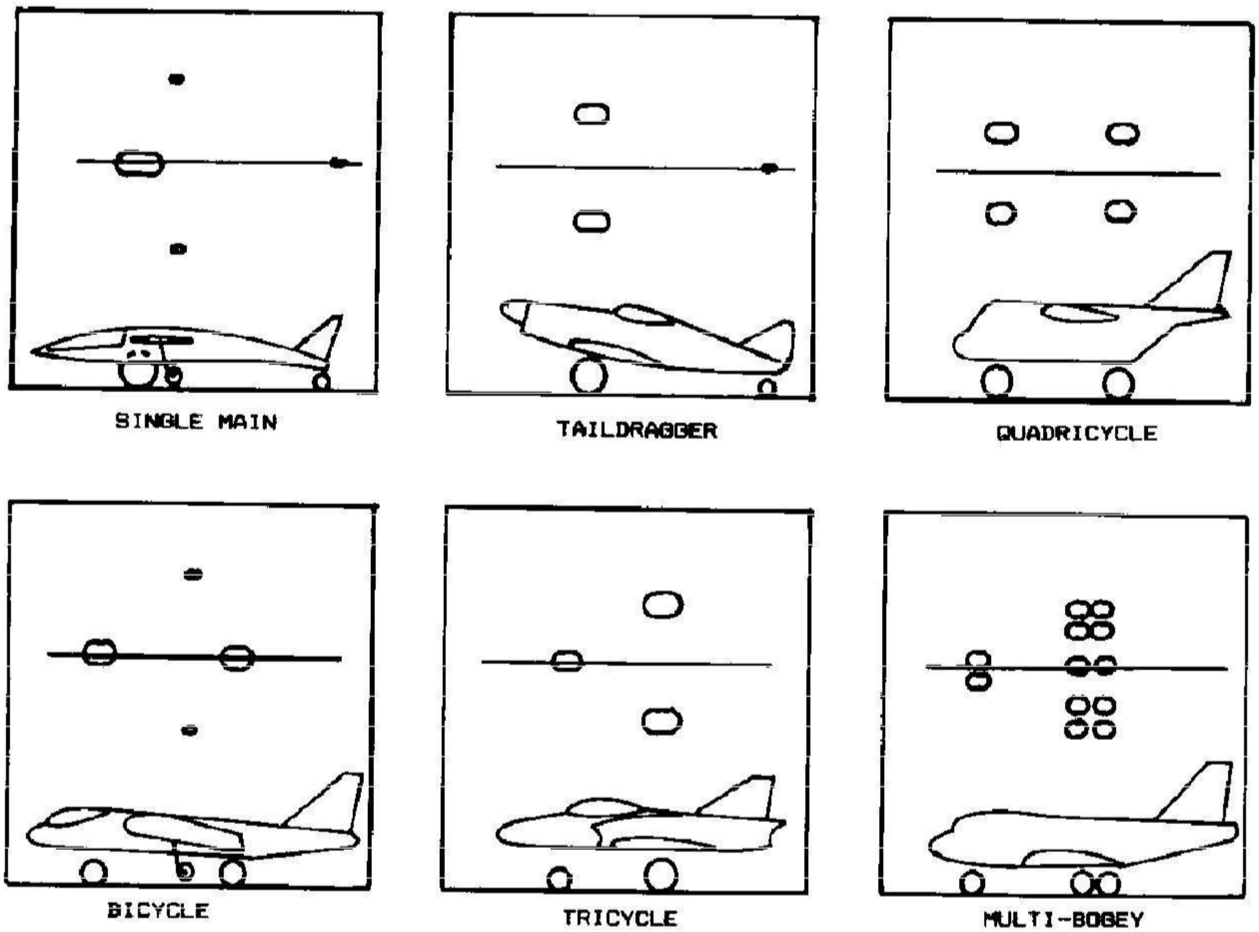
Cruciform



T-tail



Landing Gear arrangement:



Single main gear:

- Is used for many sail planes because of its simplicity. The wheel can be forward of the center of gravity or can be aft of the center of gravity with a skid under cockpit.

Bicycle gear:

- It has two main wheels, fore and aft of the center of gravity with small outrigger wheels on the wings to prevent the aircraft from tipping sideways.
- The only real advantage of bicycle gear is lower weight and drags than either the tail-dragger or tricycle arrangements.
- Bicycle gears are also useful on planes with very long and slender fuselages where there is little room for more traditional undercarriage arrangements.
- Unfortunately, bicycle gear are very demanding on the pilot who must maintain a very level attitude during
- Take off and landing while carefully managing airspeed. The pilot must also compensate for any rolling motion that could cause the plane to land unevenly on one of the outrigger gear, and crosswinds are particularly difficult to deal with.

Tricycle:

- Under carriage includes two main gears just aft of the center of gravity and a smaller auxiliary gear near the nose. The main advantage of this layout is that it eliminates the ground loop problem of the tail-dragger.
- This arrangement is instead a stable design because of the location of the main gear with respect to the center of gravity. As a result, a pilot has more latitude to land safely even when he is not aligned with the runway.
- The tricycle arrangement is generally less demanding on the pilot and is easier to taxi and steer. The tricycle gear also offers much better visibility over the nose as well as a level cabin floor to ease passenger traffic and cargo handling. A further plus is that the aircraft is at a small angle of attack so that the thrust of the engine is more parallel to the direction of travel, allowing faster acceleration during takeoff.
- In addition, the nose wheel makes it impossible for the plane to tip over on its nose during landing, as can sometimes happen on tail draggers.
- The greatest drawback to tricycle gear is the greater weight and drag incurred by adding the large nose wheel strut. Whereas many tail draggers can afford to use non-retracting gear with minimal impact on performance, planes with nose wheels almost always require retraction mechanisms to reduce drag.

Quadri cycle:

- Gear are also very similar to the bicycle arrangement except there are four main gear roughly equal in size and mounted along the fuselage. Like bicycle gear, the quadric cycle undercarriage also requires a very flat attitude during takeoff and landing.
- This arrangement is also very sensitive to roll, crosswinds, and proper alignment with the runway. The most significant advantage of quadric cycle gear is that the plane's floor can be very close to the ground for easier loading and unloading of cargo. However, this benefit comes at the price of much higher weight and drag than bicycle gear.
- Quadri cycle gears are sometimes used on cargo planes, but probably the most well known example is the B-52 bomber.

Tail wheel or tail-dragger:

- Undercarriage dominated aircraft design for the first four decades of flight and is still widely used on many small piston-engine planes.
- The tail dragger arrangement consists of two main gear units located near the center of gravity (CG) that support the majority of the plane's weight. A much smaller support is also located at the rear of the fuselage such that the plane appears to drag its tail, hence the name.
- This tail unit is usually a very small wheel but could even be a skid on a very simple design. . Another potential advantage results from the fact that the plane is already tilted to a large angle of attack as it rolls down the runway.
- This attitude helps to generate greater lift and reduce the distance needed for takeoff or landing. This attitude is also an advantage on propeller-driven planes since it provides a large clearance

between the propeller tips and the ground. Furthermore, tail dragger planes are generally easier for ground personnel to maneuver around in confined spaces like a hangar.

Multi-Bogey:

- A final variation that is worth mentioning is the use of multiple wheels per landing gear strut. It is especially common to place two wheels on the nose strut of the tricycle arrangement to provide safety and steering control in case of a tire blowout.
- This additional tire is particularly useful on carrier-based aircraft where two nose wheels are a requirement. Multiple wheels are also often used on main gear units for added safety, especially on commercial airliners.
- When multiple wheels are placed on the same gear unit, they are attached together on a structural device called a bogey. The heavier the aircraft becomes, the more wheels are typically added to the bogey to spread the plane's weight m ore evenly across the runway pavement.
- The best examples of multi-bogey aircraft are large mega jets like the An-225. This mammoth cargo plane has seven pairs of wheels on each main gear assembly plus four nose wheels, combining for a total of 32 tires.

Unconventional Design configuration
Biplane:

- Two wing planes of similar size, stacked one above the other. The most common configuration until the 1930s, when the monoplane took o ver. The Wright Flyer I was a biplane.

Triplane:

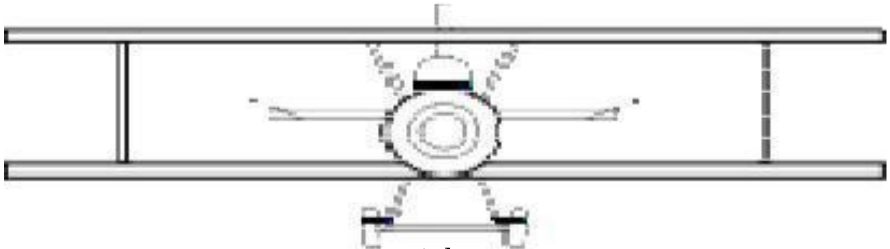
- Three planes stacked one above another. Tri planes such a s the Fokker Dr .I enjoyed a brief period of popularity during the First World War due to their maneuverability, but were soon replaced by improved biplanes.

Quadriplane:

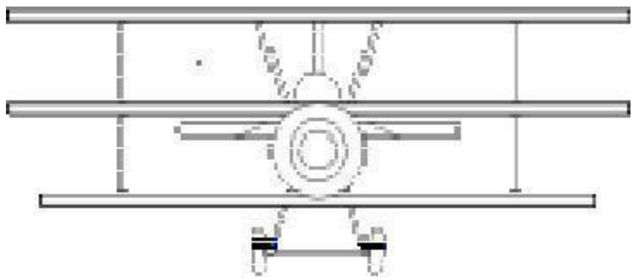
- Four planes stacked one above another. A small number of the Armstrong Whitworth F. K.10 was built in the First World War but never saw service.

Multiplane:

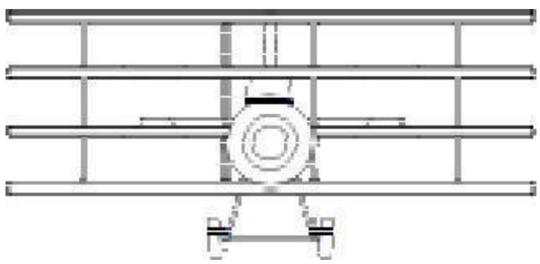
- Many plane sometimes used to mean more than one or more than some arbitrary number.



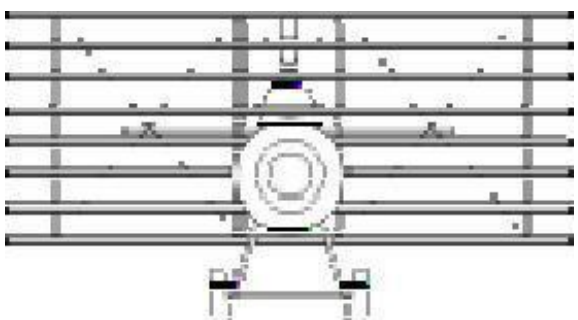
Biplane



Triplane



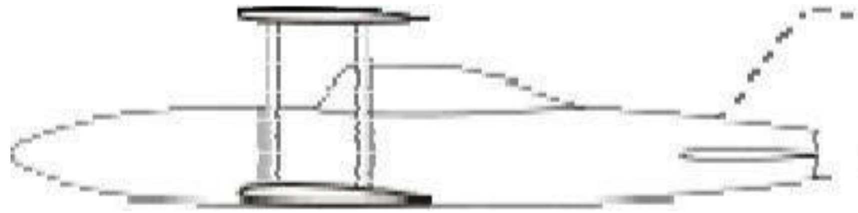
Quadriplane



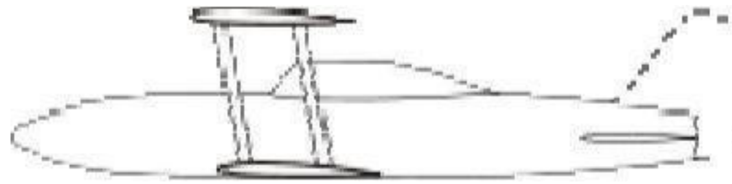
Multiplane

- A staggered design has the upper wing slightly forward of the lower. Long thought to reduce the interference caused by the low pressure air over the lower wing mixing with the high pressure air under the upper wing however the improvement is minimal and its primary benefit is to improve access to the fuselage. It is common on many success full biplanes and triplanes.

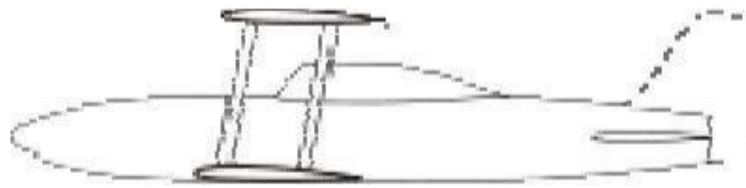
Unstaggered biplane



Forwards stagger



Backwards stagger



Wing sweep

- Wings may be swept back, or occasionally forwards, for a variety of reasons. A small degree of sweep is sometimes used to adjust the centre of lift when the wing cannot be attached in the ideal position for some reason, such as a pilot's visibility from the cockpit.

Straight:

- Extends at right angles to the line of flight.
- The most efficient structurally and common for low-speed designs

Swept back:

- From the root, the wing angles backwards towards the tip. In early tailless examples, such as the Dunne aircraft, this allowed the outer wing section to act as a conventional tail empennage to provide aerodynamic stability.
- At transonic speeds swept wings have lower drag, but can handle badly in or near a stall and require high stiffness to avoid aero elasticity at high speeds. Common on high-subsonic and early supersonic designs

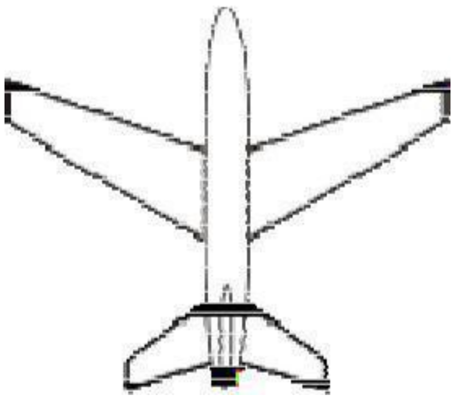
Forward swept:

- The wing angles forward from the root. Benefit s are similar to backward sweep, also it avoids the stall problems and has reduced tip losses allowing a smaller wing, but requires even greater stiffness to avoid aero elastic flutter as on the Sukhoi Su-47.
- Sometime s also done in order to avoid having the wing spar passes through the cabin, as on the HFB-320 Hansa Jet. Some types of variable geometry vary the wing sweep during flight:

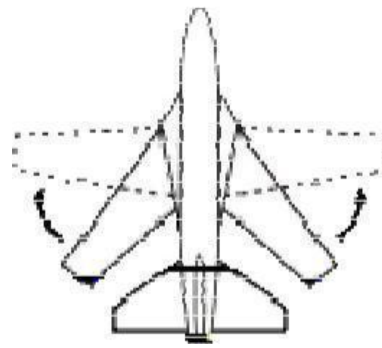
- **Swing-wing** also called "**variable sweep wing**": The left and right hand wings vary their sweep together, usually backwards. Seen in a few types of military aircraft, such as the General Dynamics F-111.

Oblique wing:

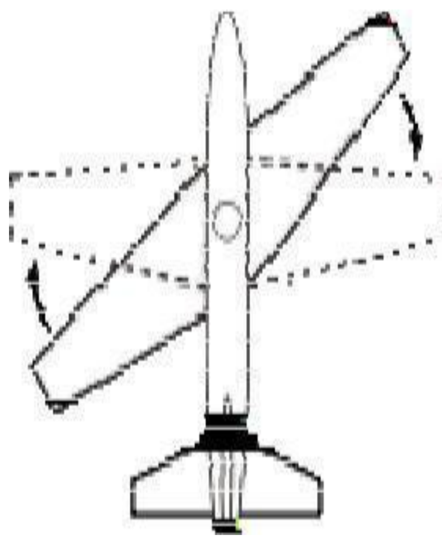
- A single full-span wing pivots about its midpoint, so that one side sweeps back and the other side sweeps forward. Flown on the NASA AD-1 research aircraft.



Forward swept



Variable sweep (swing- wing)



Oblique-wing

Tail planes or fore planes

Canard:

- "Fore plane" surface at the front of the aircraft. Common in the pioneer years, but from the outbreak of World War I no production model appeared until the Saab Viggen.
- This model introduced the use of a close-coupled canard to help direct airflow over the wing at high angles of attack rather than provide dynamic stability or control.

Tandem:

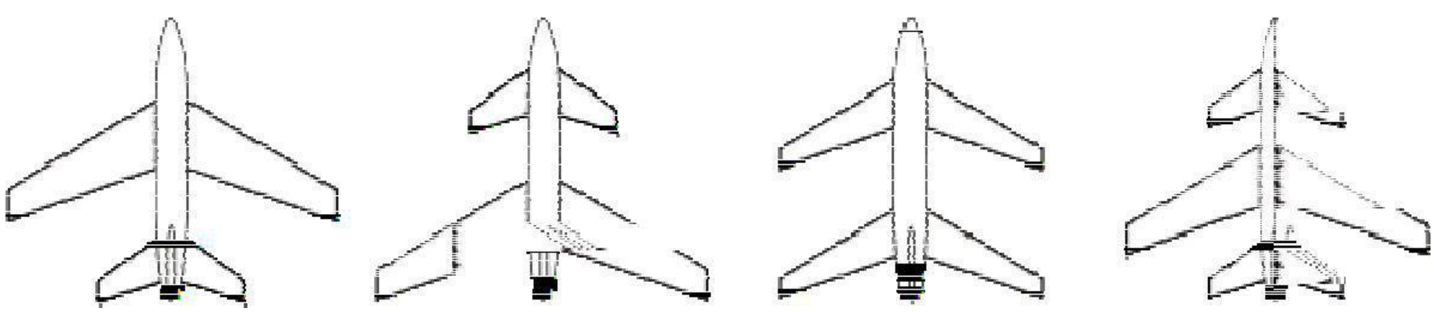
- Two main wings, one behind the other. The two acts together to provide stability and both provide lift.
- An example is the Rutan Quickie. According to NASA research, the wings must differ in aerodynamic characteristics or the air craft will tend to oscillate in pitch. Either span, chord or wing section must be different between the two wings.

Three lifting surface, 3LSC, Three surfaces, Triplet:

- Used to describe types having both conventional tail and canard auxiliary surfaces. Modern examples include the Sukhoi Su-33 and Piaggio P.180 Avanti.
- Pioneer examples included the Voisin-Far man I and Curtiss No. 1, however historically the smaller planes were not regarded as part of the main wing arrangement and these were not understood as three surface types. Sometimes incorrectly referred to as a tandem tri plane.

Tailless:

- No separate surface, at front or rear. The lifting and stabilizing surfaces may be combined in a single plane, as on the Short SB.4 Sherpa whose whole wing tip sections acted as elevons.
- Alternatively the aerofoil profile may be modified to provide inherent stability. Aircraft having a tail plane but no vertical tail fin have also been described as "tailless".



Conventional Canard Tandem Three surface

FINS

Twin tail:

- A twin tail, al so called an H-tail, consists of two small vertical stabilizers on either side of the horizontal stabilizer. Examples include the Antonov An-225 Mriya, B-25 Mitchell and Avro Lancaster.

Twin boom:

- A twin boo m has two fuselages or booms, with a vertical stabilizer on each and a horizontal stabilizer between them. Examples include the P-38 Lightning.

V tail:

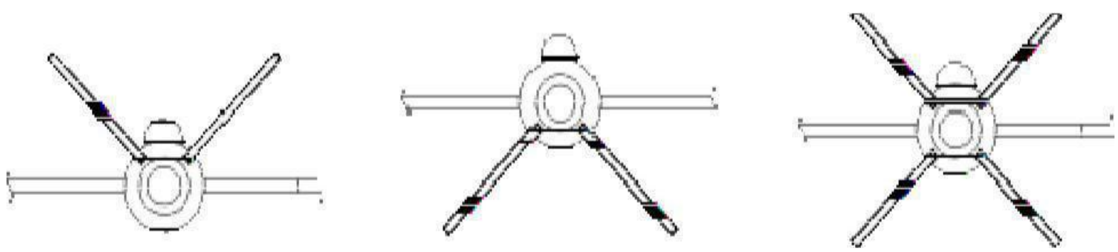
- A V-tail can be lighter than a conventional tail in some situations and produce Less drag, as on the Fouga Magister trainer, Northrop Grumman RQ-4 Global Hawk RPV and X-37 spacecraft. A V-tail may also have a smaller radar signature.

Inverted V tail:

- The unmanned Predator uses an inverted V-tail as does the Lazair.

X tail:

- The Lockheed XF V featured an "X" tail, which was reinforced and fitted with wheel on each surface so that the craft could sit on its tail and take off and land vertically.



