23AST101 - FUNDEMENTAL OF AEROSPACE ENGINEERING

NOTES

UNIT I: History of Flight:

Evolution of Flight-Usage of Balloons, dirigibles-Heavier than air aircraft:

Early Aviation period is from 1783 till 1915.

The development can be grouped as

- Balloons
- Derigibles
- Airships

Flying Vehicles can be broadly classified as

- Lighter-than-air aircraft
- Heavier-than-aircraft

Manned Flight began in France in 1783. Joseph and Etienne Montgolfier invented the "hot air Balloon"

From the balloon, came dirigibles, the addition of power and controls and other developments.

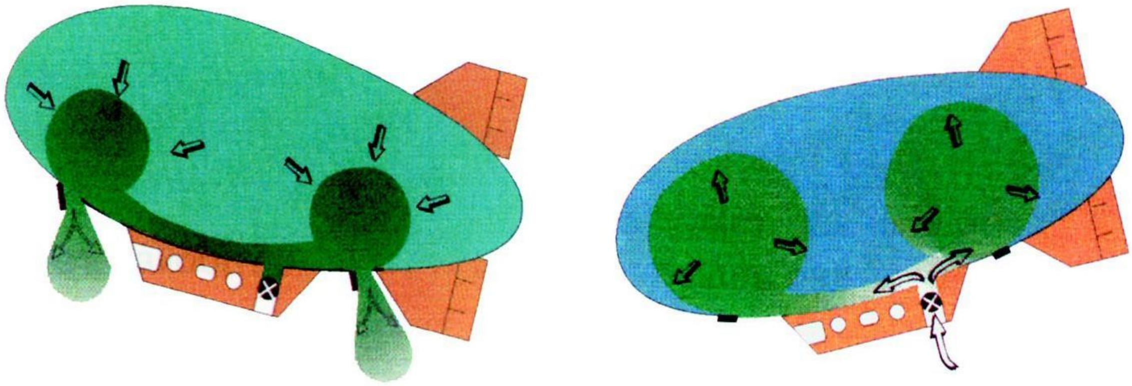
Lighter-than-aircraft: Montgolfier brothers built the first hot air balloon in Apr 1783.

Hot air balloons were very popular till the 1900s; hydrogen was preferred as the filling gas, but, was considered unsafe, causing few explosions.

Balloons (airships) were used to carry cargo, passengers, observation platforms etc.

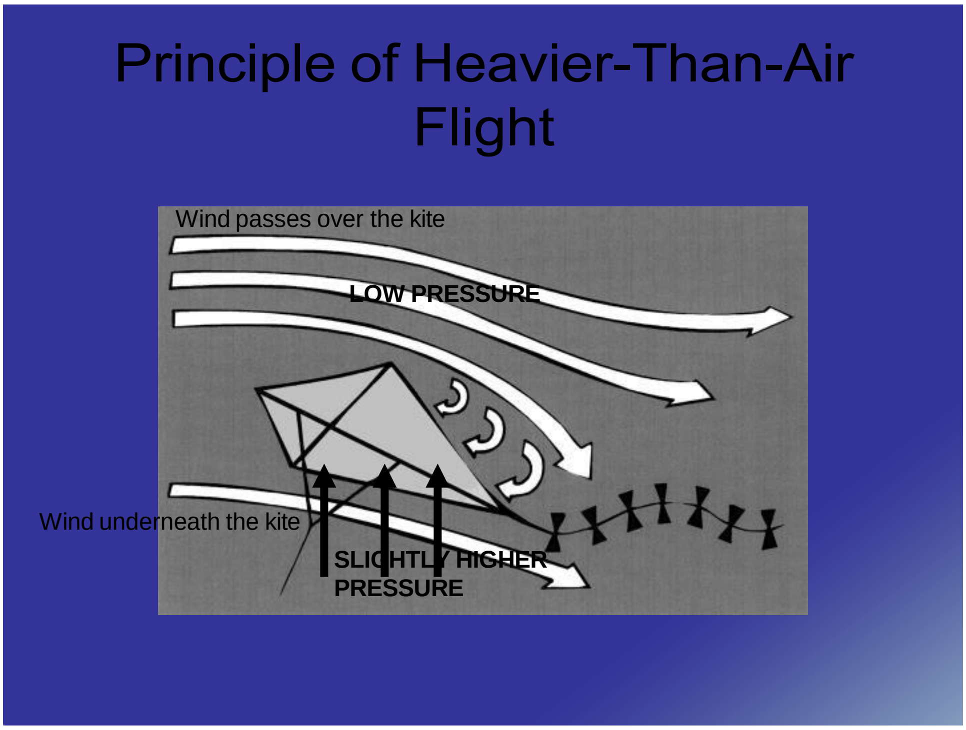
Controlling airships: Two inflatable air bags were kept inside the main balloon; these inflatable air bags, called “ballonets” are filled with helium. By varying the quantity of helium in the ballonets, the airship is controlled for maneuvering.

By releasing air into the ballonets or by pumping in more air into the ballonets, the helium inside ballonets is compressed or made to expand, thereby causing the airship to raise or descend.

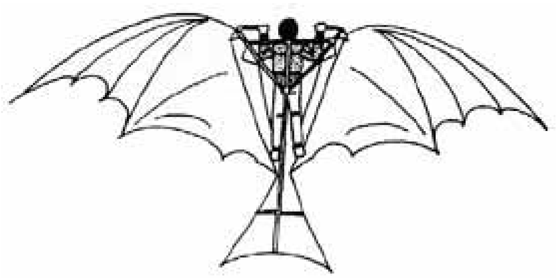


Heavier-than-air-aircraft- Principle:

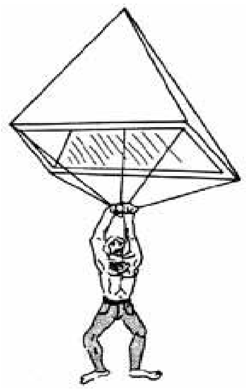
- Developed from the flight of a kite
- The shape of kite and its tail enable the kite fly at the correct angle in to the wind
- The weight of the kite is balanced by the force of the wind underneath (Lift)
- The wind passing over the top of the kite creates an area of low pressure
- The air underneath the kite is slightly higher in pressure, so it allows the kite to lift into the lower pressure



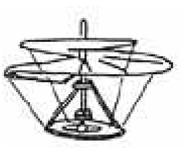
- In 1804, Dir George Caylay built a glider (kite without the string), with no controls
- In 1885, Gottlieb Daimler developed the first single cylinder (combustion engine) aircraft
- In 1903, Wright brothers flew their aircraft



Ornithopter

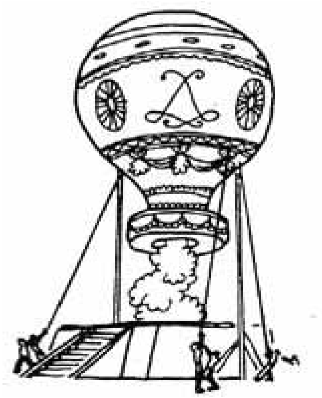


Parachute



Helicopter

Figure 1.- Designs of Leonardo da Vinci.



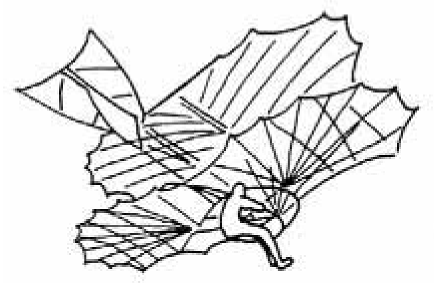


Figure 2.- Montgolfier balloon (1783). Figure 3.- Lilienthal glider (1896)

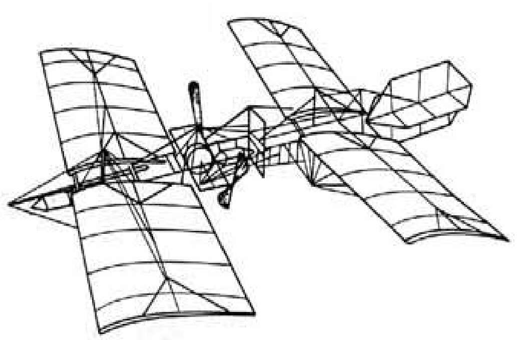
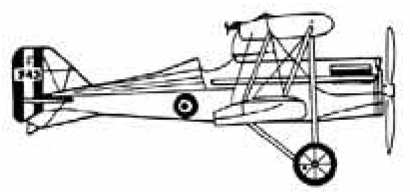


Figure 4.- Samuel Langley's "Aerodrome" (1903).

YF-16Modern (1974)



Commercial air transport, introduction of jet aircraft, helicopters:

1.1 Evolution of Flight Propulsion:

Classes of Aircraft:

- Lighter than air category-Airships; Free balloons; Captive balloons
- Heavier than air category-Power driven; non-power driven
  - Power driven category-Aeroplane; Rotorcraft; ornithopters
  - Aeroplanes-Landplanes; Seaplanes & Amphibians

History of flight Propulsion:

Earliest known propulsive device: Hero's Aeoipile in Year 250 B.C

The Aeolipile is a steam reaction turbine, invented by Egyptian inventor, Hero of Alexandria, in the year 250 BC. The Aeolipile is a steam reaction turbine.