V-tail Inverted V-tail X-tail

Plan form variation along span:

- The wing chord may be varied along the span of the wing, for both structural and aerodynamic reasons.

Elliptical:

- Leading and/ or trailing edges are curved such that the chord length varies elliptically with respect to span. Theoretically the most efficient, but difficult to make. Famously used on the super marine Spitfire.

- The wings of the Sever sky P-35 were semi-elliptical, having a straight leading edge and progressively curved trailing edge. (Note that in aerodynamics theory, the term "elliptical" describes the optimal lift distribution over a wing and not the shape).

Constant chord:

- Parallel leading & trailing edges. Simplest to make, and common where low cost is important, e.g. in the Piper J-3 Cub but inefficient as the outer section generates little lift.
- Sometimes known as the Hershey Bar wing in North America due to its similarity in shape to a chocolate bar.

Tapered:

- Wing narrows towards the tip, with straight edges. Structurally and aerodynamically more efficient than a constant chord wing, and easier to make than the elliptical type. It is one o f the most common wing plan forms, as seen on the Grumman F6F Hellcat.

Trapezoidal :

- Low aspect ratio tapered wing, where the leading edge sweeps back and the trailing edge sweeps forwards as on the Lockheed F-22 Raptor.

Wings and bodies

- Some designs have no clear join between wing and fuselage, or body. This may be because one or other of these is missing, or because they merge into each other:

Flying wing:

- The aircraft has no distinct fuselage or horizontal tail (although fins and pods, blisters, etc. may be present) such as on the B-2 stealth bomber.

Blended body or blended wing-body:

- Reduces wetted area and can also reduce interference between airflow over the wing root and any adjacent body, in both cases reducing drag. The Lockheed SR-71 spy plane exemplifies this approach.

Lifting body:

- The aircraft lacks identifiable wings but relies on the fuselage (usually at high speeds or high angles of attack) to provide aerodynamic lift as on t he X-24.

STOL:

- STOL is an acronym for short take-off and landing, a term used to describe aircraft with very short runway requirements. There is no one accepted definition of STOL and many different definitions have been used by different authorities and nations at various times and for a myriad of regulatory and military purposes. Some accepted definitions of STOL includes:

- "STOL (Short Take Off and Landing). STOL performance of an air craft is the ability of aircraft to take off and clear a 50-foot obstruction in a distance of 1,500 feet from beginning the takeoff run. It must also be able to stop within 1,500 feet after crossing a 5 0-foot obstacle on landing."
- "An aircraft that , at some weight within its approved operating weight, is capable of operating from a STOL runway in compliance with the applicable STOL characteristics and airworthiness, operations, noise, and pollution standards"and ""aircraft" means any machine capable of deriving support in the atmosphere"
- "short takeoff and landing aircraft (STOL), heavier-than-air craft, capable of rising from and descending to the ground with only a short length of runway, but incapable of doing so vertically.

V/STOL:

- Vertical and/or short take-off and landing (V/STOL) is a term used to describe airplanes that are able to take-off or land vertically or on short runways.
- Generally, a V/STOL aircraft needs to be able to hover. Helicopters are not considered under the V/STOL classification as it is only used for airplanes, aircraft that achieve lift in forward flight by planning the air, thereby achieving speed and fuel efficiency that is typically greater than helicopters are capable of.
- V/STOL aircraft types that have been produced in large numbers include the Harrier, Yak-38 Forger and V-22 Osprey.
- Although many aircraft have been proposed, built, and some even tested, the F-35B is expected to be the first supersonic VTOL aircraft in operational service.

Stealth aircraft

- Stealth aircrafts are aircrafts that use stealth technology to avoid detection by employing a combination of features to interfere with radar as well as reduce visibility in the infrared, visual, audio, and radio frequency (RF) spectrum.
- Development of stealth technology likely began in Germany during World War II. Well-known modern examples of stealth aircraft include the United States' F-117 Nighthawk (1981–2008), the B-2 Spirit, the F-22 Raptor and the F-35 Lightning II.
- While no aircraft is totally invisible to radar, stealth aircraft prevent conventional radar from detecting or tracking the aircraft effectively, reducing the odds of a successful attack.
- The general design of a stealth aircraft is always aimed at reducing radar and thermal detection. It is the designer's top priority to satisfy the following conditions; some of which are listed below, by using their skills, which ultimately decides the success of the aircraft:-
  - Reducing thermal emission from thrust

- Reducing radar detection by altering some general configuration (like introducing the split rudder)
- Reducing radar detection when the aircraft opens its weapons bay
- Reducing infra-red and radar detection during adverse weather conditions

Advantages of Stealth Technology:

- A smaller number of stealth vehicles may replace fleet of conventional attacks vehicles with the same or increased combat efficiency. Possibly resulting in longer term savings in the military budget.
- A Stealth vehicles strike capability may deter potential enemies from taking action and keep them in constant fear of strikes, since they can never know if the attack vehicles are already underway.
- The production of a stealth combat vehicles design may force an opponent to pursue the same aim, possibly resulting in significant weakening of the economically inferior party.
- Stationing stealth vehicles in a friendly country is a powerful diplomatic gesture as stealth vehicles incorporate high technology and military secrets. Decreasing causality rates of the pilots and crew member

Disadvantages of Stealth Technology:

- Stealth technology has its own disadvantages like other technologies. Stealth aircraft cannot fly as fast or is not maneuverable like conventional aircraft. The F-22 and the aircraft of its category proved this wrong up to an extent. Though the F-22 may be fast or maneuverable or fast, it can't go beyond Mach 2 and cannot make turns like the Su-37.
- Another serious disadvantage with the stealth aircraft is the reduced amount of payload it can carry. As most of the payload is carried internally in a stealth aircraft to reduce the radar signature, weapons can only occupy a less amount of space internally. On the other hand a conventional aircraft can carry much more payload than any stealth aircraft of its class.
- Whatever may be the disadvantage a stealth vehicles can have, the biggest of all disadvantages that it faces is its sheer cost. Stealth aircraft literally costs its weight in gold. Fighters in service and in development for the USAF like the B-2 ($2 billion), F-117 ($70million) and the F-22 ($100 million) are the costliest planes in the world. After the cold war, the number of B-2 bombers was reduced sharply because of its staggering price tag and maintenance charges.
- The B-2 Spirit carries a large bomb load, but it has relatively slow speed, resulting in 18 to 24hour long missions when it flies half way around the globe to attack overseas targets.
- Therefore advance planning and receiving intelligence in a timely manner is of paramount importance.
- Stealth aircraft are vulnerable to detection immediately before, during and after using their weaponry. Since reduced RCS bombs and cruise Missiles are yet not available; all armament must be carried internally to avoid increasing the radar cross section. As soon as the bomb bay doors opened, the planes RCS will be multiplied.

- Another problem with incorporating "stealth" technology into an aircraft is a wing shape that does not provide the optimum amount of lift. The resulting increase in drag reduces flight performance. "Stealth" shapes, such as the "faceting" found on Lockheed's F-117 "stealth" fighter, also tend to be aerodynamically destabilizing.
- This is brought under control only through the use of highly sophisticated computers that serve to electronically balance the aircraft in flight through its autopilot and control system. All of these modifications, however, hurt the plane's performance, adding weight, affecting aerodynamics, and altering the structure of the aircraft.

UNIT – III
FLIGHT VEHICLE PERFORMANCE AND STABILITY

Steady flight:

- Steady flight, un accelerated flight, or equilibrium flight is a special case in flight dynamics where the aircraft's linear and angular velocity are constant in a body-fixed reference frame.
- Basic aircraft maneuvers such as level flight, climbs and descents, and coordinated turns can be modeled as steady flight maneuvers.
- Typical aircraft flight consists of a series of steady flight maneuvers connected by brief, accelerated transitions. Because of this, primary applications of steady flight models include aircraft design, assessment of aircraft performance, flight planning, and using steady flight states as the equilibrium conditions around which flight dynamics equations are expanded.
- Steady flight analysis uses three different reference frames to express the forces and moments acting on the aircraft. They are defined as:
- Earth frame (assumed inertial)
- Origin - arbitrary, fixed relative to the surface of the Earth
  - Xe axis - positive in the direction of north
  - Ye axis - positive in the direction of east
  - Ze axis - positive towards the center of the Earth

Body frame

- Origin - airplane center of gravity
  - Xb (longitudinal) axis - positive out the nose of the aircraft in the plane of symmetry of the aircraft
  - Zb (vertical) axis - perpendicular to the xb axis, in the plane of symmetry of the aircraft, positive below the aircraft
  - Yb (lateral) axis - perpendicular to the xb, zb-plane, positive determined by the right-hand rule (generally, positive out the right wing)

Wind frame:

- Origin - airplane center of gravity
  - Xw axis - positive in the direction of the velocity vector of the aircraft relative to the air
  - Zw axis - perpendicular to the xw axis, in the plane of symmetry of the aircraft, positive below the aircraft
  - Yw axis - perpendicular to the xw, zw-plane, positive determined by the right hand rule (generally, positive to the right)
- The Euler angles linking these reference frames are:
  - Earth frame to body frame: yaw angle ψ, pitch angle θ, and roll angle φ
  - Earth frame to wind frame: heading angle σ, flight-path angle γ, and bank angle μ

- Wind frame to body frame: angle of sideslip β, angle of attack α (in this transformation, the angle analogous to φ and μ is always zero)Force Balance and the Steady Flight Equations:
- The forces acting on an aircraft in flight are the weight, aerodynamic force, and thrust. The weight is easiest to express in the Earth frame, where it has magnitude W and is in the +ze direction, towards the center of the Earth.
- The weight is assumed to be constant over time and constant with altitude. Expressing the aerodynamic force in the wind frame, it has a drag component with magnitude D opposite the velocity vector in the −xw direction, a side force component with magnitude C in the +yw direction, and a lift component with magnitude L in the −zw direction.
- In general, the thrust can have components along each body frame axis. For fixed wing aircraft with engines or propellers fixed relative to the fuselage, thrust is usually closely aligned with the +xb direction.
- Other types of aircraft, such as rockets and airplanes that use thrust vectoring, can have significant components of thrust along the other body frame axes. In this article, aircraft are assumed to have thrust with magnitude T and fixed direction +xb. Steady flight is defined as flight where the aircraft's linear and angular velocity vectors are constant in a body-fixed reference frame such as the body frame or wind frame.
- The Earth frame, the velocity may not be constant since the airplane may be turning, in which case the airplane has a centripetal acceleration $(V\cos(\gamma))^2/R$ in the xE-yE plane, where Vis the magnitude of the true airspeed and R is the turn radius.
- This equilibrium can be expressed along a variety of axes in a variety of reference frames. The traditional steady flight equations derive from expressing this force balance along three axes: the xw-axis, the radial direction of the aircraft's turn in the in the xE-yE plane, and the axis perpendicular to xw in the xw-zE plane.

$$T\cos\alpha\cos\beta - W\sin\gamma - D = 0 \quad (x_w\text{-axis})$$

$$C\cos\mu + L\sin\mu + T(\sin\alpha\sin\mu + \cos\alpha\cos\mu\sin\beta) = \frac{W}{g}\frac{(V\cos\gamma)^2}{R} \quad (x_E\text{-}y_E \text{ plane radia}$$

$$W\cos\gamma + C\sin\mu - L\cos\mu - T\sin\alpha\cos\mu = 0 \quad (\text{axis perpendicular to } x_w \text{ in the } x_w\text{-}z_E$$

- These equations can be simplified with several assumptions that are typical of simple, fixed-wing flight.
- First, assume that the sideslip β is zero, or coordinated flight.
- Second, assume the side force C is zero.
- Third, assume that the angle of attack α is small enough that cos (α) ≈1 and
- Sin (α) ≈α, which is typical since airplanes stall at high angles of attack.
- Similarly, assume that the flight-path angle γ is small enough that cos (γ) ≈1 and sin (γ) ≈γ, or equivalently that climbs and descents are at small angles relative to horizontal. Finally, assume

that thrust is much smaller than lift, T«L. Under these assumptions, the equations above simplify to

$$T = W\gamma + D$$
$$L\sin\mu = \frac{W}{g}\frac{V^2}{R}$$
$$L\cos\mu = W$$

- These equations show that the thrust must be sufficiently large to cancel drag and the longitudinal component of weight. They also show that the lift must be sufficiently large to support the aircraft weight and accelerate the aircraft through turns.
- Dividing the second equation by the third equation and solving for R shows that the turn radius can be written in terms of the true airspeed and the bank angle.

$$R = \frac{V^2}{g\tan\mu}$$

Steady Flight Maneuvers:

- The most general maneuver described by the steady flight equations above is a steady climbing or descending coordinated turn. The trajectory the aircraft flies during this maneuver is a helix with ze as its axis and a circular projection on the Xe-Ye plane. Other steady flight maneuvers are special cases of this helical trajectory.Steady longitudinal climbs or descents (without turning): bank angle μ=0, Steady level turns: γ=0
- Steady level longitudinal flight, also known as "flying straight and level": bank angle μ=0 and flight-path angle γ=0, Steady gliding descents, whether turning or longitudinal: T=0
- The definition of steady flight also allows for other maneuvers that are steady only instantaneously if the control inputs are held constant. These include the steady roll, where there is a constant and non-zero roll rate, and the steady pull up, where there is a constant but non-zero pitch rate.

Cruise (aeronautics)

A four-engine Boeing 747-400 jet in cruise

- Cruise is the level portion of aircraft travel where flight is most fuel efficient. It occurs between ascent and descent phases and is usually the majority of a journey. Technically, cruising consists of heading (direction of flight) changes only at a constant airspeed and altitude.
- It ends as the aircraft approaches the destination where the descent phase of flight commences in preparation for landing.
- For most commercial passenger aircraft, the cruise phase of flight consumes the majority of fuel. As this lightens the aircraft considerably, higher altitudes are more efficient for additional fuel economy.
- However, for operational and air traffic control reasons it is necessary to stay at the cleared flight level. On long haul flights, the pilot may climb from one flight level to a higher one as clearance is requested and given from air traffic control. This maneuver is called a step climb.
- Commercial or passenger aircraft are usually designed for optimum performance at their cruise speed or VC.
- There is also an optimum cruising altitude for a particular aircraft type and conditions including payload weight, Center of gravity of an aircraft, air temperature, humidity, and speed. This altitude is usually where the higher ground speeds, the increase
- In aerodynamic drag power and the decrease in engine thrust and efficiency at higher altitudes are balanced.
- Typical cruising air speed for long-distance commercial passenger flights is 475–500 knots (878-926 km/h; 546–575 mph).

Climb:

- For other uses, see Climbing (disambiguation) and The Climb (disambiguation).

An Embraer ERJ 145 climbing

- In aviation, a climb is the operation of increasing the altitude of an aircraft. It is also the logical phase of a typical flight (the climb phase or climb out) following takeoff and preceding the cruise.
- During the climb phase there is an increase in altitude to a predetermined level.

Climb operation:

- A climb is carried out by increasing the lift of airfoils (wings) supporting the aircraft until their lifting force exceeds the weight of the aircraft. Once this occurs, the aircraft will climb to a higher altitude until the lifting force and weight are again in balance.
- The increase in lift may be accomplished by increasing the angle of attack of the wings, by increasing the thrust of the engines to increase speed (thereby increasing lift), by increasing the surface area or shape of the wing to produce greater lift, or by some combination of these techniques.
- In most cases, engine thrust and angle of attack are simultaneously increased to produce a climb.
- Because lift diminishes with decreasing air density, a climb, once initiated, will end by itself when the diminishing lift with increasing altitude drops to a point that equals the weight of the aircraft. At that point, the aircraft will return to level flight at a constant altitude.
- However, during a constant rate climb at a reasonably steady angle the lift force is generally less than the weight with the engine operating. This is due to the upward fraction of the thrust vector.
- This in turn causes the load factor to be slightly less than 1. It is only during the radial (constant increase in pitch) or vertical acceleration that the lift vector is larger than the weight vector.

Climb phase:

An Enter Air Boeing 737 climbing

- The climb phase, also known as climb out, of a typical flight of an aircraft is the period during which the aircraft climbs to a predetermined cruising altitude after take-off. Depending on the aircraft, the altitudes involved, and other factors, this phase may last from a minute or two to half an hour or more.
- The climb phase immediately follows take-off and precedes the cruise phase of the flight. Although a single climb phase is typical, multiple climb phases may alternate with cruise phases, particularly for very long flights in which altitude is increased as the weight of fuel aboard decreases (see step climb).
- During long climbs the angle or rate of climb is often reduced. This slows the speed of ascent but increases the speed of forward progress towards the destination.

- A gradual climb improves forward visibility over the nose of the aircraft and decreases wear and tear on engines that rely on air cooling.
- If an aircraft exceeds its critical angle of attack, in a climb or otherwise, the wings may stall.
- Aircraft also climb by entering a zone of rising air, but since such zones are unpredictable and inconveniently located, and since most are poorly adapted to passive climbs of this type, only gliders attempt such climbs on a regular basis.
- A passive climb combined with an active climb can produce a higher climb rate than either method alone.
- The opposite of a climb is a descent.

“Normal” climb:

- In some jurisdictions and under some conditions, “normal” climbs are defined by regulations or procedures, and are used to develop airway systems, airspaces, and instrument procedures.
- Normal climbs are simply standardized climb rates achievable by most aircraft under most conditions that are used as conservative guidelines when developing procedures or structures that are partially a function of such rates.
- For example, a normal climb of 120 feet per nautical mile might be assumed during the development of a navigational procedure or while defining airspace limits in airport terminal areas.

Range (aeronautics):

- The maximal total range is the distance an aircraft can fly between takeoff and landing, as limited by fuel capacity in powered aircraft, or cross-country speed and environmental conditions in unpowered aircraft.
- Ferry range means the maximum range the aircraft can fly. This usually means maximum fuel load, optionally with extra fuel tanks and minimum equipment. It refers to transport of aircraft for use on remote location without any passengers or cargo.
- Combat range is the maximum range the aircraft can fly when carrying ordnance.
- Combat radius is a related measure based on the maximum distance a warplane can travel from its base of operations, accomplish some objective, and return to its original airfield with minimal reserves.
- The fuel time limit for powered aircraft is fixed by the fuel load and rate of consumption. When all fuel is consumed, the engines stop and the aircraft will lose its propulsion. For unpowered aircraft, the maximum flight time is variable, limited by available daylight hours, aircraft design (performance), weather conditions, aircraft potential energy, and pilot endurance.
- The range can be seen as the cross-country ground speed multiplied by the maximum time in the air. The range equation will be derived in this article for propeller and jet aircraft.

Propeller aircraft:

- With propeller driven propulsion, the level flight speed at a number of airplane weights from the equilibrium condition $P_a = P_r$ has to be noted.
- To each flight velocity, there corresponds a particular value of propulsive efficiency η_j and specific fuel consumption c_p.
- The successive engine powers can be found:

$$P_{br} = \frac{P_a}{\eta_j}$$

- The corresponding fuel weight flow rates can be computed now:

$$F = c_p P_{br}$$

- Thrust power, is the speed multiplied by the drag, is obtained from the lift-to-drag ratio:

$$P_a = V \frac{C_D}{C_L} W$$

- The range integral, assuming flight at constant lift to drag ratio, becomes

$$R = \frac{\eta_j}{c_p} \frac{C_L}{C_D} \int_{W_2}^{W_1} \frac{dW}{W}$$

- To obtain an analytic expression for range, it has to be noted that specific range and fuel weight flow rate can be related to the characteristics of the airplane and propulsion system; if these are constant:

$$R = \frac{\eta_j}{c_p} \frac{C_L}{C_D} ln \frac{W_1}{W_2}$$

Jet propulsion:

- The range of jet aircraft can be derived likewise. Now, quasi-steady level flight is assumed. The relationship $D = \frac{C_D}{C_L} W$ is used.
- The thrust can now be written as:

$$T = D = \frac{C_D}{C_L} W$$

- Jet engines are characterized by a thrust specific fuel consumption, so that rate of fuel flow is proportional to drag, rather than power.

$$F = -c_T T = -c_T \frac{C_D}{C_L} W$$

- Using the lift equation, $\frac{1}{2}\rho V^2 S C_L = W$ where ρ is the air density, and S the wing area
- The specific range is found equal to:

$$\frac{V}{F} = \frac{1}{c_T W}\sqrt{\frac{W}{S}\frac{2}{\rho}\frac{C_L}{C_D^2}}$$

- Therefore, the range becomes:

$$R = \int_{W_2}^{W_1} \frac{1}{c_T W}\sqrt{\frac{W}{S}\frac{2}{\rho}\frac{C_L}{C_D^2}}dW$$

- When cruising at a fixed height, a fixed angle of attack and a constant specific fuel consumption, the range becomes:

$$R = \frac{2}{c_T}\sqrt{\frac{2}{S\rho}\frac{C_L}{C_D^2}}\left(\sqrt{W_1} - \sqrt{W_2}\right)$$

- Where the compressibility on the aerodynamic characteristics of the airplane are neglected as the flight speed reduces during the flight.

Cruise/climb:

- For long range jet operating in the stratosphere, the speed of sound is constant, hence flying at fixed angle of attack and constant Mach number causes the aircraft to climb, without changing the value of the local speed of sound.
- In this case:

$$V = aM$$

- Where M are the cruise Mach number and a the speed of sound. The range equation reduces to:

$$R = \frac{aM}{c_T}\frac{C_L}{C_D}\int_{W_2}^{W_1}\frac{dW}{W}$$

Or

$$R = \frac{aM}{c_T}\frac{C_L}{C_D} ln \frac{W_1}{W_2},$$

- Also known as the Breguet range equation after the French aviation pioneer, Breguet.

Endurance (aeronautics):

- In aviation, endurance is the maximum length of time that an aircraft can spend in cruising flight.
- Endurance is different from range, which is a measure of distance flown.
- For example, a typical sailplane exhibits high endurance characteristics but poor range characteristics.
- Endurance can be defined as:

$$E = \int_{t_1}^{t_2} dt = -\int_{W_1}^{W_2} \frac{dW}{F} = \int_{W_2}^{W_1} \frac{dW}{F}$$

Where W stands for fuel weight, F for fuel flow, and t for time.

- Endurance can factor into aviation design in a number of ways. Some aircraft, such as the P-3Orion or U-2 spy plane, require high endurance characteristics as part of their mission profile (often referred to as loiter time (on target)).
- The Endurance plays a prime factor in finding out the fuel fraction for an aircraft.
- The Endurance, like range, is also related to fuel efficiency; fuel-efficient aircraft will tend to exhibit good endurance characteristics.

Basic fighter maneuvers:

- Basic fighter maneuvers (BFM) are tactical movements performed by fighter aircraft during air combat maneuvering (also called ACM, or dog fighting), in order to gain a positional advantage over the opponent.
- BFM combines the fundamentals of aerodynamic flight and the geometry of pursuit with the physics of managing the aircraft's energy-to-weight ratio, called its specific energy. Maneuvers are used to gain a better angular position in relation to the opponent.
- They can be offensive, to help an attacker get behind an enemy, or defensive, to help the defender evade an attacker's air-to-air weapons.
- They can also be neutral, where both opponents strive for an offensive position, or disengagement maneuvers, to help facilitate an escape.
- Awareness is often taught as the best tactical defense, removing the possibility of an attacker getting or remaining behind the pilot; even with speed a fighter is open to attack from the rear.

Takeoff and landing:

- Vehicles that can fly can have different ways to take off and land. Conventional aircraft accelerate along the ground until sufficient lift is generated for takeoff, and reverse the process to land.
- Some aircraft can take off at low speed, this being a short takeoff. Some aircraft such as helicopters and Harrier Jump Jets can take off and land vertically. Rockets also usually take off vertically, but some designs can land horizontally.

Conventional takeoff and landing (CTO):

- Take off is the phase of flight in which an aircraft goes through a transition from moving along the ground (taxiing) to flying in the air, usually starting on a runway.
- For balloons, helicopters and some specialized fixed-wing aircraft (VTOL aircraft such as the Harrier), no runway is needed. Takeoff is the opposite of landing.

Takeoff of the Shuttle Carrier Aircraft carrying the Space Shuttle Enterprise

Landing:

An airliner flaring at London Heathrow Airport (Air Jamaica Airbus A340-300)

A landing Qantas Boeing 747-400passes close to houses on the boundary of Heathrow Airport, England

A Mute Swan alighting

- Note the ruffled feathers on top of the wings indicate that the swan is flying at the stalling speed.
- The extended and splayed feathers act as lift augmenters in the same way as an aircraft's slats and flaps.

F-18 landing on an aircraft carrier

- Landing is the last part of a flight, where a flying aircraft or spacecraft (or animals) returns to the ground.

- When the flying object returns to water, the process is called alighting, although it is commonly called "landing" and "touchdown" as well.

Short takeoff and landing (STOL):

- STOL is an acronym for short take-off and landing, aircraft with very short runway requirements.

Catapult launch and arrested recovery (CATOBAR):

- CATOBAR (catapult assisted takeoff but arrested recovery) is a system used for the launch and recovery of aircraft from the deck of an aircraft carrier.
- Under this technique, aircraft are launched using a catapult and land on the ship (the recovery phase) using arrestor wires.
- Although this system is more costly than alternative methods, it provides greater flexibility in carrier operations, since it allows the vessel to support conventional aircraft. Alternate methods of launch and recovery can only use aircraft with STOVL or STOBAR capability.

Short Take Off But Arrested Recovery (STOBAR):

- STOBAR (Short Take off but Arrested Recovery) is a system used for the launch and recovery of aircraft from the deck of an aircraft carrier, combining elements of both STOVL (Short Take-Off and Vertical Landing) and CATOBAR (Catapult Assisted Take-Off But Arrested Recovery).

Spacecraft (HTHL):

- Horizontal takeoff, horizontal landing (HTHL) — is the mode of operation for the first private commercial space plane, the two-stage-to-space Scaled Composites Tier
- One from the Ansari X-Prize Space Ship One/White Knight One combination. It is also used for the upcoming Tier 1b Space Ship Two / White Knight Two combination.
- A prominent example of its use was the North American X-15 program. In these examples the space craft are carried to altitude on a "mother ship" before launch. The failed proposals for NASA Space Shuttle replacements, Rockwell X-30 NASP used this mode of operation but were conceived as single stage to orbit.
- The Lynx rocket plane is a suborbital HTHL space plane that is slated to begin atmospheric flight testing in late 2011.
- Reaction Engines Skylon, a design descendant of the 1980s British HOTOL ("Horizontal Take-Off and Landing") design project, is an HTHL space plane currently under development in the United Kingdom.
- Both the Lynx rocket plane and Space Ship Two have been proffered to NASA to carry suborbital research payloads in response to NASA's suborbital reusable launch vehicle (sRLV) solicitation under the NASA Flight Operations Program.

Vertical takeoff and landing:

- Different terms are used for takeoff and landing depending on the source of thrust used. VTVL uses rockets, whereas VTOL uses air, propelled via some kind of rotor system.
- Aircraft (VTOL is an acronym for vertical take-off and landing aircraft. This classification includes fixed-wing aircraft that can hover, take off and land vertically as well as helicopters and other aircraft with powered rotors, such as tilt rotors.
- The terminology for spacecraft and rockets is VTVL (vertical takeoff with vertical landing).
- Some VTOL aircraft can operate in other modes as well, such as CTOL (conventional take-off and landing), STOL (short take-off and landing), and/or STOVL (short take-off and vertical landing). Others, such as some helicopters, can only operate by VTOL, due to the aircraft lacking landing gear that can handle horizontal motion. VTOL is a subset of V/STOL (vertical and/or short take-off and landing).
- Besides the ubiquitous helicopter, there are currently two types of VTOL aircraft in military service: craft using a tilt rotor, such as the BellBoeingV-22 Osprey, and aircraft using directed jet thrust such as the Harrier family.
- Rocket (VTVL) Vertical takeoff, vertical landing (VTVL) is a form of takeoff and landing often proposed for expendable spacecraft. Multiple VTVL rocket craft have flown.

Vertical takeoff and horizontal landing:

- In aviation the term VTOHL ("Vertical Take-Off and Horizontal Landing") as well as several VTOHL aviation-specific sub types: VTOCL, VTOSL, VTOBAR exist.
- The zero length launch system or zero length take-off system (ZLL, ZLTO, ZEL, ZELL) was a system whereby jet fighters and attack aircraft were intended to be placed upon rockets attached to mobile launch platforms.
- Most zero length launch experiments took place in the 1950s, during the Cold War.
- Spacecraft (VTHL)VTHL—vertical takeoff, horizontal landing—is the mode of operation for all current and formerly operational orbital space planes, such as the BoeingX-37, the NASA Space Shuttle, the 1988 Soviet Buran space shuttle, as well as the circa-1960 USAF Boeing X-20 Dyna- Soarproject. For launch vehicles an advantage of VTHL over HTHL is that the wing can be smaller, since it only has to carry the landing weight of the vehicle, rather than the takeoff weight.
- There have been several other VTHL proposals that never flew including NASA Space Shuttle proposed replacements Lockheed Martin X-33 and Venture Star. The 1990s NASA concept space plane, the HL-20 Personnel Launch System (HL stands for "Horizontal Lander"), was VTHL, as was a circa-2003 derivative of the HL-20,N the Orbital Space Plane concept.
- As of March 2011, two VTHL commercial space planes were in various stages of proposal/development, both successors to the HL-20 design. The Sierra Nevada Corporation Dream Chaser, currently in development as of 2014, follows the outer mold line of the earlier HL-20.

- The circa-2011 proposed Orbital Sciences Corporation Prometheus was a blended lifting body space plane that followed the outer mold line of the circa-2003 Orbital Space Plane, itself a derivative of the HL-20; but Prometheus did not receive any NASA contracts and Orbital has announced they will not pursue further development.
- German Aerospace Center studied reusable VTHL Liquid Fly-back Boosters from 1999. Design was intended to replace Ariane 5 solid rocket boosters.
- The U.S. government-funded, US$250 million, Reusable Booster System program, initiated by the USAF in 2010, had specified a high-level requirement that the design be VTHL, but the funding was discontinued after 2012.

HTVL:

- HTVL or horizontal takeoff and vertical landing is the spaceflight equivalent of aviation HTOVL (and its subtypes CTOVL, STOVL, CATOVL).
- This mode of operation has not been used, but has been proposed for some systems that use a two-stage to orbit launch system with a plane based first stage, and a capsule return vehicle.
- One of the few HTVL concept vehicles is the 1960s concept spacecraft Hyperion SSTO, designed by Philip Bono.

Vertical/Short takeoff landing (V/STOL):

- Vertical and/or short take-off and landing (V/STOL) aircraft that are able to take off or land vertically or on short runways.
- Vertical takeoff and landing (VTOL) includes craft that do not require runways at all. Generally, a V/STOL aircraft needs to be able to hover; helicopters are not typically considered under the V/STOL classification.
- A rolling takeoff, sometimes with a ramp (ski-jump), reduces the amount of thrust required to lift an aircraft from the ground (compared with vertical takeoff), and hence increases the payload and range that can be achieved for a given thrust.
- For instance, the Harrier is incapable of taking off vertically with a full weapons and fuel load. Hence V/STOL aircraft generally use a runway if it is available. I.e. Short Take-Off and Vertical Landing (STOVL) or Conventional Take-off and Landing (CTOL) operation is preferred to VTOL operation.
- V/STOL was developed to allow fast jets to be operated from clearings in forests, from very short runways, and from small aircraft carriers that would previously only have been able to carry helicopters.
- The main advantage of V/STOL aircraft is closer basing to the enemy, which reduces response time and tanker support requirements. In the case of the Falklands War, it also permitted high performance fighter air cover and ground attack without a large aircraft carrier equipped with a catapult.
- The latest V/STOL aircraft is the F-35B, which is expected to enter service in 2016.

- An airplane in flight is constantly subjected to forces that disturb it from its normal horizontal flight path. Rising columns of hot air, down drafts gusty winds, etc., make the air bumpy and the airplane is thrown off its course. Its nose or tail drops or one wing dips. How the airplane reacts to such a disturbance from its flight attitude depends on its stability characteristics.
- Stability is the tendency of an airplane in flight to remain in straight, level, upright flight and to return to this attitude, if displaced, without corrective action by the pilot.
- Static stability is the initial tendency of an airplane, when disturbed, to return to the original position.
- Dynamic stability is the overall tendency of an airplane to return to its original position, following a series of damped out oscillations.
- Stability may be (a) positive, meaning the airplane will develop forces or moments which tend to restore it to its original position; (b) neutral, meaning the restoring forces are absent and the airplane will neither return from its disturbed position, nor move further away; (c) negative, meaning it will develop forces or moments which tend to move it further away. Negative stability is, in other words, the condition of instability.
- A stable airplane is one that will fly "hands off" and is pleasant and easy to handle. An exceedingly stable airplane, on the other hand, may lack maneuverability.
- An airplane which, following a disturbance, oscillates with increasing up and down movements until it eventually stalls or enters a dangerous dive would be said to be unstable, or to have negative dynamic stability.
- An airplane that has positive dynamic stability does not automatically have positive static stability. The designers may have elected to build in, for example, negative static stability and positive dynamic stability in order to achieve their objective in maneuverability. In other words, negative and positive dynamic and static stability may be incorporated in any combination in any particular design of airplane.
- An airplane may be inherently stable, that is, stable due to features incorporated in the design, but may become unstable due to changes in the position of the center of gravity (caused by consumption of fuel, improper disposition of the disposable load, etc.).
- Stability may be (a) longitudinal, (b) lateral, or (c) directional, depending on whether the disturbance has affected the airframe in the (a) pitching, (b) rolling, or (c) yawing plane.

LONGITUDINAL STABILITY:

- Longitudinal stability is pitch stability, or stability around the lateral axis of the airplane.
- To obtain longitudinal stability, airplanes are designed to be nose heavy when correctly loaded.
- The center of gravity is ahead of the center of pressure. This design feature is incorporated so that, in the event of engine failure, the airplane will assume a normal glide.
- It is because of this nose heavy characteristic that the airplane requires a tail plane. Its function is to resist this diving tendency. The tail plane is set at an angle of incidence that produces a negative lift and thereby, in effect, holds the tail down. In level, trimmed flight, the nose heavy tendency and the negative lift of the tail plane exactly balance each other.

- Two principal factors influence longitudinal stability: (1) size and position of the horizontal stabilizer, and (2) position of the center of gravity.

The Horizontal Stabilizer:

- The tail plane, or stabilizer, is placed on the tail end of a lever arm (the fuselage) to provide longitudinal stability. It may be quite small.
- However, being situated at the end of the lever arm, it has great leverage. When the angle of attack on the wings is increased by a disturbance, the center of pressure moves forward, tending to turn the nose of the airplane up and the tail down. The tail plane, moving down, meets the air at a greater angle of attack, obtains more lift and tends to restore the balance.
- On most airplanes, the stabilizer appears to be set at an angle of incidence that would produce an upward lift. It must, however, be remembered that the tail plane is in a position to be in the downwash from the wings.
- The air that strikes the stabilizer has already passed over the wings and been deflected slightly downward. The angle of the downwash is about half the angle of attack of the main airfoils.
- The proper angle of incidence of the stabilizer therefore is very important in order for it to be effective in its function.

Center of Gravity:

- The center of gravity is very important in achieving longitudinal stability. If the airplane is loaded with the center of gravity too far aft, the airplane may assume a nose up rather than a nose down attitude.
- The inherent stability will be lacking and, even though down elevator may correct the situation, control of the airplane in the longitudinal plane will be difficult and perhaps, in extreme cases, impossible.

LATERAL STABILITY:

- Lateral stability is stability around the longitudinal axis, or roll stability.
- Lateral stability is achieved through (1) dihedral, (2) sweepback, (3) keel effect, and (4) proper distribution of weight.

Dihedral:

- The dihedral angle is the angle that each wing makes with the horizontal. The purpose of dihedral is to improve lateral stability. If a disturbance causes one wing to drop, the unbalanced force produces a sideslip in the direction of the down going wing.
- This will, in effect, cause a flow of air in the opposite direction to the slip. This flow of air will strike the lower wing at a greater angle of attack than it strikes the upper wing.
- The lower wing will thus receive more lift and the airplane will roll back into its proper position.

- Since dihedral inclines the wing to the horizontal, so too will the lift reaction of the wing be inclined from the vertical. Hence an excessive amount of dihedral will, in effect, reduce the lift force opposing weight.
- Some modern airplanes have a measure of negative dihedral or anhedral, on the wings and/or stabilizer.
- The incorporation of this feature provides some advantages in overall design in certain type of airplanes. However, it does have an effect, probably adverse, on lateral stability.

Keel Effect:

- Dihedral is more usually a feature on low wing airplanes although some dihedral may be incorporated in high wing airplanes as well.
- Most high wing airplanes are laterally stable simply because the wings are attached in a high position on the fuselage and because the weight is therefore low.
- When the airplane is disturbed and one wing dips, the weight acts as a pendulum returning the airplane to its original attitude.

Sweepback:

- A sweptback wing is one in which the leading edge slopes backward. When a disturbance causes an airplane with sweepback to slip or drop a wing, the low wing presents its leading edge at an angle that is perpendicular to the relative airflow.
- As a result, the low wing acquires more lift, rises and the airplane is restored to its original flight attitude.
- Sweepback also contributes to directional stability. When turbulence or rudder application causes the airplane to yaw to one side, the right wing presents a longer leading edge perpendicular to the relative airflow.
- The airspeed of the right wing increases and it acquires more drag than the left wing. The additional drag on the right wing pulls it back, yawing the airplane back to its original path.

DIRECTIONAL STABILITY:

- Directional stability is stability around the vertical or normal axis.
- The most important feature that affects directional stability is the vertical tail surface, that is, the fin and rudder.
- Keel effect and sweepback also contribute to directional stability to some degree.

The Fin:

- An airplane has the tendency always to fly head-on into the relative airflow. This tendency which might be described as weather vaning is directly attributable to the vertical tail fin and to some extent also the vertical side areas of the fuselage.
- If the airplane yaws away from its course, the airflow strikes the vertical tail surface from the side and forces it back to its original line of flight.

- In order for the tail surfaces to function properly in this weather vaning capacity, the side area of the airplane aft of the center of gravity must be greater than the side area of the airplane forward of the C.G.
- If it were otherwise, the airplane would tend to rotate about its vertical axis.
- Handling qualities is one of the two principal regimes in the science of flight test (the other being performance).
- Handling qualities involves the study and evaluation of the stability and control characteristics of an aircraft. They have a critical bearing on the safety of flight and on the ease of controlling an airplane in steady flight and in maneuvers.

Relation to stability:

- To understand the discipline of handling qualities, the concept of stability should be understood.
- Stability can be defined only when the vehicle is in trim; that is, there are no unbalanced forces or moments acting on the vehicle to cause it to deviate from steady flight.
- If this condition exists, and if the vehicle is disturbed, stability refers to the tendency of the vehicle to return to the trimmed condition.
- If the vehicle initially tends to return to a trimmed condition, it is said to be statically stable. If it continues to approach the trimmed condition without overshooting, the motion is called a subsidence.
- If the motion causes the vehicle to overshoot the trimmed condition, it may oscillate back and forth.
- If this oscillation damps out, the motion is called a damped oscillation and the vehicle is said to be dynamically stable. On the other hand, if the motion increases in amplitude, the vehicle is said to be dynamically unstable.
- The theory of stability of airplanes was worked out by G. H. Bryan in England in 1904.
- This theory is essentially equivalent to the theory taught to aeronautical students today and was a remarkable intellectual achievement considering that at the time Bryan developed the theory, he had not even heard of the Wright brothers' first flight.
- Because of the complication of the theory and the tedious computations required in its use, it was rarely applied by airplane designers.
- Obviously, to fly successfully, pilotless airplanes had to be dynamically stable.
- The airplane flown by the Wright brothers, and most airplanes flown thereafter, was not stable, but by trial and error, designers developed a few planes that had satisfactory flying qualities. Many other airplanes, however, had poor flying qualities, which sometimes resulted in crashes.

Historical development:

- Bryan showed that the stability characteristics of airplanes could be separated into longitudinal and lateral groups with the corresponding motions called modes of motion.

- These modes of motion were either a periodic, which means that the airplane steadily approaches or diverges from a trimmed condition, or oscillatory, which means that the airplane oscillates about the trim condition.
- The longitudinal modes of a statically stable airplane following a disturbance were shown to consist of a long-period oscillation called the phugoid oscillation, usually with a period in seconds about one-quarter of the airspeed in miles per hour and a short-period oscillation with a period of only a few seconds.
- The lateral motion had three modes of motion: an a periodic mode called the spiral mode that could be a divergence or subsidence, a heavily damped a periodic mode called the roll subsidence, and a short-period oscillation, usually poorly damped, called the Dutch roll mode.
- Some early airplane designers attempted to make airplanes that were dynamically stable, but it was found that the requirements for stability conflicted with those for satisfactory flying qualities. Meanwhile, no information was available to guide the designer as to just what characteristics should be incorporated to provide satisfactory flying qualities.
- By the 1930s, there was a general feeling that airplanes should be dynamically stable, but some aeronautical engineers were starting to recognize the conflict between the requirements for stability and flying qualities.
- To resolve this question, Edward Warner, who was working as a consultant to the Douglas Aircraft Company on the design of the DC-4, a large four-engine transport airplane, made the first effort in the United States to write a set of requirements for satisfactory flying qualities. Dr. Warner, a member of the main committee of the NACA, also requested that a flight study be made to determine the flying qualities of an airplane along the lines of the suggested requirements.