Hero mounted a sphere on top of a water kettle. A fire below the kettle turned the water into steam, and the gas traveled through the pipes to the sphere. Two L-shaped tubes on opposite sides of the sphere allowed the gas to escape. This produced a thrust to the sphere that caused it to rotate almost silently .

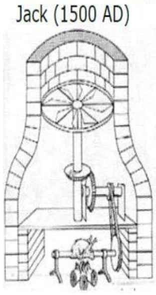
The aeolipile achieved spin speeds of at 1500 RPM.

Chinese used rockets with gunpowder, around AD 1000. They attached these rocket (bamboo) tubes to arrows and launched them with bows. Soon they discovered that these gunpowder tubes could launch themselves just by the power produced from the escaping gas. The true rocket was born.

Gunpowder changed the methods of war forever.

Da Vinci visualized flight vehicles as early as 1500 AD

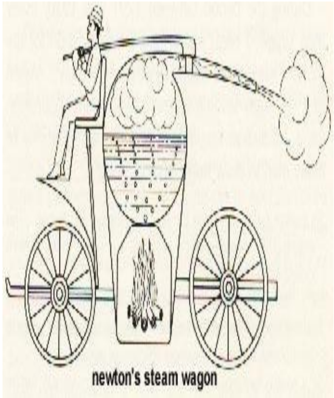
Da Vinci's Chimney Jack (1500 AD)



Da Vinci' Ornithopter

In 1629 an Italian engineer, Giovanni Branca, was probably the first to invent an actual **impulse turbine**. This device, a stamping mill, was generated by a steam-powered turbine.

Newton's Steam Wagon 1687:

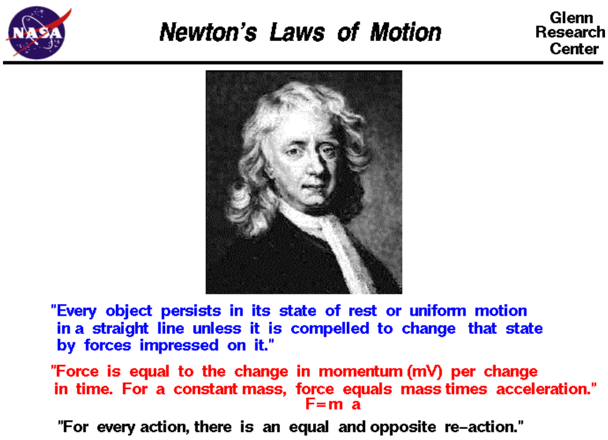


In 1687, Jacob Govesand, a Dutchman designed and built a carriage driven by steam power. Sir Isaac Newton was believed to have supplied the idea in an attempt to put his laws of motion to test.

The first Gas Turbine: In 1791 John Barber, an Englishman, was the first to patent a design that used the thermodynamic cycle of the modem gas turbine.

Wright Brothers first Airplane "Triumph": First Flight 1903 Dec

Concept of Jet Propulsion:



Newton’s Laws of Motion

Newton's first law.

An object at rest will remain at rest unless acted on by an external force. An object in motion continues in motion with the same speed and in the same direction unless acted upon by an external force.
This law is often called "the law of inertia" as it establishes the Newtonian frame of reference.

Newton's law I

This law states that if the vector sum of all the forces acting on an object is zero, then the velocity of the object is constant.
Consequently:

- An object that is at rest will stay at rest unless an unbalancing force acts upon it.
- An object that is in motion will not change its velocity (magnitude and/or direction) unless an unbalancing force acts upon it.

Newton’s Laws of Motion

Newton's second law

Acceleration is produced when a force acts on a mass. The greater the mass (of the object) being accelerated the greater the amount of force needed to accelerate the object.

$$F = MA$$

<u>From Newton's 2nd law of motion</u>

The second law states that the net force on a body is equal to the time rate of change of its linear momentum **M_t** in a specified reference frame for the inertial motion under interest:

$$F=\frac{dM_t}{dt}=\frac{d(mV)}{dt}=m\frac{dv}{dt}$$

For a constant mass system

Any mass that is gained or lost by the system will cause a change in momentum that is not the result of an external force. A different equation is necessary for a variable-mass systems

Newton's Laws of Motion

<u>Newton's third law</u>

For every action there is an equal and opposite re-action.