Evaluation of handling qualities

- The technique for the study of flying qualities requirements used by Gilruth was first to install instruments to record relevant quantities such as control positions and forces, airplane angular velocities, linear accelerations, airspeed, and altitude.
- Then a program of specified flight conditions and maneuvers was flown by an experienced test pilot. After the flight, data were transcribed from the records and the results were correlated with pilot opinion.
- This approach would be considered routine today, but it was a notable original contribution by Gilruth that took advantage of the flight recording instruments already available at Langley and the variety of airplanes available for tests under comparable conditions.

UNIT-IV
INTRODUCTION TO AIRPLANE STRUCTURES AND MATERIALS, POWER PLANTS

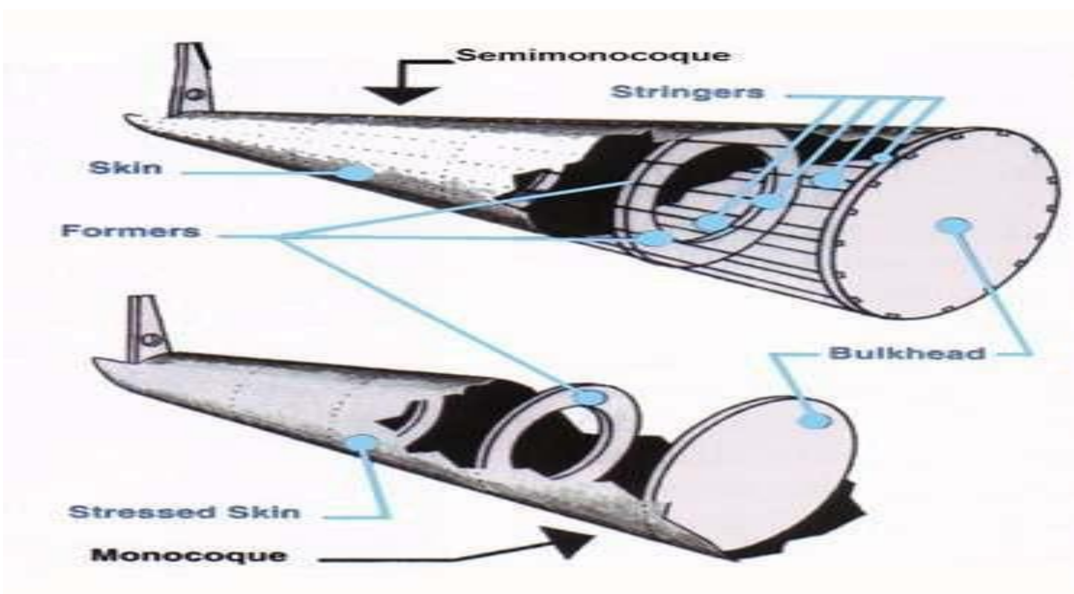
- Fuselage of an aircraft is mainly made-up of 2 types of construction. They are
  - Monocoque
  - Semi-Monocoque

Monocoque:

- Is a construction technique that supports structural load by using an object's external skin. No other components are used in supporting the skin.

Semi-Monocoque:

- System uses a substructure to which the airplane´s skin is attached. The sub structure, which consists of bulkheads and/or formers of various sizes and stringers, reinforces the stressed skin by taking some of the bending stress from the fuselage.
- Since the skin of the semi-monocoque structure must carry much of the fuselage's strength, it will be thicker in some places than at other places.



Longerons:

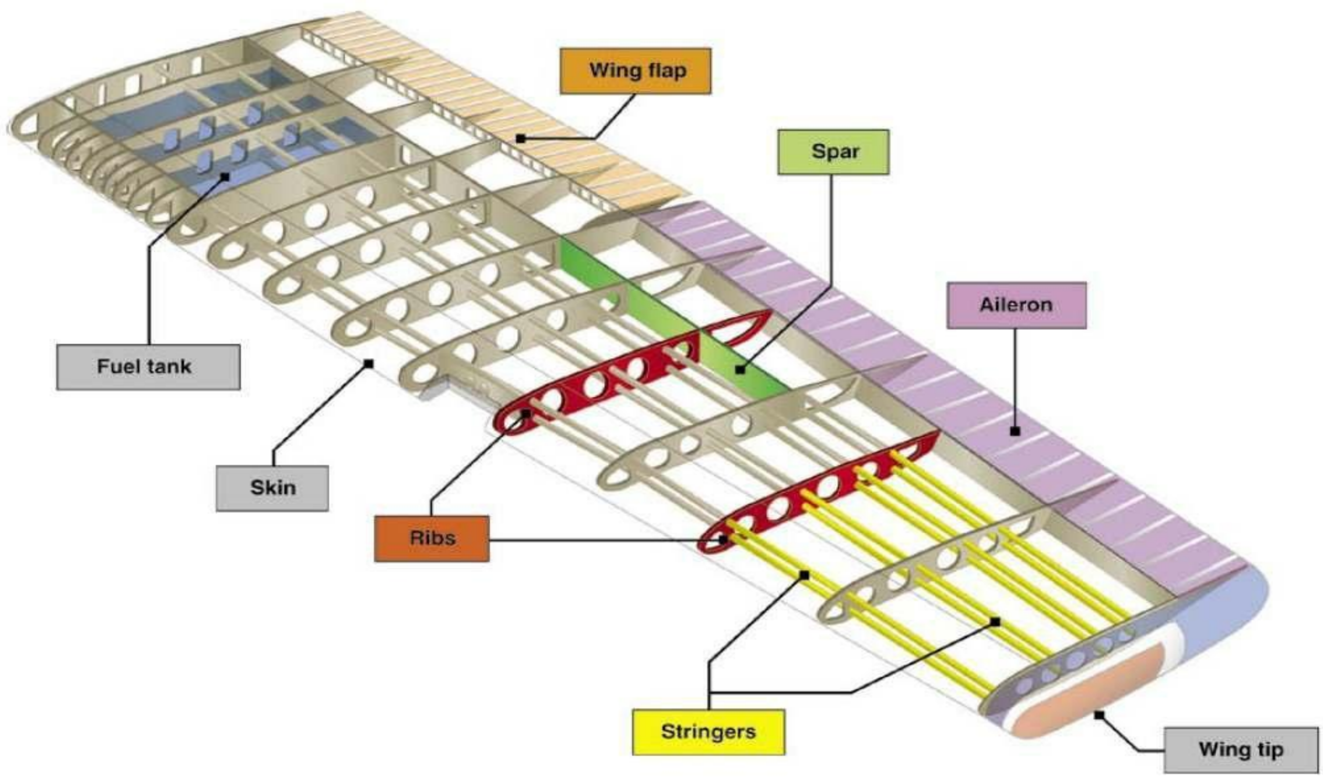
- In aircraft construction, a longerons or stringer or stiffener is a thin strip of material, to which the skin of the aircraft is fastened. In the fuselage, longerons are attached to formers (also called frames) and run the longitudinal direction of the aircraft.

Structural members of a wing:

- The main Structural members of a wing are:

- Skin
- Ribs
- Spars
- Stringers

- The ribs attach to the main spar, and by being repeated at frequent intervals, form a skeletal shape for the wing. Usually ribs incorporate the airfoil shape of the wing, and the skin adopts this shape when stretched over the ribs.
- In a fixed-wing aircraft, the spar is often the main structural member of the wing, running span-wise at right angles (or thereabouts depending on wing sweep) to the fuselage. The spar carries flight loads and the weight of the wings whilst on the ground.



Wing structural members

High lift devices:

- High lift devices are used in combination with airfoils in order to reduce the takeoff or landing speed in by changing the lift characteristics of an airfoil during the characteristics of an air foil during the landing or takeoff phases.
- When these devices are no longer needed they are returned to a position within the wing to regain the normal characteristics of the airfoil. Two high –lift devices commonly used on aircraft are slots and flaps.

- Slot is used as a passageway through the leading edge of the wing. At high angles of attack the air flows through the slot and smoothes out the airflow over the top surfaces of the wing.
- This enables the wing to pass beyond its normal stalling point without stalling. Greater lift is obtained with the wing operating at the higher angle of attack.
- The other high lift devices are known as a flap. It is a hinged surface on the trailing edge of the wing. The flap is controlled from the cockpit, and when not in use fits smoothly into the lower surface of each wing.
- The use of flaps increases the camber of a wing and therefore the lift of the wing, making it possible for the speed of the aircraft to be decreased without stalling.
- This also permits a steeper gliding angle to be obtained as in the landing approach. Flaps are primarily used during takeoff and landing.
- The **spoilers**, or speed brakes as they are also called, are plates fitted to the upper surface of the wing.
- They are usually deflected upward by hydraulic actuators in response to control wheel movement in the cockpit.
- The purpose of the spoilers is to disturb the smooth airflow across the top of the airfoil thereby creating an increased amount of drag and a decreased amount of lift on that airfoil. **Spoilers** are used primarily for lateral control.
- When banking the airplane, the spoilers function with the ailerons. The spoilers on the up aileron side rise with that aileron to further decrease the lift on the wing.
- The spoilers on the opposite side remain in the faired position.
- When the spoilers are used as a speed brake, they are all deflected upward simultaneously.
- A separate control lever is provided for operating the spoilers as speed brakes.

Spar loads:

- The wing spar provides the majority of the weight support and dynamic load integrity of cantilever monoplanes, often coupled with the strength of the wing 'D' box itself.
- Together, these two structural components collectively provide the wing rigidity needed to enable the aircraft to fly safely.
- Biplanes employing flying wires have much of the flight loads transmitted through the wires and inter plane struts enabling smaller section and thus lighter spars to be used at the cost of increasing drag.

Forces:

- Main article: Aircraft flight mechanics
- Some of the forces acting on a wing spar are
- Upward bending loads resulting from the wing lift force that supports the fuselage in flight. These forces are often offset by carrying fuel in the wings or employing wing-tip-mounted fuel tanks; the Cessna 310 is an example of this design feature.

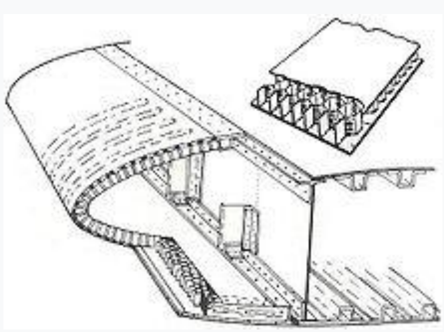
- Downward bending loads while stationary on the ground due to the weight of the structure, fuel carried in the wings, and wing-mounted engines if used.
- Drag loads dependent on airspeed and inertia.
- Rolling inertia loads.
- Chord wise twisting loads due to aerodynamic effects at high airspeeds often associated with washout, and the use of ailerons resulting in control reversal. Further twisting loads are induced by changes of thrust settings to under wing-mounted engines. The "D" box construction is beneficial to reduce wing twisting.
- Many of these loads are reversed abruptly in flight with an aircraft such as the Extra 300 when performing extreme aerobatic maneuvers; the spars of these aircraft are designed to safely withstand great load factors.

Materials and construction:

Wooden construction:

- Early aircraft used spars often carved from solid spruce or ash. Several different wooden spar types have been used and experimented with such as spars that are box-section in form; and laminated spars laid up in a jig, and compression glued to retain the wing dihedral.
- Wooden spars are still being used in light aircraft such as the Robin DR400 and its relatives. A disadvantage of the wooden spar is the deteriorating effect that atmospheric conditions, both dry and wet, and biological threats such as wood-boring insect infestation and fungal attack can have on the component; consequently regular inspections are often mandated to maintain airworthiness.
- Wood wing spars of multi piece construction usually consist of upper and lower members, called spar caps, and vertical sheet wood members, known as shear webs or more simply webs, that span the distance between the spar caps.
- Even in modern times, "homebuilt replica aircraft" such as the replica Spitfires use laminated wooden spars. These spars are laminated usually from spruce or douglas fir (by clamping and glueing). A number of enthusiasts build "replica" Spitfires that will actually fly using a variety of engines relative to the size of the aircraft.

Metal spars:



- Basic metal-sparred wing using a honeycomb 'D' box leading edge. A typical metal spar in a general aviation aircraft usually consists of a sheet aluminum spar web, with "L" or "T" -shaped spar caps being welded or riveted to the top and bottom of the sheet to prevent buckling under applied loads.
- Larger aircraft using this method of spar construction may have the spar caps sealed to provide integral fuel tanks. Fatigue of metal wing spars has been an identified causal factor in aviation accidents, especially in older aircraft.

Tubular metal spars:

- The German Junkers J.I armored fuselage ground-attack sesquiplane of 1917 used a Hugo Junkers-designed multi-tube network of several tubular wing spars, placed just under the corrugated duralumin wing covering and with each tubular spar connected to the adjacent one with a space frame of triangulated duralumin strips — usually in the manner of a Warren truss layout — riveted onto the spars, resulting in a substantial increase in structural strength at a time when most other aircraft designs were built almost completely with wood-structure wings.
- The Junkers all-metal corrugated-covered wing / multiple tubular wing spar design format was emulated after World War I by American aviation designer William Stout for his 1920s-era Ford Trimotor airliner series, and by Russian aerospace designer Andrei Tupolev for such aircraft as his Tupolev ANT-2 of 1922, upwards in size to the then-gigantic Maksim Gorki of 1934.
- A design aspect of the Super marine Spitfire wing that contributed greatly to its success was an innovative spar boom design, made up of five square concentric tubes that fitted into each other.
- Two of these booms were linked together by an alloy web, creating a lightweight and very strong main spar.A version of this spar construction method is also used in the BD-5, which was designed and constructed by Jim Bede in the early 1970s.
- The spar used in the BD-5 and subsequent BD projects was primarily aluminum tube of approximately 2 inches (5.1 cm) in diameter, and joined at the wing root with a much larger internal diameter aluminum tube to provide the wing structural integrity.

Engineering materials:

- Almost every substance known to man has found its way into the engineering workshop at some time or other. The most convenient way to study the properties and uses of engineering materials is to classify them into ‘families’.

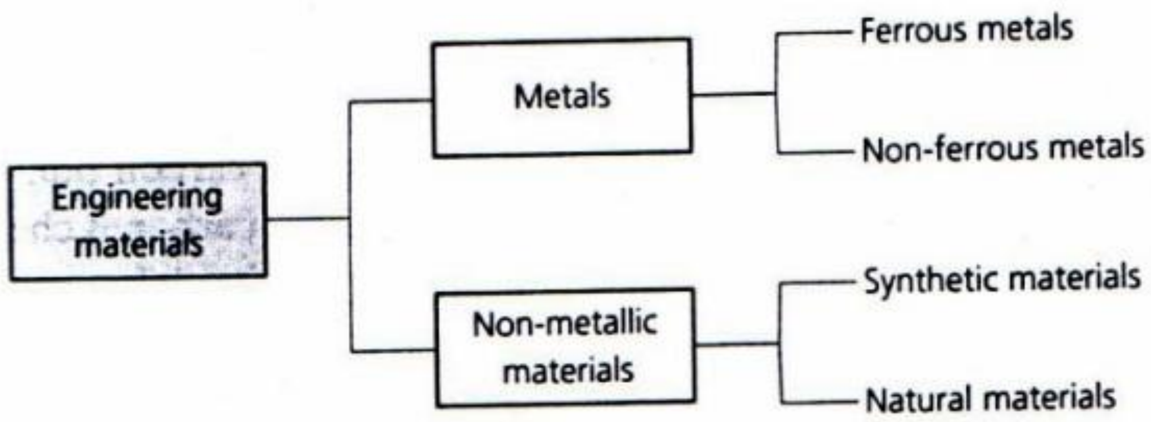
Classification of engineering materials.

Metals

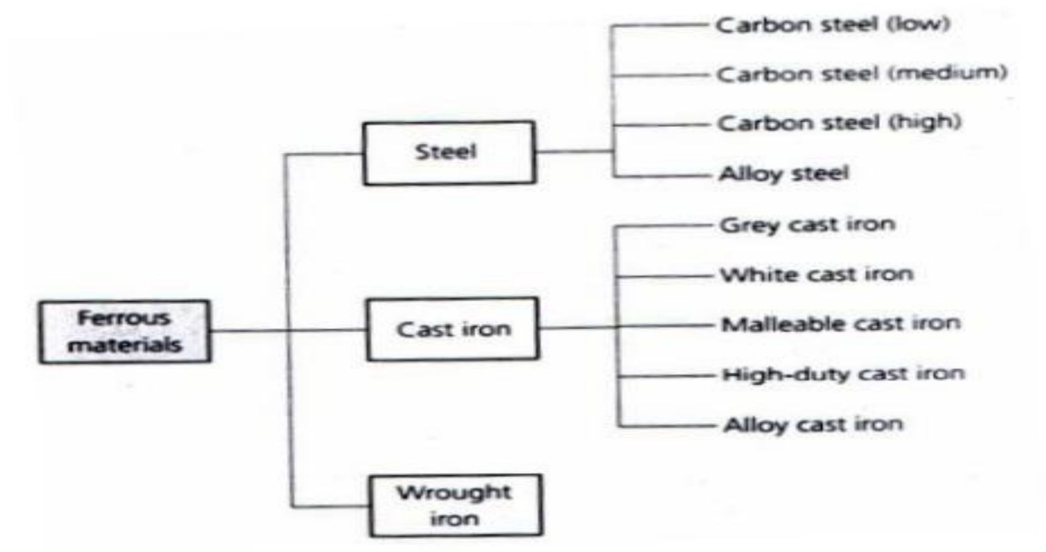
Ferrous metals

- These are metals and alloys containing a high proportion of the element iron.

- They are the strongest materials available and are used for applications where high strength is required at relatively low cost and where weight is not of primary importance.
- As an example of ferrous metals such as : bridge building, the structure of large buildings, railway lines, locomotives and rolling stock and the bodies and highly stressed engine parts of road vehicles.
- The ferrous metals themselves can also be classified into "families'.



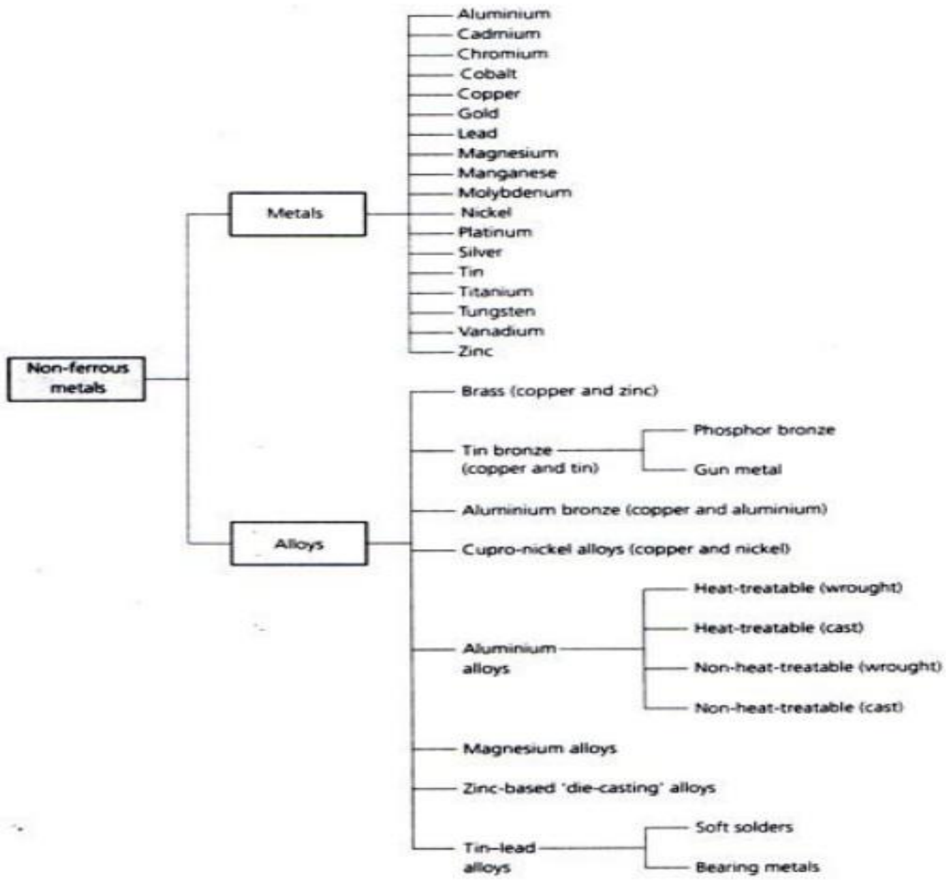
classification of engineering materials.



Classification of ferrous metals.

Non – ferrous metals:

- These materials refer to the remaining metals known to
  - Mankind.
  - The pure metals are rarely used as structural materials as they
  - Lack mechanical strength.
  - They are used where their special properties such as corrosion.
  - Resistance, electrical conductivity and thermal conductivity are required. Copper and aluminum are used as electrical conductors and, together with sheet zinc and sheet lead, are use as roofing materials.
  - They are mainly used with other metals to improve their.
  - Strength. Some widely used non-ferrous metals and alloys are classified.

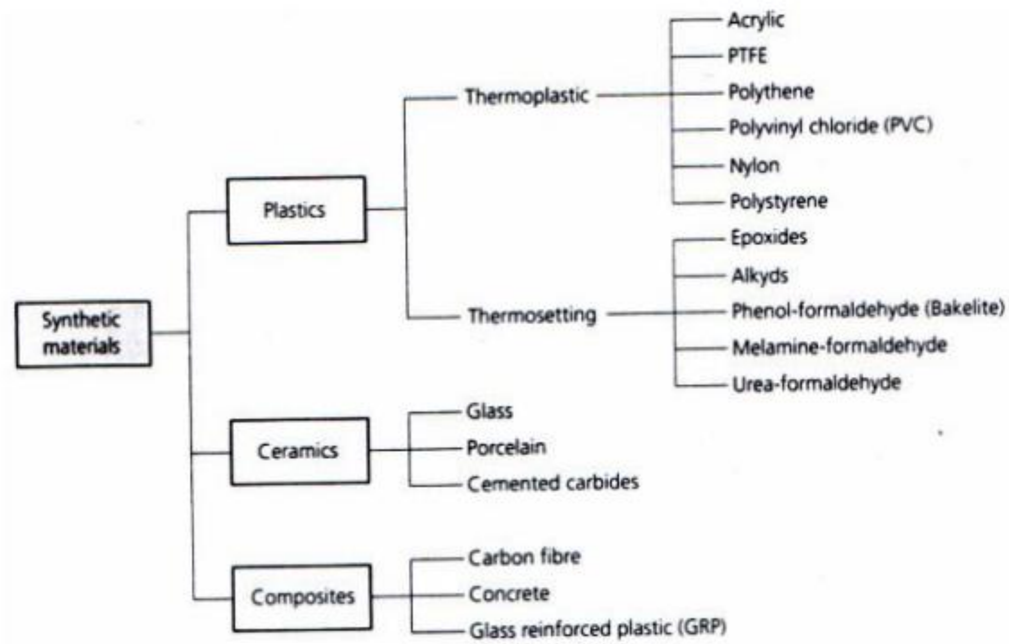


Classification of non-ferrous metals and alloys.

Non – metallic materials:

Non – metallic (synthetic materials):

- These are non – metallic materials that do not exist in nature, although they are manufactured from natural substances such as oil, coal and clay.
- Some typical examples are classified.
- They combine good corrosion resistance with ease of manufacture¬ by moulding to shape and relatively low cost.
- Synthetic adhesives are also being used for the joining of metallic¬ components even in highly stressed applications.

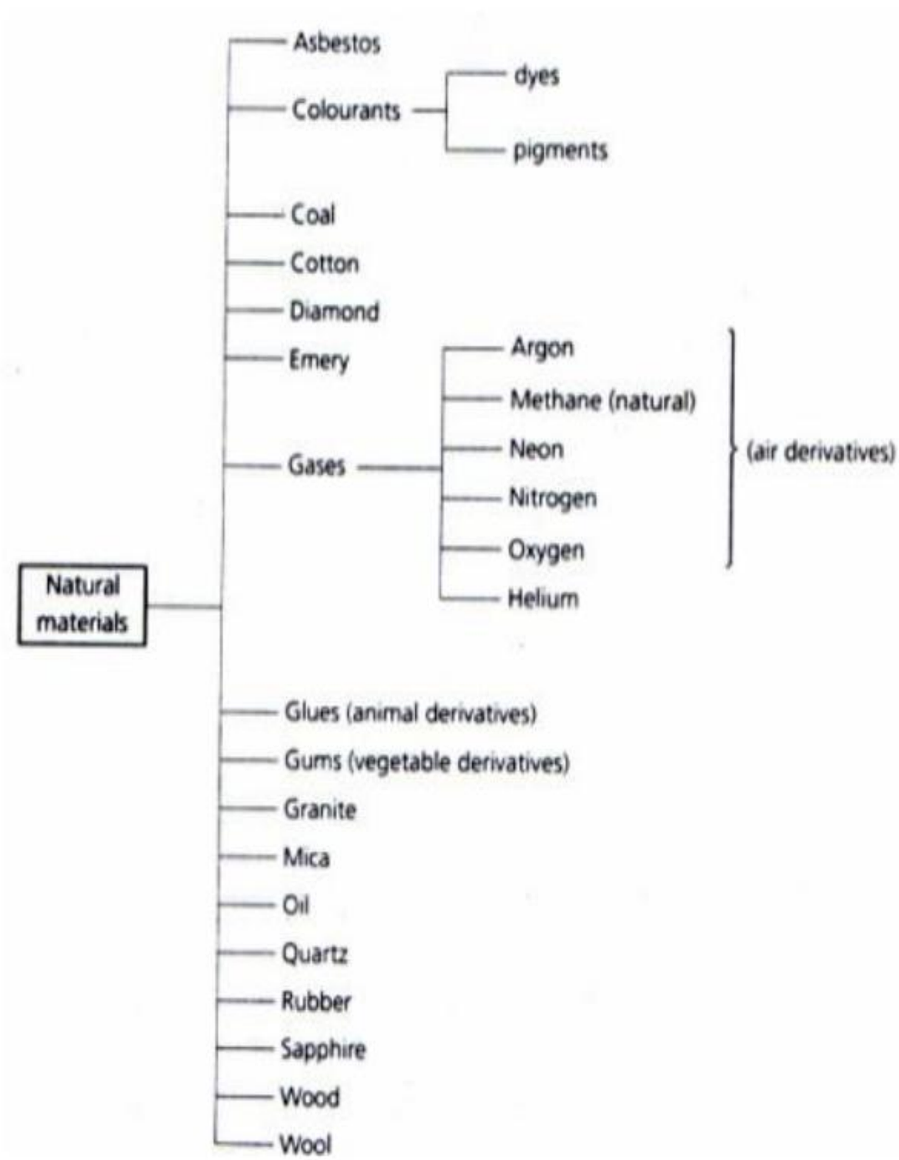


. classification of synthetic materials.

Non – metallic (Natural materials):

- Such materials are so diverse that only a few can be listed here to give a basic introduction to some typical applications.
  - Wood: This is naturally occurring fibrous composite material used¬ for the manufacture of casting patterns.
  - Rubber: This is used for hydraulic and compressed air hoses and oil¬ seals. Naturally occurring latex is too soft for most engineering uses but it is used widely for vehicle tyres when it is compounded with carbon black.
  - Glass: This is a hardwearing, abrasion-resistant material with excellent weathering properties. It is used for electrical insulators, laboratory equipment, optical components in measuring instruments in the form of fibers, is used to reinforce plastics. It is made by melting together the naturally occurring materials: silica (sand), limestone (calcium carbonate) and soda (sodium carbonate).
  - Emery: This is a widely used abrasive and is a naturally occurring aluminum oxide. Nowadays it is produced synthetically to maintain uniform quality and performance.
  - Ceramic: These are produced by baking naturally occurring clays at high temperatures after moulding to shape. They are used for high – voltage insulators and high – temperature – resistant cutting tool tips.
  - Diamonds: These can be used for cutting tools for operation at high speeds for metal finishing where surface finish is greater importance. For example, internal combustion engine pistons and bearings. They are also used for dressing grinding wheels.
  - Oils: Used as bearing lubricants, cutting fluids and fuels.

- Silicon: This is used as an alloying element and also for the¬ manufacture of semiconductor devices. These and other natural, non-metallic materials can be classified as Composite materials (composites).
- These are materials made up from, or composed of, a combination of different materials to take overall advantage of their different properties. In man-made composites, the advantages of deliberately combining materials in order to obtain improved or modified properties was understood by ancient civilizations.
- An example of this was the reinforcement of air-dried bricks by mixing the clay with straw. This helped to reduce cracking caused by shrinkage stresses as the clay dried out. In more recent times, horse hair was used to reinforce the plaster used on the walls and ceiling of buildings.
- Again this was to reduce the onset of drying cracks. Nowadays, especially with the growth of the plastics industry and the development of high-strength fibers, a vast range combination of materials is available for use in composites.
- For example, carbon fiber reinforced frames for tennis rackets and shafts for golf clubs have revolutionized these sports.



THE PROPELLER

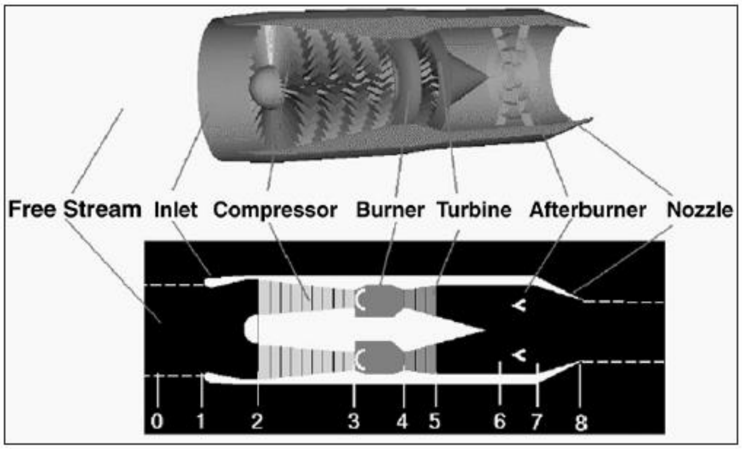
- Thrust is the force that moves an aircraft through the air and is generated by the propulsion system. Different types of propulsion systems develop thrust in different ways.
- The Mathematical Principles of Natural Philosophy, commonly known as the Principia, Newton states to every action there is an equal and opposite reaction.
- In other words, if particle 1acts on particle 2 with a force F12 in a direction along the line adjoining the particles; while particle 2 acts on particle 1 with a force F21, then F12 _ F21 for 40 years following the Wright brothers' first flight, airplanes used internal combustion engines to turn propellers to generate thrust.
- Most general aviation or private airplanes are powered by propellers and internal combustion engines similar to automobile engines.

- The engine takes air from the surroundings, mixes it with fuel, burns the fuel, thereby releasing the energy in the fuel, and uses the heated gas exhaust to move a piston that is attached to a crankshaft.
- In the automobile, the shaft is used to turn the wheels of the car whereas in an airplane, the shaft turns a propeller. What is the difference between an engine and a motor? An engine produces work from heat (combustion), and a motor typically produces work from the conversion of electrical energy to mechanical energy.,
- “Design: Lighter-Than-Air (LTA) Vehicle Module,” where batteries supply the electrical energy that is converted to the mechanical energy that turns the propellers to propeller the lighter-than-air vehicles. State-of-the-art, solar-powered electric aircraft also use propellers.

THE ILLUSTRATED JET ENGINE

- There are several different types of jet engines; often referred to as gas turbine engines, but all turbine engines share the same core elements: an inlet, compressor, burner, turbine, and nozzle. The inlet brings free stream air into the engine, which sits upstream of the compressor.
- The compressor increases the pressure of the incoming air before it enters the burner (sometimes called the combustor).Fuel is combined with high-pressure air and burned at this stage of the engine.
- The resulting high-temperature exhaust gas is used to turn the power turbine and to produce thrust when passed through a nozzle. The power turbine is locateddownstream of the burner and extracts energy from the hot flow, which is thenused to turn the compressor.
- The nozzle is downstream of the power turbine. The figure shows an afterburner, which most modern fighter aircraft incorporate into their engine design to fly faster than the speed of sound, or at supersonic speed.
- Details of the core components are given, followed by description of six types of jet engines:

1) Turbojets.
2) Turbofans.
3) Turboprops.
4) Afterburning turbojets.
5) Ramjets.
6) Ultra high bypass engines.



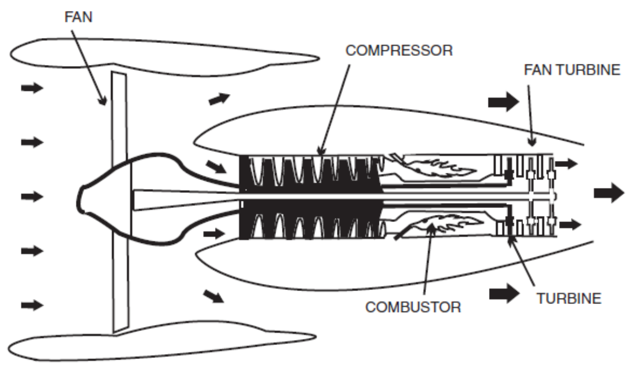
How Does a Turbojet Work?

- The common components of the engine have been described, so now we concentrate on the entire engine system operation. The different types of engines will be discussed, specifically; the turbojet, turbofan, turboprop, afterburning turbojets, ramjets, and ultra high bypass engines.
- The turbojet is the basic engine of the jet age. Large amounts of air surrounding the engine are continuously brought into the engine through the inlet which then enters the compressor. Many rows of compressor squeeze the air to many times the free stream pressure.
- The compressor requires air and an energy supply to operate. At the exit of the compressor, the compressed air is forced into the burner. In the burner a small amount of fuel is sprayed into the compressed air, is ignited, and is burned continuously.
- A typical jet engine ratio has a 50:1 ratio of air mass flow to fuel mass flow. Leaving the burner, the hot, expanding exhaust is passed through the turbine. The turbine works as a windmill and extracts energy from the expanding gases while the blades rotate in the flow.
- In a jet engine the energy extracted by the turbine drives through a linked central shaft. The turbine depletes some energy from the hot exhaust, but there is sufficient energy left over to provide aircraft forward thrust by increasing the flow velocity through the nozzle—a demonstration of the action-and-reaction principle.
- For a jet engine, the exit mass flow is nearly equal to the free stream mass flow, since very little fuel is added to the stream. The thrust equation given in Equation (6.1) contains two interesting terms.
- Aerospace engineers often refer to the first term (exit mass flow rate times exit velocity) as the gross thrust since this term is mostly associated with conditions in the nozzle.
- The second term (free stream mass flow rate times freestream velocity) is called the ram drag. For clarity, the engine thrust is then called the net thrust. Our thrust equation indicates that net thrust equals gross thrust minus ram drag

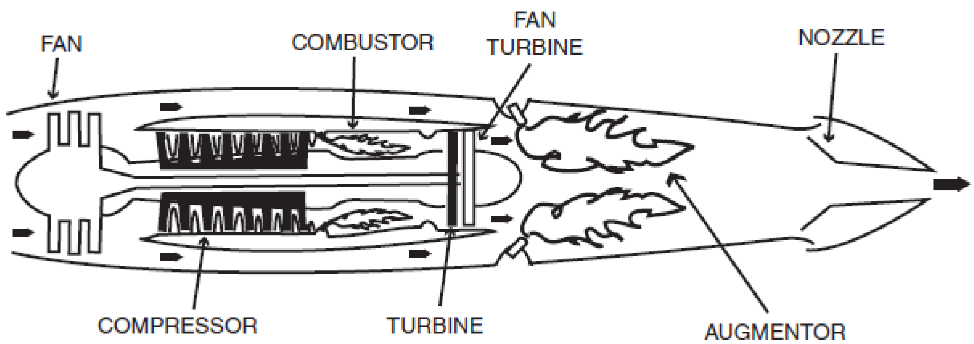
How Does a Turbofan Work?

- Most modern airliners use turbofan engines because of their high thrust and good fuel efficiency. A turbofan engine is a variation of the basic gas turbine engine, where the core engine is surrounded by a fan in the front and an additional fan turbine at the rear.
- The fan and fan turbine are composed of many blades, as are the core compressor and core turbine, and are connected to an additional shaft. As with the core compressor and turbine, some of the fan blades turn with the shaft and other blades remain stationary.
- The fan shaft typically passes through the core shaft for mechanical reasons. This type of arrangement is called a two-spool engine (one spool for the fan, one spool for the core). Some advanced engines have additional spools for even higher efficiency.
- The incoming air is captured by the engine inlet. Some of the incoming air passes through the fan and continues on into the core compressor, then into the burner, where it is mixed with fuel and combustion occurs. The hot exhaust passes through the core and fan turbines and then out the nozzle, identical to the process in a basic turbojet.
- The fan causes additional air to flow around (bypass) the engine, just like the air through a propeller. This produces greater thrust and reduces specific fuel consumption. Therefore, a turbofan gets some of its thrust from the core and some from the fan.
- The ratio between the air mass that flows around the engine and the air mass that goes through the core is called the bypass ratio**.** Because the fuel flow rate for the core is changed only a small amount by the addition of the fan, a turbofan generates more thrust for nearly the same amount of fuel used by the core.
- A turbofan is very fuel-efficient—in fact, high bypass ratio turbofans are nearly as fuel-efficient as turboprops. Because the fan is enclosed by the inlet and is composed of many blades, it operates more efficiently at higher speeds than a simple propeller. That is why turbofans are found on high-speed transports and propellers are used on low-speed transports.
- There are two types of turbofans: high bypass and low bypass. High bypass turbofans have large fans in front of the engine and are driven by a fan turbine located behind the primary turbine that drives the main compressor. For supersonic flight, a low bypass fans used that has a much smaller front fan, and often afterburners are added for additional thrust.
- Even low bypass ratio turbofans are more fuel-efficient than basic turbojets. They can then cruise efficiently but have sufficient thrust for dog-fighting and military maneuvers.
- Even though the fighter plane can fly much faster than the speed of sound, the air going into the engine must travel at less than the speed of sound for high efficiency. The airplane inlet slows the air down from supersonic speeds.

High bypass turbofan engine schematic.



Low bypass turbofan engine schematic.

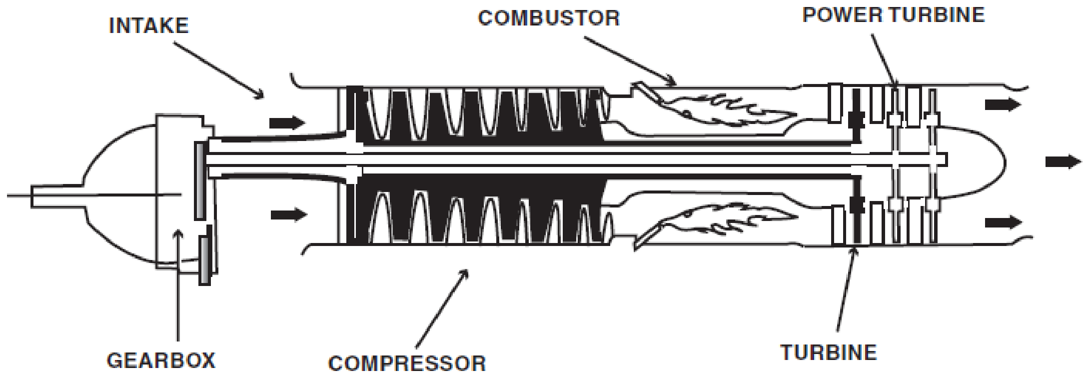


How Does a Turboprop Work?

- Many small commuter aircraft use turboprop engines that have a gas turbine core to turn a propeller. As mentioned previously, propeller engines develop thrust by moving a large mass of air through a small change in velocity.
- Propellers are very efficient and can use nearly any kind of engine (including humans!) to turn the propeller. There are two main parts to a turboprop propulsion system: the core engine and the propeller.
- The core is very similar to a basic turbojet except that instead of expanding all the hot exhaust gases through the nozzle to produce thrust, most of the exhaust energy is used to turn the turbine. There may be an additional turbine stage present, which is connected to a driveshaft.
- The shaft drives the propeller through gear connections and produces most of the thrust. The exhaust velocity of a turboprop is low and contributes a small amount of thrust since most of the energy of the core exhaust has gone into turning the driveshaft.
- The thrust of a turboprop is the sum of the thrust of the propeller and the thrust of the core. We can use our basic thrust equation on the propeller and core to obtain the thrust equation for the turboprop.