While the Newton's 3rd law allows us to comprehend the mechanics of action of the propulsive force (Thrust) acting on a flying body, the production of thrust is actually facilitated by the Newton's 2nd law, active on the engine body. Hence it is not only the jet coming out at the exhaust that creates thrust, but the entire body of the engine participates in creation of thrust.

History of Internal Combustion (I.C) Engines:

The first 4 stroke engine was built by the Germans, August Otto and Evgen Langer in 1876. As a result, the 4 stroke engine cycle are always called Otto Cycle engines.

George Brayton of the USA, also built a gasoline engine in 1876. Gottieb Daimler has built most successful 4 stroke engine in 1885. The first 4 stroke engine was built by the Germans, August Otto and Evgen Langer in 1876. As a result, the 4 stroke engine cycle are always called Otto Cycle engines.

Same year, Karl Benz, has built a similar engine. These two engines were extensively used in automobiles.

Wright brothers used 4 stroke four cylinder IC Engine in 1903.

- **Air Breathing Engines**-Reciprocating& Jet Propulsion Engines.

1.2.1 : Types of Aerospace Propulsion:

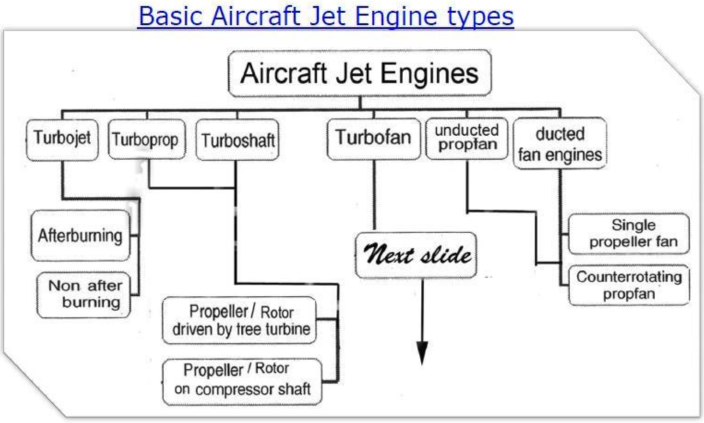
Air Breathing Systems

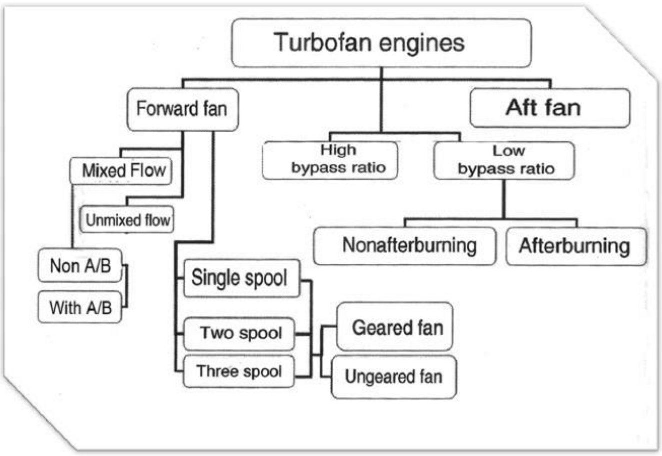
- Reciprocating Engines
- Gas Turbine Engines
- Ram Jets, Pulse Jets & Scram Jets

Non Air Breathing Systems

- Rockets

Basic Aircraft Jet Engine types





Missiles, conquest of space, commercial use of space, exploring solar system and beyond

In military parlance, missiles are powered / guided munitions are broadly categorised as follows:

- A powered, guided munition that travels through the air or space is known as a military **missile** (or *guided missile*.)
- A powered, *un*guided munition is known as a **rocket**.

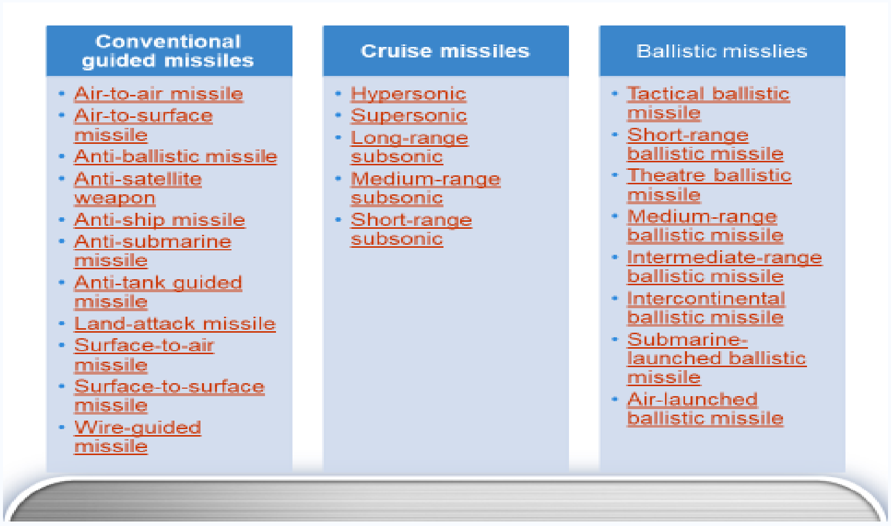
TECHNOLOGY :