- As we have noted above, the mass flow through the propeller is much greater than the mass flow through the core engine. And we have also noted that the exhaust velocity of the core is low and almost equal to the velocity into the core.
- The mass flow rate exiting the core is almost equal to the mass into the core. Comparing with the pure propeller theory, the thrust is equal to the mass flow through the propeller times the velocity change across the propeller plus a smaller amount of thrust from the core engine.
- Because propellers become less efficient as the speed of the aircraft increases, turboprops are only used for low-speed aircraft. A variation of the turboprop engine is the turbo shaft engine.
- In a turbo shaft engine, the gearbox is not connected to a propeller but to some other drive device.
- Many helicopters use turbo shaft engines, as well as tanks, boats, and even some old race cars.

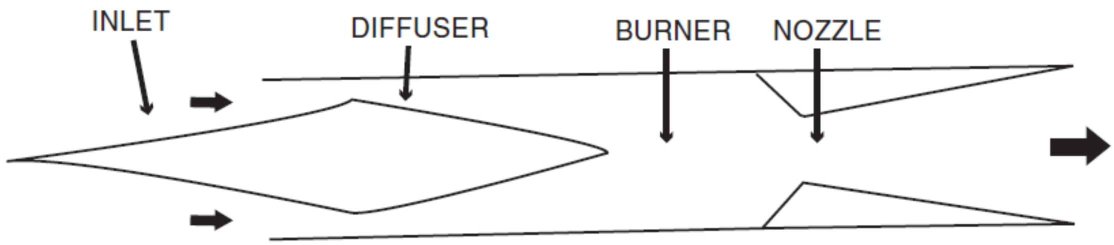
Turboprop engine schematic.



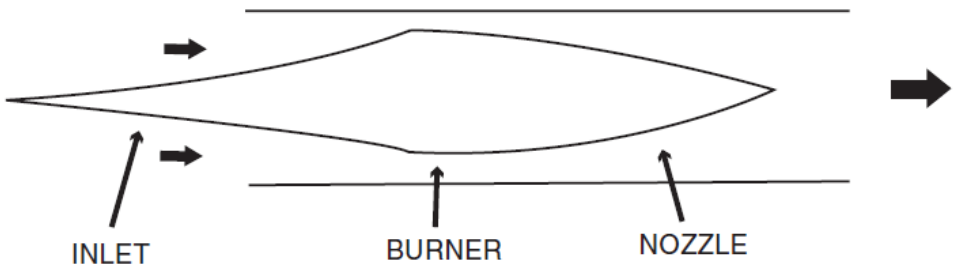
How Do Ramjets Work?

- A ramjet is a very different engine design from a gas turbine engine since it has no moving parts. It achieves compression of intake air by the actual forward speed of the aircraft.
- Air entering the intake of a supersonic aircraft is slowed by aerodynamic diffusion created by the inlet and a diffuser to velocities comparable to those in a turbojet afterburner.
- The expansion of hot gases after fuel injection and combustion accelerates the exhaust air to a velocity higher than that at the inlet, thus creating positive forward thrust.
- The name scramjet is an acronym for supersonic combustion ramjet.
- The scramjet differs from the ramjet in that combustion takes place at supersonic air velocities through the engine.
- It is a simple, elegant physical design, but vastly more complicated aerodynamically than a jet engine.
- Hydrogen is usually the fuel used in the burner.

Ramjet engine schematic.



Supersonic combustion ramjet (Scramjet) engine schematic.



Rocket engines in brief:

- A rocket in its simplest form is a chamber enclosing a gas under pressure. A small opening at one end of the chamber allows the gas to escape, and in doing so it provides a thrust that propels the rocket in the opposite direction.
- Think of the example of a balloon. Air inside a balloon is compressed by the balloon’s rubber walls. The air pushes back so that the forces on each side are balanced.
- When the nozzle is released, air escapes through it and the balloon is propelled in the opposite direction. For spacecraft, the gas is produced by burning propellants that can be solid or liquid in form or a combination of the two.
- All three of Newton’s axioms of mechanics are applicable to rocket flight. The second and third laws have already been stated in this chapter, and the first law states that every particle persists in a state of rest or of uniform motion in a straight line unless acted on by a force.
- When a rocket is at rest, then the forces on it are balanced. It takes an external force to unbalance the forces and make the object move.
- If the object is already moving, it takes such a force to stop it, change its direction from a straight-line path, or alter its speed.
- In rocket flight, forces become balanced and unbalanced all the time. A rocket on the launch pad is balanced.
- The surface of the pad pushes the rocket up while the gravitational acceleration pulls it toward the center of Earth. As the engines are ignited, the thrust from the rocket unbalances the forces, and the rocket travels upward. Later, when the rocket runs out of fuel, it slows down, stops at the highest point of its flight, then falls back to Earth.

- Applying Newton’s second law to rocket flight highlights the pressure differential created by the controlled explosion inside the rocket’s engines as extreme thrust propels the rocket skyward. That pressure accelerates the gas one-way and the rocket the other.
- The thrust for the rocket continues as long as its engines are firing. Because propellant is burned, the mass of the rocket changes during flight.
- Rocket components include engines, payload, control system, propellant tanks, and propellants. By far, the largest contributor to the rocket’s mass is the propellant.
- Newton’s second law of motion is especially useful for designing efficient rockets. For a rocket to climb into low Earth orbit, it must achieve a speed in excess of 28,000 km/h.
- A speed of over 40,250 km/h, called the escape velocity, enables a rocket to leave Earth and travel out into deep space. Attaining spaceflight speeds require the rocket engine to achieve the greatest thrust possible in the shortest time.
- In other words, the engine must burn a large mass of fuel and push the resulting gas out of the engine as rapidly as possible.
- Newton’s second law of motion can be restated in the following way: The greater the mass of rocket fuel burned, and the faster the gas produced can escape the engine, the greater the upward thrust of the rocket.
- Newton’s third law of action–reaction also applies to rocket flight, as mentioned previously. A rocket can lift off from a launch pad only when it expels gas from its engine.
- The rocket pushes on the gas, and the gas in turn pushes on the rocket. With rockets, the action is the expulsion of gas from the engine.
- The reaction is the movement of the rocket in the opposite direction. To enable a rocket to lift off from the launch pad, the action, or thrust, from the engine must be greater than the mass of the rocket.
- In space, however, even tiny thrusts will cause the rocket to change direction. An unbalanced force must be exerted for a rocket to lift off from a launch pad or for a craft in space to change speed or direction (first law).
- The amount of thrust (force) produced by a rocket engine will be determined by the mass of rocket fuel that is burned and how fast the gas escapes the rocket (second law).
- The reaction, or motion, of the rocket is equal to and in the opposite direction of the action, or thrust, from the engine (third law).

UNIT-V
SATELLITE SYSTEMS ENGINEERING HUMAN SPACE EXPLORATION

Satellite Mission:

- We define a satellite in general terms to be any human-made craft or vehicle in a space orbit.
- In space exploration, this permits the study of distant celestial bodies such as the planets of the solar system
- In Earth orbit, satellites provide humans with one key benefit— altitude. The use of a satellite's altitude is the primary reason we place satellites into Earth orbit, thereby gaining a wide view of Earth. Satellite missions serve many purposes, but can generally be divided into four main categories:
    - Scientific
    - Military and national security
    - Civil
    - Commercial

Scientific:

- These are typically government-funded missions assembled and operated by consortia from universities, industry, and national space administrations.
- The primary role of these missions is to provide answers to questions; for example, the Lunar Prospector mission's primary function was to determine if there was ice on the lunar polar caps. (Yes, there is!)

Military and National Security:

- Military and national security missions are conducted with the intent to protect, monitor, and learn about world situations pertinent to the security of a nation.
- These missions involve early-warning satellites, communications satellites, and reconnaissance satellites that are used to learn about what is occurring in other countries, such as weapons stockpiling and troop movements.
- This information is captured as visual imagery or intercepted communications. Once analyzed, the data are used to warn the communities that are affected by the situation, to plan countermeasures, and to document the events for publicity to the world at large.

Civil:

- Civil satellites have the primary function of supporting the well-being of humans, either directly or indirectly.
- These satellites are usually government funded, and they provide information that is critical for helping society.

National weather satellites:

- Satellites monitor Earth’s weather (Meteorologists monitor and disseminate weather information that can be vital for emergencies, such as approaching hurricanes, or equally vital for farmers who need to be warned of flooding or frosts that may damage crops.

Commercial:

- Telecommunications satellites - Commercial satellites are ordered by companies who wish to offer a service for a fee.
- In the case of a telecommunications satellite, a service provider orders a satellite that is capable of routing a given amount of information at a predetermined rate.
- For example, current commercial capabilities for satellite data routing are on the order of 1 to 3.2 gigabits per second (Gbps) and entail a process known as trunking–uplink–downlink.
- Data are routed through ground (called trunking), to a major switch and transmitter that pack and then send the information to the satellite (uplink), which then transmits the information down to another switch elsewhere in the world (downlink), and then data are sent via terrestrial lines to the end destination.
- The advent of low earth orbit (LEO) and medium earth orbit (MEO) communication constellations aimed at providing global coverage for handsets that communicate directly via satellites, to omit the trunking activity, thus providing point-to-point communication capabilities virtually anywhere on Earth with a single telephone number.

An operational Satellite system:

- Once a Satellite is launched and placed into an orbit, there are several necessary interactive components for operating a satellite mission.
- The five main system components include the

1) Satellite Ground station
2) Command and Control Center Data storage
3) System Data Analysis and Distribution Center

- Last 4 are typically housed in one facility.

Ground Station:

- It will receive data from the Satellite and transmit data to the Satellite.
- Downlink provides data on the “health” of the satellite, or how well its subsystems are operating, and the mission data that are collected from the onboard payload to the Ground Control.
- The uplink provides ground controllers with the capability to send command information to the satellite to perform certain functions such as orbit changes, equipment resets, or even modification of the onboard control software.

- In the case of telecommunications satellites, the payload is essentially a large number of receivers and transmitters that receive and retransmit data as their sole function, continuously up linking and down linking data.

Command and Control Center:

- The command and control center is the center for satellite operations. The down linked operational information is reviewed and analyzed in this center, and consequently decisions are made about any necessary changes to the satellite's operational parameters (i.e., orbit, inclination).
- Likewise, some satellites have multiple missions that require several changes in orbit and operational configuration throughout their lifetimes. In both cases; the command and control center issues uplink commands to make necessary changes.

Data Storage System:

- The data storage center is the main storehouse of down linked information.
- This usually constitutes some form of electronic mass-data storage medium that is a repository for the health data of the satellite and the unprocessed payload data (essentially streams of bits) generated by payloads (i.e., imagery, measurements).
- Over time, the data storage has progressed from print and magnetic-tape systems to more advanced optical drive and optical tape storage devices.
- If one considers a satellite with a sensor that takes 8 bit data (a number between 1 and 255), sampling at a rate of 10 Hz (10 times per second) for 1 year, you acquire approximately 2.5 Gbits of data, as you can see:
- If you decide to use high-resolution 32 bit data and create an array of 100 sensors, this number increases to 1 terabit (Tbit) (1012 bits) of stored information every year!

Data analysis and distribution center:

- The data analysis and distribution center is responsible for processing the raw down linked data into some form of interpretable information.
- In the case of many remote-sensing satellites, high-spatial-resolution data (10 m resolution) are converted to images used for city or regional planning.
- The final images are then digitally archived, allowing the original raw data to be destroyed. However, in the case of some scientific missions, the raw data are kept for many years to allow multiple researchers to investigate the information.
- This places a significant requirement on the type of storage medium used in the data storage centers, especially as some forms of data storage are prone to time-induced data loss (i.e., magnetic tapes that can demagnetize over time) and media storage technologies are likely to significantly change about 10 times during a 20 year archival span.
- As a result, the data may be well archived, but the means to access them will no longer exist.

Elements of a Satellite:

- There are 3 main elements in a Satellite system. Payload, Bus and Launch vehicle Adapter assembly.

Payload:

- The payload is defined as the equipment that performs the satellite mission function.
- For example, a telecommunication satellite's payload would be defined as the equipment that receives, processes, and transmits communication data.

Bus:

- The satellite bus is defined as the systems and structure within the satellite, which provide functions to allow the payload to perform its intended mission.
- This includes providing power, thermal protection, stability, and orbital control so the payload performs within its design limits.

Launch vehicle Adapter assembly:

- It acts as the interface between the satellite bus and the launch vehicle that boosts the satellite into orbit.
- The launch vehicle adapter assembly acts as the interface between the satellite bus and the launch vehicle that boosts the satellite into orbit. The adapter assembly is typically custom-designed for individual types of satellites.
- The launch vehicle provider issues a payload interface document describing how and where the satellite can be attached to the launch vehicle. Some launch vehicle companies retain design ownership of the adapter assembly.
- The satellite designer plans according to three budgets: the mass budget, the power budget, and the cost budget.
- The mass budget is the primary concern, since the satellite can only be launched by existing launch vehicles, all of which have a limit on the amount of mass they can place into orbit.
- The power budget is the next most important, as power is required to maintain and operate the satellite once on orbit. Finally, the satellite cost budget must be maintained.
- A good satellite design meets all three budgetary requirements.

Satellite Bus System

- There are two design philosophies used in satellite configuration and design, namely, spin-stabilized satellites and 3-axis stabilized satellites. The former uses the angular momentum of the rotating satellite to maintain stability and control, while the latter maintains a stable platform using large momentum wheels and onboard thrusters for stability and control.
- A satellite bus is typically composed of the following systems.

1) Structures and mechanisms.
2) Power.

3) Communications and Telemetry.
4) Thermal control.
5) Attitude determination and control. Propulsion and station keeping.

- Satellites total weight is distributed as follows in %.
- The various structures must be strong enough to withstand launch forces, be of minimal mass, and provide damping to avoid structural oscillations while in orbit.
- Usually composed of two energy systems, namely,
- Short term energy system - used for prelaunch and initial orbit acquisition activities.
- Long term energy system - functions throughout the satellite's operational life.
- Communications and Telemetry subsystem orchestrates the flow of data between onboard subsystem components and between the satellite and the ground station. This subsystem is typically composed of the communications portion, and the telemetry, tracking, and control (TT&C) portion.
- The communications and telemetry subsystem handles data flow between all the satellite subsystems reports operational status, sends payload data to the ground station, and receives uplinked commands from ground controllers.

Thermal control subsystem:

- Responsible for maintaining the components of the satellite within operational temperature limits.
- Accomplished via passive methods, such as reflection and radiation, or active methods that involve on-board heat exchangers and mechanically activated deflectors.

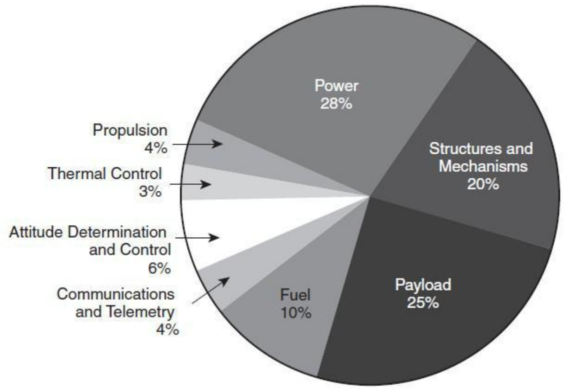
Attitude determination and control subsystem (ADCS):

- Maintains pointing accuracy of satellite by controlling the motion of the satellite in any of the pitch, roll, or yaw axes
- The required orbital pointing accuracy is primarily determined by the mission requirements of the payload, but may be influenced by the type of antenna used in the satellite design.
- Both active and passive attitude controls are available, and sometimes a combination of both is implemented.

Propulsion and station-keeping:

- To keep the satellite in its intended orbit
- It can also perform desired orbital changes as dictated by the mission.
- The subsystem is usually composed of thrusters and a source of fuel and oxidizer, or liquefied gas, whose limited volume usually determines the duration of the mission.
- Although the electrical systems of a satellite may continue to function long after the station-keeping fuel has run out, the mission will most likely be unable to continue due to the subsequent orbit degradation and loss of satellite control.

Figure 10.1 | Satellite mass as represented by percentage of the overall design [41].



Structures, Mechanisms and Materials:

- Satellite structures to support all spacecraft subsystem components
- Provide mechanism for attaching the satellite to the launch vehicle.
- Materials must meet the strength and stiffness requirements necessary to survive the launch environment and on-orbit operational environment.
- High linear accelerations due to the vehicle acceleration (3 to 12 G's sustained). Shocks from stage separations and stage firings (2,000 G's).
- Acoustically induced vibration from engine sound pressure waves reflecting off the launch pad structure (140 dB at 0 to 20,000 Hz).
- High-energy structural vibrations from any of the above sources that excite the natural frequency of structural members in the launch vehicle and are transmitted to the satellite being launched.
- The launch loads require structures to be sized and designed to avoid structural failure. The on-orbit loads are much smaller than the launch loads, but are equally important since structural stiffness is typically needed to ensure normal satellite operations.
- On Orbit loads are created by:
- Internal motion of momentum wheels and gyroscopes.
- Attitude control adjustments.
- Mechanism deployment (i.e., solar arrays).
- Thermal stresses.
- Primary structures carry the major loads on a satellite and are considered mission-critical (i.e., they cannot be allowed to fail).
- Secondary structures have non-mission-critical roles of supporting small components (5 kg) whose failure will not necessarily lead to the failure of the entire satellite or mission.
- Structural designers normally use a factor of safety of 1.5 times the yield stress of the material as a design limit.
- When choosing materials for structures, one must be wary of the space environment. Historically, aluminum has been the design material of choice for satellite structures—it is lightweight, can be alloyed and heat-treated for stiffness, is relatively nonreactive (chemically), is readily available, is cheap, and is easy to work with.

- Composite materials might offer greater stiffness with a lighter mass, but they are more costly and suffer from material degradation in space caused by the out gassing of trapped gases in the matrix materials.
- Additionally, composites are poor thermal conductors and do not facilitate heat dissipation from on-board electronics.
- As satellite designs progress in the future, the trend will be toward materials of high specific stiffness and specific strength that meet the cost and longevity requirements associated with satellite mission requirements.

Power Systems:

- Three main functions:

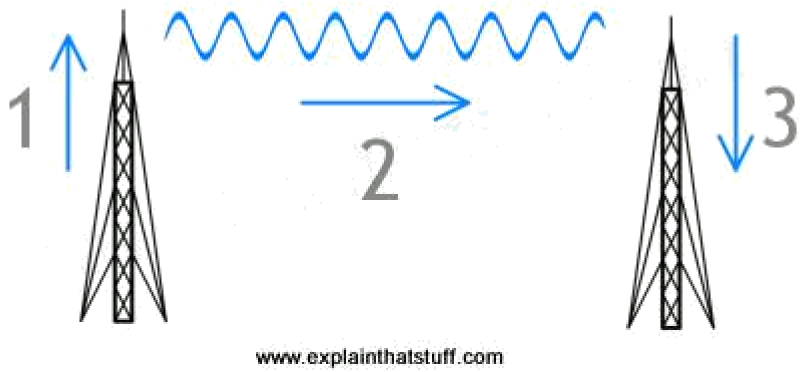
1) Provide/produce energy;
2) Store energy;
3) Regulate, distribute, and control power flow

- Average solar flux is 1,358 W/m^2. Solar panels can provide energy conversion efficiencies of 14 percent (silicon) to 18 percent (gallium arsenide)of the local radiant solar power.
- This translates to 190 to 240 W/m^2, of solar panel under direct solar light (i.e., perpendicular to the sun's incident radiation).
- However, as satellites travel deeper into the solar system, the available solar energy flux decreases with the square of the distance from the Sun, resulting in insufficient energy density to power satellites.
- For these missions, nuclear isotope-based energy sources are used.
- Power is available from two sources, primary sources and secondary sources.
- Primary sources provide energy for the duration of the mission (i.e., solar cells for Earth orbit).
- Secondary power sources are used for short duration power requirements, such as from the time a satellite is launched until the solar panels are deployed and operational.
- Secondary power sources usually consist of some form of battery.
- The spacecraft designer must keep a power budget of all onboard systems. This sets the preliminary size of the power system.
- For solar panels, the end-of life efficiency of the cells must be used in the calculation, since the efficiency of the cells decreases several percent over a 5 to 10 year period in orbit.
- For silicon solar cells this results in a power production decrease of between 2.5 and 3.5 percent per year.
- Additionally, a power margin must be built in since there can be peak loads that need to be covered above and beyond nominal loads.
- Some of this peak loading can be provided by batteries that are charged by the panels during off-peak periods.
- These batteries will eventually be needed to supply all the power during periods of eclipse for solar-powered satellite.

Communication and Telemetry:

1) The operation of a satellite requires knowing a satellite's location in space (tracking),
2) The health of the onboard subsystems and payload (telemetry),
3) An ability to tell the satellite what to do (control).

- All these procedures require some form of communication between the satellite and a ground station



Parts of this communication / Telemetry:

- Fundamentally there are two parts of this engagement of communication: there must be a transmitter at one end of the link and a receiver at the other.

- Imagine holding out your hand and catching words, pictures, and information passing by.
- That's more or less what an antenna (sometimes called an aerial) does: it's the metal rod or dish that catches radio waves and turns them into electrical signals feeding into something like a radio or television or a telephone system.
- Antennas like this are sometimes called receivers. A transmitter is a different kind of antenna that does the opposite job to a receiver: it turns electrical signals into radio waves so they can

travel sometimes thousands of kilometers around the Earth or even into space and back. Antennas and transmitters are the key to virtually all forms of modern telecommunication. Let's take a closer look at what they are and how they work.

How Antennas work?

- Suppose you're the boss of a radio station and you want to transmit your programs to the wider world. How do you go about it? You use microphones to capture the sounds of people's voices and turn them into electrical energy.
- You take that electricity and, loosely speaking, make it flow along a tall metal antenna (boosting it in power many times so it will travel just as far as you need into the world). As the electrons (tiny particles inside atoms) in the electric current wiggle back and forth along the antenna, they create invisible electromagnetic radiation in the form of radio waves.
- These waves travel out at the speed of light, taking your radio program with them. What happens when I turn on my radio in my home a few miles away? The radio waves you sent flow through the metal antenna and cause electrons to wiggle back and forth. That generates an electric current —a signal that the electronic components inside my radio turn back into sound I can hear.

Artwork:

- How a transmitter sends radio waves to a receiver.

1) Electricity flowing into the transmitter antenna makes electrons vibrate up and down it, producing radio waves.
2) The radio waves travel through the air at the speed of light.
3) When the waves arrive at the receiver antenna, they make electrons vibrate inside it. This produces an electric current that recreates the original signal.

- An antenna radiates energy that dissipates as you go farther from the antenna. Everyone has experienced this phenomenon when listening to a radio—it is louder if you sit closer to the speakers and gets quieter as you moves away from the speakers.
- Although the radio is still using the same amount of energy and outputting the same power level, the sound appears louder as you get closer, because the power in the sound waves has only filled a small volume of space.
- As you move farther away, the volume that the sound fills increases and these results in a lower power density (watts per square meter) at your new position
- The same is true for transmitters and antennas: The power density decreases as you move away from the source.
- The simplest design is an Omni directional transmitter or antenna, like you have on a car. This type of transmitter sends signals out in all directions, creating a propagating sphere of energy. The power of the signal at any given point is thus proportional to the inverse of the square of the distance (directly related to the surface area of the sphere).

- The antenna requires a signal that is powerful enough to be recognized by the electronics that decode the signal. Thus orbital altitude can be used to determine how much power is required at a minimum for sizing the communications system.
- Antenna design has moved a long way from the simple omni directional antenna. Parabolic dishes and phased-array antennas can direct the communications signal energy and result in all the energy being focused in a given direction (show fig. 10.3). This is called gain.
- Gain is a measure of a transmitter's or antenna's power density compared to an omni directional design.

Other points:

- Telemetry data are multiplexed into a single stream that contains subsystem information, including component temperatures, bus voltages, battery supplies, and attitude parameters.
- Synchronization and reference codes are included in the data stream to allow the receiver to sort and report the data to a ground station controller.
- The satellite control functions are used to tell the satellite what to do (e.g., change orbit, point in a new direction). Based on the telemetry data of all the subsystems and payload, the ground station operators monitor the satellite and determine if operational corrections need to be made.
- Control transmission rates are typically very low, on the order of hundreds to thousands of bits per second when transmitting.
- Satellite payloads often have higher communication rate requirements than telemetry and command, and are thus the driving design parameter for the communication system. For example, an Earth imagery satellite that scans an area of 10,000 km2 with 5 meter resolution (i.e., 1 pixel sees 25 m2) in a 2 min time frame needs to transmit at a rate of about 3 Mbps (3 x106 bps). Thus a communications bandwidth of at least 3 Mbps is required by the satellite.

Thermal Control:

Purpose:

- Satellite thermal design is necessary to ensure that onboard satellite components operate within tolerable temperature limits and that structural components not bend beyond acceptable limits or even fail due to thermal stresses.
- In space, there are four primary heat sources for satellites,

1. Direct solar heating
2. Reflected solar energy from Earth's albedo
3. Earth's infra-red energy
4. Onboard sources (i.e., electronics).

- The only way to dissipate heat from a satellite is by radiating heat away from the satellite, as there is no atmosphere in space for convective cooling.
- On board the satellite, heat is transported via conduction between elements, heat pipes that use a working fluid, and internal radiation.

- The thermal designer must utilize arrangements of materials, coatings, and heat conduits on board satellites to maintain the components within their operating limits. In some cases heaters must also be added to maintain temperatures within acceptable limits.
- All materials have the ability to absorb, reflect, and emit certain amounts of thermal energy. The absorptive α and emissivity of a surface are the fractions of energy emitted or absorbed compared to a perfect black body. Materials that absorb a large amount of heat are said to have high absorptive.
- Likewise, materials that have the ability to radiate a large amount of energy are said to have high emissivity. Examples of material properties used in satellite applications

Selected satellite material emissivities and absorptivities

Material	Emissivity ε	Absorptivity α
Aluminum	0.38	0.035
Gold	0.30	0.023
Titanium	0.77	0.47
White paint	0.25	0.85
Black paint	0.98	0.87
Aluminized Teflon	0.16	0.80

- The only practical way to expel heat from a satellite is via radiation. Radiation is a function of the object temperature to the fourth power; and the total emitted, or radiated; power emitted from a body was given in Equation and can be written as

Table 10.2 | Design temperature ranges for satellite components [41]

Satellite component	Temperature range (K)	Temperature range (°C)
Electronics	273–313	0–40
Batteries	278–293	5–20
Solar arrays	173–373	−100–100
Liquid propellant	280–308	7–35
Structural elements	228–338	−45–65
Infrared sensors	73–193	−200–−80

$$P_{emitted} = A_{rad}\varepsilon\sigma T^4$$

where

$P_{emitted}$ = total radiated power, W

A_{rad} = surface area of radiator, m^2

ε = emissivity of radiator (no units)

σ = Stefan–Boltzmann constant = 5.669×10^{-8} W/($m^2 \cdot K^4$)

T = surface temperature of radiator, K

- To design and analyze the thermal control capability of any satellite, the process begins by setting the sum of the heat inputs equal to the sum of the heat outputs and calculating the steady-state temperature.
- Material properties and component locations must be continuously iterated until overall operating temperatures are met.

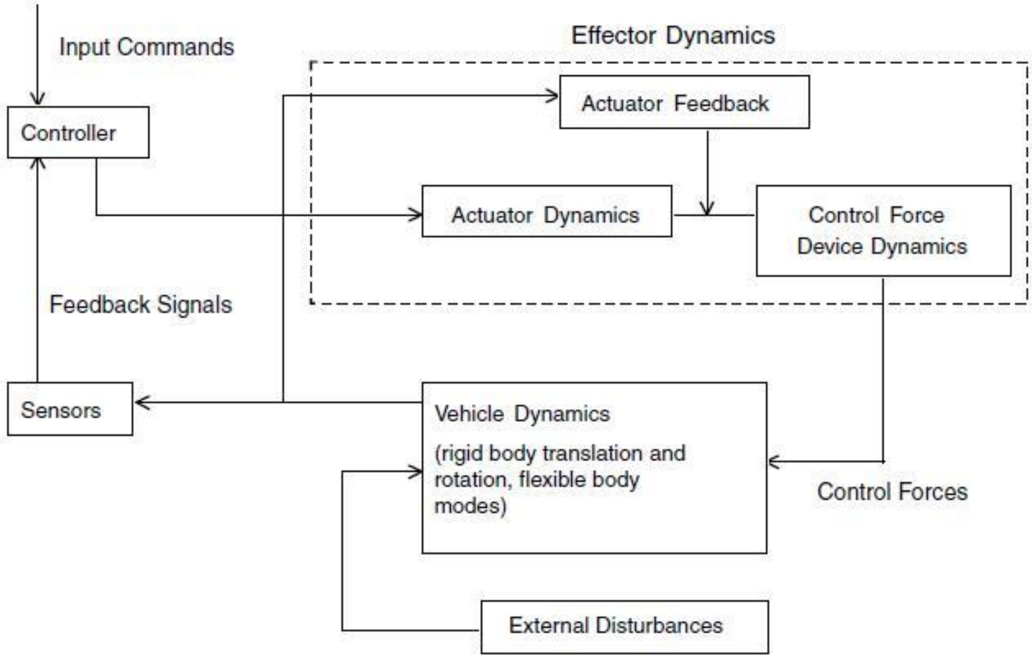
Attitude determination and Control:

- Spacecraft are continuously subjected to perturbation torques while in orbit. Onboard torques can be caused by the motion of mechanisms, momentum wheels, or the firing of thrusters.
- External torques are produced by Earth's gravity gradient, interaction with Earth's magnetic field, solar radiation pressure, thermally induced flexure in satellite structures, and aerodynamic drag in LEO.
- It is the job of the attitude determination and control subsystem (ADCS) to measure and counter these perturbations to ensure the spacecraft can perform its mission.
- These adjustments include maintaining orbital position and satellite pointing accuracy.
- The ADCS requires four main elements to function,

1. A reference from which to take measurements
2. A sensor
3. A controller
4. An actuator.

- First, references must be selected for pointing knowledge. Second, a series of sensors observe the references, allowing for determination of position and relative attitude with respect to the reference.
- Based on the position and attitude, the controller determines the difference between the actual and the desired position and attitude.
- Using mathematical models of the dynamics of the spacecraft, the controller sends command signals to actuators that act to restore the satellite to its desired position and attitude.

Figure 10.6 | Attitude determination and control subsystem block diagram.



- Five major references are typically used in satellite design

1. Sun
2. Earth
3. Earth's magnetic field
4. Stars and planets
5. Inertial sensors (gyroscopes).

- Optical Sun sensors require relatively little power and are lightweight. However, satellites in LEO can lose the Sun reference if eclipsed. Additionally, the Sun only provides measurement about two independent axes.
- Earth is an excellent reference for Earth-orbiting satellites as it is close and bright. Earth sensors scan to detect the horizon, the boundary between the blackness of space and the brightness of Earth.
- Earth sensors must be protected from sunlight as they are more sensitive. The Earth's magnetic field works well for low-altitude missions.
- The sensors measure alignment of the magnetic field with respect to the satellite-centric coordinate frame. The sensors are low-weight and low-power, but require that the satellite be magnetically clean.
- The intensity of Earth's magnetic field decreases with the cube of the distance from Earth, and thus becomes very small at geostationary orbits. As such, magnetic sensors work better in lower orbits.
- Stars and planets (other than the Sun and Earth) are by far the most accurate references, providing pointing reference of up to 0.0008° as measured by star sensors .

- However, star sensors are heavy, complex sensors that require Sun protection and take periodic readings. The sensor takes a snapshot of its surrounding field of view and matches the image to an electronic database of star maps.
- The only satellite-based reference is an inertial measurement unit (IMU). The motion of the satellite can be measured with respect to a stabilized gyroscopic unit carried onboard. These are available for almost any mission; however, the drift of the gyroscope associated with friction losses in the spinning mechanisms results in increasing measurement errors over time.
- Thus, the IMU needs to be regularly updated (or reset) from other onboard sensors. Although accurate over short periods of time, IMUs require strict manufacturing quality control and may need to be carried in redundant configurations to ensure mission reliability.
- There is an expectation from some that the global positioning (satellite) system (GPS) might provide a reliable reference.
- Currently, experiments are being flown to characterize GPS signal quality in LEO to determine if GPS can be used as a reference for on-orbit satellite position and attitude determination.
- Once the satellite's attitude has been determined, the control processor determines the necessary orientation changes that the satellite must make to be within operational tolerances, and sends control commands to actuators to make the orientation changes.
- These orientation changes are made by thrusters, magnetic torquers, and/or momentum wheels. Magnetic torquers are simply electromagnets, or wound magnetic coils, that generate a magnetic dipole moment.
- A magnetic torque produces a torque that is perpendicular and proportional to Earth's varying magnetic field. A magnetometer is used to sense the magnetic field, and a wire-wrapped metal rod in each axis is used to create a torque on the satellite.
- At higher orbits (1,000 km) magnetic torques become less effective due to the diminishing strength of Earth's magnetic field. Although small, magnetic torques offer the advantage of no moving parts, no fuel, and relative simplicity of design, integration, and testing.
- Reaction wheels are torque motors that have high-inertia rotors.
- The spinning of the rotor in either direction provides one axis of control for the satellite. (Note: For every action there is an equal and opposite reaction; thus, if you spin a high-inertia rotor clockwise, the satellite begins to spin counterclockwise.)
- Momentum wheels are a class of reaction wheel that maintains a nominal spin rate to provide gyroscopic stiffness to the satellite in two axes, and pointing accuracy in a third axis with the use of a control motor on the wheel to slow it down or speed it up.
- To control a satellite's orientation about 3 axes, three wheels are required with non-coplanar spin axes. With no means of self-repair for mechanical systems on satellites, redundant wheels are often added to a satellite for reliability.
- Satellite geometry may ultimately result in the need for a combination of control devices to ensure pointing accuracy and system reliability.

Propulsion and Station Keeping:

- Once in orbit, the propulsion system provides a satellite with several operational roles given below:

Initial spin-up:

- It is performed on spin-stabilized satellites, whose large angular momentum is used to provide stability.
- The satellite must gain this angular momentum by being spun once it is placed in orbit. Offset thrusters are used to torque the satellite to rates typically ranging from 1 to 50 rpm.

Station keeping (North–South, East–West):

- Perturbations to the satellite orbit result in the satellite's moving from its optimal design orbit. Station keeping is performed to maintain orbital position and consumes the largest portion of on-orbit fuel.

Attitude control:

- Attitude control thrusters are much smaller and are fired for brief periods to affect small changes to a satellite's orientation.

Satellite orbit change:

- Satellite missions sometime require orbit changes. This may be driven by missions that require multiple orbits.
- The delta vee (v, change in satellite velocity vector) necessary for these maneuvers can consume substantial amounts of fuel.

Angular-momentum management:

- Momentum management is required when momentum wheels gain excessive energy from the satellite.
- This requires thrusters that fire and create an opposing torque on the satellite, allowing the excess energy in the momentum wheels to be dissipated.

Satellite end-of-life (EOL) disposal:

- EOL satellite disposal is becoming more and more critical with the increasing amount of orbital debris in space. Satellites are now being designed with an EOL disposal reserve of fuel so that they can be de orbited to burn up during reentry into Earth's atmosphere, or placed in non useful parking orbits.
- However, parking orbits for defunct satellites do not lessen the problem of orbital debris, but merely make the existing satellite's orbital slot available for use by another satellite at the end of its life.

- The propulsion system and fuel can account for up to 20 percent of the satellites mass. Onboard fuel storage capacity can limit a satellite's useful life to 7 to 10 years (although some satellites are being considered for longer on-orbit duration). The two classes of propulsion systems used are monopropellant (single liquid) and bipropellant (dual liquid, oxidation reaction). Monopropellant systems require a pressure vessel for storage of the liquid.
- Generally, monopropellant systems have low specific impulse [a measure of efficiency] but are much less complex than bipropellant systems. Conversely, bipropellant systems are more complex, requiring fuel and oxidizer storage tanks and a mixing and combustion chamber, but have a much higher specific impulse than monopropellant systems.
- This results in a much greater energy density per unit mass of propellant, which translates into more thrust than for a monopropellant system of comparable mass. The rocket equation is derived in the following section to enable analysis of satellite thrusters.

SPACE MISSION CASE STUDIES:

Four Satellite case studies:

- For different types of Satellites are considered as a case study. Scientific, military, civil, and commercial.
- Topex/Poseidon mission: a satellite dedicated to monitoring the global ocean circulation and improving global climate predictions (scientific, public).
- Landsat 7: remote-sensing satellite and instruments provide low-cost, multipurpose, land remote-sensing data for Earth with a focus on technology and images applicable for the next century (commercial, public).
- Thuraya system: a space-based telecommunication system that consists of two satellites in GEO offering mobile telephone services (commercial).
- The Magellan interplanetary spacecraft designed to reveal Venus's surface (volcanic lava flows, quake faults, and other features) through the planet's thick atmosphere (scientific, public).

Topex/Poseidon: An Oceanographic Mission:

- Topex/Poseidon is a joint mission of the National Aeronautics and Space Administration (NASA) and the French space agency, Centre National d'Etudes Spatiales (CNES).
- Its mission statement is to measure the precise shape of the ocean's surface and how this surface changes through time.
- This mission is of a scientific and public nature where scientists and engineers calculate ocean currents, identify climate trends, and improve weather forecasting models. More precisely, there are seven scientific goals of the mission:
- Make precise and accurate measurements of sea level worldwide.
- Determine the global ocean circulation and its change through time
- Understand ocean tides and the relationship between the ocean circulation and climate changes.
- Describe the nature of ocean dynamics.

- Compute how the heat, water mass, nutrients, and salt are transported in the oceans.
- Analyze the interaction between currents and waves.
- Understand how the oceans affect the atmosphere and world climate.
- These mission objectives led to the design of the Topex/Poseidon satellite, which encompasses two major components, namely, the satellite bus and the instrument module. The satellite bus design was taken from an existing multi-mission modular spacecraft (MMS), and it consists of four primary modules and two sub modules.
- The primary modules include the power, altitude control, command, and propulsion. Additional sub modules include an Earth sensor assembly module and the signal conditioning and control unit. The instrument module (IM), which is a large aluminum box attached to the MMS, consists of all the scientific sensors and systems required for data collection, communication, and solar power.
- The satellite was launched on August 10, 1992 on an Ariane 42P from the European Space Agency's Guiana Space Center located in Kourou, French Guiana. It orbits Earth at an altitude of 1,336 km (830 mi) with an inclination angle of 66° and a period of 112 min, carrying two altimeters.
- The satellite measures the height of the ocean at the same location every 10 days using two laser altimeters. Topex/Poseidon measures the satellite altitude above the sea surface while three independent satellite tracking systems measure the satellite's position, that is, the distance between the satellite and the center of Earth (geocenter).
- Then the altimetry measurements are subtracted from the satellite position, resulting in a precise height measurement of the ocean above the geo-center, which is the sea level.

Landsat 7:

- Is the last of a series of six satellites with the mission statement to Supply data users worldwide with low cost, multi-purpose, land remote sensing data into the next century? Landsat 7 carries a single instrument onboard called the ETM_ for Enhanced Thematic Mapper Plus.
- It is a passive sensor that measures solar radiation reflected or emitted by Earth. The instrument has eight bands sensitive to different wavelengths of visible and infrared radiation with a resolution ranging from 15 to 60 m. Landsat 7 was launched on April 1999 from the Western Test Range on a Delta-II launch vehicle. At launch, the satellite weighed approximately 2,200 kg (4,800 lb).
- The spacecraft is about 4.3 m (14 ft) in length and 2.8 m (9 ft) in diameter. It consists of a spacecraft bus and the ETM + instrument. The satellite orbits Earth at an altitude of 705 km (±5 km at the equator) in a Sun-synchronous polar orbit with an inclination of 98.2° ± 0.15°.

Thuraya:

- The Thuraya mobile telecommunications satellite system mission statement is to meet the need for affordable, high-quality mobile phone service in some of the world's most populous regions: the Middle East, North and Central Africa, Europe, Central Asia and the Indian subcontinent. The Thuraya system is a commercial endeavor of Hughes Space and Communications International consisting of two satellites (an operational and a spare).

- Thuraya's satellites have been designed to achieve a network capacity of about 13,750 telephone channels. The first satellite was launched in May 2000 and has been designed for a life span of 12 to 15 years. The system provides

- Voice telephone
- Fax.
- Data.
- Location Determination.
- Emergency services.
- High-power alerting.

Magellan: A Mission to Venus:

- Magellan spacecraft was launched on May 4, 1989, and arrived at Venus on August 10, 1990. The satellite mission objectives are to .Obtain near-global radar images of Venus's surface, with resolution equivalent to optical imaging of 1 km per line pair. Obtain a near-global topographic map with 50 km spatial and 100 m vertical resolution.
- Obtain near-global gravity field data with 700 km resolution. Develope an understanding of the geological structure of the planet, including its density distribution and dynamics. The Magellan spacecraft was built partially with spare parts from other missions, and it is 4.6 m (15.4 ft) long, topped with a 3.7 m (12 ft) high-gain antenna. Mated to its retrorocket and fully tanked with propellants, the spacecraft weighs a total of 3,460 kg (7,612 lb) at launch.

HUMAN SPACE EXPLORATION:

- Historical background & Space Flights Soviet Union / Russians – Have many firsts in human spaceflight under seven main programs.

- Sputnik
- Vostok
- Voskhod
- Soyuz (Soyuz and Kosmos launches)
- Lunar (Zond and Kosmos launches)
- Salyut
- Mir

- United States programs:

- Mercury
- Gemini
- Apollo
- Skylab
- Shuttle-Mir (denoted as phase I of ISS)
- Space Shuttle

- ISS Program

Mercury:

- First human space program for US.
- Initiated in 1958 and completed in 1963.
- Mercury program goal was to demonstrate that humans could survive in space.
- The objectives of the program, which culminated in six human spaceflights between 1961 and 1963, were
- To orbit a human-occupied spacecraft around Earth.
- To investigate a human's ability to function in space
- To recover both the crew and spacecraft safely
- First project so lot of new things had to be learned that we see is already in place today. Development of life support systems for operation under conditions of thermal extremes, acceleration, and microgravity.
- The primary biomedical findings were weight loss, mostly due to dehydration, and some impairment of cardiovascular function.
- Cardiovascular data from the final and longest Mercury flight showed post flight orthostatic intolerance, or dizziness upon return to Earth when standing.

Gemini:

- Project Gemini, the second U.S. human space program, was announced in January 1962. Gemini involved 12 flights, including two flight tests of the equipment without crew. Between March 1965 and November 1966, the United States flew 10 Gemini two-person spacecraft.
- The Gemini objectives were to .Demonstrate the feasibility of spaceflight lasting long enough to complete a lunar landing. Perfect the techniques and procedures for orbital rendezvous and docking of two spacecraft.
- Achieve precisely controlled reentry and landing capability. Establish capability in extravehicular activity.
- Enhance flight and ground crew proficiency .A major focus of the Gemini human medical investigations was evaluation of the changes in cardiovascular function noted in the Mercury program. New research such as bone mineral loss was noted.

Apollo:

- The Apollo program included a large number of un Crewed test missions and 11 human missions.
- The human missions included two Earth orbiting missions, two lunar orbiting missions, a lunar swing by, and six Moon landing missions.
- The Apollo program was designed to land humans on the Moon and bring them safely back to Earth. Six of the missions (Apollo's 11, 12, 14, 15, 16, and 17) achieved this goal.

- Lunar surface experiments included soil mechanics, meteoroids, seismic, heat flow, lunar ranging, magnetic fields, and solar wind experiments.
- Apollo's 7, which tested the Command Module, and 9, which tested both the Command Module and Lunar Module, were Earth orbiting missions.
- Apollo's 8 and 10 tested critical components while orbiting the Moon and returned photography of the lunar surface. Apollo 13 did not land on the lunar surface due to a life support system malfunction, but during the brief orbit around the Moon, the crew was able to collect photographs.
- Because the crew time and weight restrictions were very critical during the Apollo missions, only human investigations and science experiments requiring no or only small additional hardware items were flown, one example being a small container to measure the effects of radiation on biological samples. Overall, 21 life science experiments were conducted during the Apollo and Apollo-Soyuz programs. The Apollo biomedical program had three major goals:
- Ensure the safety and health of crew members (e.g., precautions for in-flight sickness because during a lunar mission no fast recovery was possible).Prevent contamination of Earth by extraterrestrial organisms.
- To ensure that unwanted microorganisms were not transported in either direction, strict quarantine and decontamination procedures were implemented before and after each mission.
- Study specific effects of human exposure to microgravity. The mission provided the opportunity to study more closely the cardiovascular and bone adaptations observed during the Mercury and Gemini programs. In addition, biology investigations were conducted, including studies of radiation effects.

Skylab:

- First experimental space station for US. Designed for long-duration mission, Skylab program objectives were: To prove that humans could live and work in space for extended periods and to expand our knowledge of solar astronomy well beyond Earth-based observations.
- Successful in all respects despite early mechanical difficulties, three- person crews occupied the Skylab workshop for a total of 171 days, 13 h. It was the site of nearly 300 scientific and technical experiments: medical experiments on humans' adaptability to microgravity, solar observations, and detailed Earth resources experiments. The empty Skylab spacecraft returned to Earth on July 11, 1979, scattering debris over the Indian Ocean and a bit of western Australia.

Apollo – Soyuz:

- Test rendezvous and docking systems that might be needed during international space-rescue missions conduct scientific experiments.
- The mission started with the Russian Soyuz launch on July 15, 1975, followed by the U.S. Apollo launch on the same day.

- Mission lasted 9 days, and docking in space of the two craft occurred on July 17 with the Soyuz and Apollo spacecraft docked for 2 days while the crews exchanged visits and conducted joint operations mission.

Medical Research:

- Biomedical analyses of skeletal muscle function in leg and arm muscles showed that the muscle dysfunction characteristics found after 59 days of microgravity exposure during the Skylab 3 mission were also present after 9 days of the ASTP mission.
- Short-term microgravity exposure also produced fatigue in muscle tissue, particularly in the antigravity muscles.

Space Shuttle:

- One of the most significant achievements as part of human space exploration World's first reusable space craft and the first U.S. vehicle having a standard sea-level atmospheric pressure and composition. Mercury, Gemini, and Apollo all operated at 33.4 kPa (5 lb/in2 or 0.33 atm) pressure and 100 percent oxygen composition.
- The capabilities of the Shuttle allow scientists to conduct experiments routinely to explore the effects of the space environment, particularly microgravity, on human physiology under conditions that cannot be duplicated on Earth.
- Shuttle-Mir investigated vital questions about the future of human life in space.
- Mir is a test site for three main areas of experience and investigation:
- Designing, building, and staffing the International Space Station.
- Participants drew from the experience and resources of many nations to learn how to work together and learn from one another.
- Mir offers a unique opportunity for long-duration data gathering. Station designers used Mir as a test site for space station hardware, materials, and construction methods.
- Mir crew members utilized the microgravity environment to conduct scientific investigations into biological and material studies.

Results from Shuttle-Mir Science Experiments:

- More than 100 investigations were conducted aboard Mir or during docked Space Shuttle operations.
- Repeat some Research investigations to validate long term effects which were performed for short term.
- A central theme of science investigations aboard the Mir was the study of the astronauts themselves and their responses to long periods in weightlessness.
- Researchers are able to better characterize human physiology and psychology in space, in particular, changes in bones and muscles, in the neuro vestibular system (responsible for human balance and orientation), and in the interactions among crew members and their ground support teams during a long mission.

- Researchers found that the rate of bone loss on the Mir, a chronic problem for space explorers, does not lessen over time, as previously thought.
- Astronauts average a 10-fold greater loss in bone mineral density in the lower hips and spine per month than when living on Earth.
- This has helped focus researchers on developing specific countermeasures.
- On the Space Shuttle, a previous series of experiments grew tissue cultures. Due to the effects of gravity, this type of research cannot be done on Earth.
- With access to Mir, the tissue growth work was extended from 10 days to 4 months with the successful culturing of cartilage cells in a device known as the bioreactor.
- The cartilage cells grew into a three-dimensional spherical structure more as tissue would grow in a living organism.
- This research holds tremendous promise in the future aboard the International Space Station, and the value of long-duration growth was validated aboard the Mir.
- For the first time in history, a complete natural cycle of plant growth has been accomplished in space. Seeds harvested from plants grown aboard Mir were in turn germinated and produced new plants—the first "seed-to-seed" experiment.

Case Study: ELDS – MIT

- One of the key missions of the International Space Station is to perform microgravity spaceflight experiments that investigate how astronauts move about in space as well as how they potentially disturb the spacecraft microgravity environment.
- While some microgravity experiments can be conducted fully automatically, many require astronauts to execute or supervise them.
- While the astronauts play a critical role in the success of experiments, we wanted to make sure that the experiments were not a significant disturbance source to the spacecraft acceleratory environment, and hence scientific research efforts.
- When astronauts move inside the cabin, they impart impulses and forces on the vehicle. External disturbances such as aerodynamic drag or solar pressure can be estimated quite easily from vehicle and environmental parameters.
- Similarly, disturbances inside the spacecraft due to the operation of mechanical equipment such as pumps and fans can be predicted.
- Astronaut-induced disturbances represent a far more challenging task to analyze due to the inherent randomness.
- Phase I of the International Space Station program provided the United States the opportunity to send astronauts to the Russian space station Mir and conduct long-duration spaceflight experiments. Seven U.S. astronauts stayed aboard Mir during Phase I.
- Within the framework of this program, the Massachusetts Institute of Technology **(M.I.T.)** conducted the enhanced dynamic load sensors (EDLS) experiment on Mir to quantify the disturbances to the microgravity environment due to the presence of astronauts. The experiment was designed with two objectives in mind.

- The primary objective was to assess nominal astronaut-induced forces and torques during long-duration space station missions.
- In other words, everyday activities and induced loads were measured with smart sensors, called restraints.
- The secondary objective of the research effort was to achieve a detailed understanding of how astronauts adapt their strategies for moving about in microgravity as they propel themselves with their hands and float from module to module.
- The experimental setup consisted of four load sensors and a specially designed computer. The sensors included an instrumented handhold, push-off pad, and two foot restraints, and provided the same functionality as the foot loops and handrails built into the Space Shuttle Orbiter and the Mir orbital complex for astronauts to secure themselves.
- The push-off pad's functionality was envisioned to be that of a flat surface the astronauts would use to push themselves off with either their hands or feet.
- The astronauts were instructed to activate the computer and go about their regular on-orbit activities.
- Whenever the computer detected that the measured forces and torques exceeded a specified threshold force, data were recorded on
- An examination of the NASA 2 and NASA 4 EDLS mission data led to the identification of several typical astronaut motions and the quantification of the associated load levels exerted on the spacecraft.
- For 2,806 astronaut activities recorded by the foot restraints and handhold sensor on Mir, the highest force magnitude was 137 N. For about 95 percent of the time the maximum force magnitude was below 60 N, and for about 99 percent of the time the maximum force magnitude was below 90 N.
- An analysis of the torques recorded showed that 99 percent of all events were less than 11 N -m, and the overall average moment was 2.35 N -m. The average momentum imparted by the astronauts on the Mir space station was 83±228 kg *m/s with 99 percent of all events having a total momentum of less than 600 kg*m/s.
- It can be concluded that expected astronaut-induced loads on the ISS from usual astronaut extravehicular activity are considerably less than previously thought and will not significantly disturb the ISS microgravity environment.
- These are very low forces when compared to typical Earth forces. Actually, they are an order of magnitude less. For example, every step you take, you exert 1 BW, or 510 N (for a 52 kg person).
- Imagine how many steps you take every day. Essentially, the data prove that the astronauts in microgravity adopt the appropriate strategy for their new weightless environment and use "finger push-offs" and "toe-offs" as they move about in space.

International Space Station

- The International Space Station will offer a world-class research laboratory in low Earth orbit. Once assembled, the ISS will afford scientists, engineers, and entrepreneurs an unprecedented platform on which to perform complex, long duration, and repeatable experiments in the unique environment of space.
- The ISS's invaluable assets include prolonged exposure to microgravity and the presence of human experimenters in the research process.
- The primary purposes for the ISS are to serve as:
- An advanced test bed for technology and human exploration.
- A world-class research facility.
- A commercial platform for space research and development.
- The governments of the United States, Canada, Europe,Japan, and Russia are collaborating with their commercial, academic, and other international affiliates in the design, operation, and utilization of the ISS.
- A summary of nine important engineering and scientific questions to be investigated on ISS includes these:
  - How did the universe, galaxies, stars, and planets form and evolve?
  - How does the Earth environment change over time, and what are the causes of these changes?
  - What is the role of gravity in the evolution, development, structure, and function of life-forms, and as a result of gravity, what are the life-forms' interactions with their environment?
  - What is required to ensure the health, safety, and productivity for humans living and working in space?
  - What technologies are best suited for long-duration missions of human space exploration?
  - What are the controlling mechanisms in the growth of cells, organisms, organs, and other biologically interesting structures?
  - What is the optimum relationship between the process used to form a material and its resultant properties, and how can we achieve this in space and on the ground?
  - How can the space environment help us obtain fundamental physical measurements of the highest accuracy?
  - What is the most effective energy conversion process involving combustion, and how can we achieve that? What are the fundamental forces affecting fluid behavior?

- Crew members on long-duration space missions fully adapt to space—sleep well, eat well, exercise regularly, etc. The completed ISS will be powered by almost an acre of solar panels and have a mass of almost 453,600 kg. (1 million lb.). The pressurized volume of the station will be roughly equivalent to the space inside two jumbo jets.
- The final ISS assembly mission is flight 16A where the U.S. habitation module is delivered to enhance crew accommodations and provide for a station crew with as many as seven members Future human exploration missions will require crew members to live and work productively for extended periods in space and on other planets.

- Key biomedical, life support, and human factors questions must be answered on the ISS to ensure crew health, well-being, and productivity for future exploration missions.

Extra Vehicular Activity:

- First Man - March 1965, cosmonaut Alexei Leonov - attached to a 5 m long umbilical that supplied him with air and communications, Leonov floated free of the Voskhod spacecraft for more than 10 min.
- Second Man - June of the same year, Edward White became the first U.S. astronaut to egress his spacecraft while in orbit.
- White performed his spectacular spacewalk during the third orbit of the Gemini–Titan 4 flight.
- EVA gained more importance during Apollo program as it was critical to function in space, rather than just carrying on experimental activity.
- Twelve crew members spent a total of 160 h in spacesuits on the moon, covering 100 km (60 mi) on foot and with the lunar rover, while collecting 2,196 soil and rock samples.
- The EVA spacesuits were pressurized to 26.2 kPa (3.9 lb/in2) with 100 percent oxygen, and the Apollo cabin pressure was 34.4 kPa (5 lb/in2) with 100 percent oxygen.
- During pre-launch, the Apollo cabin was maintained at 101.3 kPa (14.7 lb/in2) with a normal air (21 percent oxygen and 79 percent nitrogen) composition.
- Just before liftoff, the cabin was depressurized to 34.4 kPa (5 lb/in2). To counteract the risk of decompression sickness after this depressurization, the astronauts prebreathed 100 percent oxygen for 3 h prior to launch.
- Some examples of EVA:

Skylab Mission:

- The potential benefits of EVA were nowhere more evident than in the Skylab missions. When the crew first entered Skylab, the internal temperature was up to 71°C (160°F), rendering the spacecraft nearly uninhabitable.
- The extreme temperatures resulted from the loss of a portion of the vehicle’s outer skin as well as a lost solar panel.
- After failure of a second solar panel deployment and the consequent loss of power and cooling capability, astronauts Joseph Kerwin and Charles “Pete” Conrad salvaged the entire project by rigging a solar shade through the science airlock and freeing the remaining solar panel during EVA.
- The paramount flexibility offered by humans performing EVA to accomplish successful space missions, operations, and scientific endeavors was realized during Skylab.

Salyut 6 - Cosmonaut Georgi Grechko performed a critical EVA to examine the cone of the Salyut 6 docking unit that was thought to be damaged:

- Additional EVAs were performed during Salyut 6 in order to replace equipment and to return experimental equipment to Earth that had been subjected to solar radiation for 10 months.

Successful astronaut EVAs were performed to continue studying cosmic radiation and the methods and equipment for assembly of space structures.

- Ten EVAs were performed during the Salyut 7–Soyuz missions; experience and expertise in space construction, telemetry, and materials science were gained.

Svetlana Savitskaya - On 25 July 1984 during her second spaceflight:

- (Her first flight was in August 1982), cosmonaut Svetlana Savitskaya became the **first woman to perform an EVA**, during which she used a portable electron beam device to cut, weld, and solder metal plates.

Hubble Space Telescope:

- EVAs set numerous records during five consecutive days of EVA. Astronauts F. Story Musgrave (payload commander), Jeff Hoffman, Thomas Akers, and Kathryn Thornton replaced failed rate sensors (containing gyroscopes used to point Hubble precisely), electronic control units, solar arrays, Hubble's wide field/planetary camera, and a second set of corrective optics.

EVA with Ladder:

- An exciting EVA took place on 18 July 1990 when cosmonauts Alexander Balandin and Anatoly Solovyov exited the Mir space station and used a small ladder extended from the Kvant 2 module to the Soyuz TM-9capsule in order to repair the shield-vacuum heat insulation blankets.
- The ladder was employed in order to allow for maximum stability during the repairs.

Life Support Systems:

For life support in adverse situation what is needed?:

- Air (oxygen), water, food, and habitability as well as address the necessary physical factors that affect living in space, namely, thermal, pressure, vibration, noise, radiation, and gravitational requirements.
- Life support functions fall into two categories: non-regenerative (open loop) and regenerative (closed loop).
- In an open-loop LSS, matter continuously flows in and out of the system. Air, water, and oxygen are supplied from stored sources.
- The quantity of resources supplied equals the quantity of resources used.
- The advantage of open-loop LSS is that they are simple and use highly reliable technologies.
- The disadvantage is that resource requirements continue to increase linearly with duration of space mission and number of crew.
- Moving from a completely open LSS toward some closure might take on the following scenario - the initial supplies are from Earth, and then the non-useful waste products are processed in orbit to recover useful resources.

- The advantage of closed LSSs is a one-time-only transport of mass to orbit with minor resupply of irrecoverable losses.
- The disadvantages are that the technology is at a lower maturity level, and there are increased power and thermal requirements onboard the spacecraft. Closed-loop regenerative functions can be performed with physical chemical systems, which traditionally have been used.
- They are well understood and compact, require low maintenance, and have quick response times. The downside of physical chemical LSSs is that they consume a lot of energy (expensive to produce) and cannot replenish food stocks (they must still be resupplied), and solid wastes must be collected, pretreated, and stored.
- On the other hand, biological (or bioregenerative) LSSs are less well understood, but offer the potential to provide food during a space mission.
- Bioregenerative systems tend to have large volumes, are power- and maintenance-intensive, and have slow response times.
- This leads us to consider the design requirements between open and closed life support systems. Suggested design criteria to be evaluated include
- ➢ Relative cost of power, weight, and volume.
- ➢ Resupply capability.
- ➢ Crew size.
- ➢ Mission duration.
- The six major life support subsystems for a human mission are outlined, using the planned space station LSS as an example:
- Atmosphere control and supply
- ➢ O2N2 storage, distribution and resupply, venting, relief, and dumping O2N2 partial and total pressure control
- Atmosphere revitalization CO2 removal
- ➢ CO2 reduction O2 generation
- Trace chemical contamination control and monitoring
- Temperature and humidity control Air temperature control
- ➢ Thermal conditioning Humidity control
- Ventilation
- Equipment air cooling
- Airborne particulate and microbial control
- Water recovery and management Urine water recovery
- ➢ Wash water processing Potable water processing
- ➢ Water storage and distribution
- ➢ Water quality monitoring
- Waste management

  Fecal waste collection Processing and storage
- Fecal return waste storage and handling
- Fire detection and suppression

Normoxic:

- At sea level, with an O_2 concentration of 21 percent and a partial pressure of O_2 (ppO_2) of 21 kPa (158 mmHg, or 3.1 lb/in2), the respirable atmosphere is said to be normoxic (=normal oxygen concentration).

Hyperoxic:

- The same 21 percent is hypoxic (lack of oxygen) at altitude, where ppO_2 diminishes in step with total pressure, hyperoxic in hyperbaric atmospheres.
- Either of these conditions may be detrimental. Adverse physiological effects of such hypoxia include decreased night vision, impaired memory and coordination, unconsciousness, convulsions, and death of nerve tissue.
- These effects can begin within a few seconds of O_2 deprivation, depending on the degree of hypoxia, so an adequate O_2 supply is an essential design requirement.
- Airborne contaminant control is extremely important for long-duration missions since long-term exposure to even minute amounts of some chemicals can be harmful to people.
- On Earth many of these functions are performed by plants and microorganisms which transform CO_2 into O_2 via photosynthesis and purify air via other metabolic reactions. Evaporation from the oceans is the major process for purifying water, but plants also purify water via transpiration. Microorganisms are also important for purifying water by transforming contaminants into usable or benign forms.
- Biological life support systems based on these natural processes are being studied for space habitats, but they are not yet sufficiently well- defined or understood, so we rely on our understanding of physical and chemical processes to support human life away from Earth.
- On all U.S. missions to date, the O_2 has been supplied from tanks that carried sufficient O_2 for the duration of the mission.
- For longer-duration missions, the storage or resupply penalty is excessive, and some method of recovering O_2 from waste mass is required.
- For the International Space Station, the O_2 will initially be resupplied, but will later be generated by electrolysis of recovered wastewater.
- Other methods include electrolysis of water vapor and electrolysis of CO_2.
- There are also biological methods for generating O_2, including algae or other microorganisms and higher plants such as salad vegetables.