Guided missiles have a number of different system components:

- Targeting and/or guidance
- Flight system
- Engine
- Warhead

Guidance systems

- Missiles may be targeted in a number of ways. The most common method is to use some form of radiation, such as infrared, lasers or radio waves, to guide the missile onto its target. This radiation may emanate from the target ,it may be provided by the missile itself (such as a radar) or it may be provided by a friendly third party. The picture may be used either by a human operator who steers the missile onto its target, or by a computer doing much the same job.



SPACE TRANSPORT

Space transport is the use of spacecraft to transport people or cargo through outer space. In human spaceflight, the people transported are the crew who operate the spacecraft, and occasionally passengers. Some cargo carrying spacecraft, like the Progress, have no crew or passengers during their flight and operate either by telerobotic control or are fully autonomous.

Currently, spacecraft most commonly use rocket technology for propulsion. Rocket engines expel propellant to provide forward thrust. Different ranges and types of rockets and other spacecraft have been used (or proposed) for different environments and goals, including:

- expendable launch system
- single stage to orbit
- orbital maneuvering system
- interplanetary travel
- interstellar travel
- intergalactic travel

SPACE FLIGHT:

A **spaceflight** is the sustained movement of a spacecraft into and through outer space. Spaceflights primarily use rocket technology for propulsion. A spaceflight begins with a launch, which provides the initial thrust to overcome the force of gravity and propel the spacecraft from the surface of the Earth. Once in space, the motion of a spacecraft -- both when unpropelled and when under propulsion -- is determined by astrodynamics.

Spaceflight is a necessary component of space exploration. It is also necessary for commercial uses of space, such as space tourism and the launching of telecommunications satellites. Non-commercial uses of spaceflight include space observatories, reconnaissance satellites and other earth observation satellites.

History of space flight

Spaceflight became an engineering possibility with the work of Robert H. Goddard's publication in 1919 of his paper 'A Method of Reaching Extreme Altitudes'; where his application of the de Laval nozzle to liquid fuel rockets gave sufficient power that interplanetary travel became possible. This paper was highly influential on Hermann Oberth and Wernher Von Braun, later key players in spaceflight.

The first rocket to reach space was a prototype of the German V-2, on a test flight in 1942. In 1957 the Soviet Union launched Sputnik 1, which became the first artificial satellite to orbit the Earth. The first human spaceflight was Vostok 1 on April 12, 1961, aboard which Soviet cosmonaut Yuri Gagarin made one orbit around the Earth.

Rockets remain the only currently practical means of reaching space. Other technologies such as scramjets still fall far short of orbital speed, although show some potential.

Reaching space

The most commonly used definition of outer space is everything beyond the Kármán line, which is 100 kilometers (62.1 mi) above the Earth's surface. (The United States sometimes uses a 50 miles (80.5 km) definition.)

Sub-orbital spaceflight

On a sub-orbital spaceflight the spacecraft reaches space, but does not achieve orbit. Instead, its trajectory brings it back to the surface of the Earth. Suborbital flights can last many hours. Pioneer 1 was NASA's first space probe, intended to reach the Moon. A partial failure caused it to instead follow a suborbital trajectory to an altitude of 113,854 kilometers (70,747.5 mi) before reentering the Earth's atmosphere 43 hours after launch.

On May 17, 2004, Civilian Space exploration Team launched the Go-Fast Rocket on a suborbital flight, the first amateur space flight. On June 21, 2004, Spaceship One was used for the first privately-funded human spaceflight.

Orbital spaceflight

A minimal orbital spaceflight requires very much higher velocities than a minimal sub-orbital flight, and so it is technologically much more challenging to achieve. To achieve orbital spaceflight, the tangential velocity around the Earth is just as important as height. In order to perform a stable and lasting flight in space, the velocity of the launched craft should be such that a closed orbit is possible.

Launch pads and Spaceports, takeoff

A launch pad is a fixed structure designed to dispatch airborne vehicles.It generally consists of a launch tower and flame trench. It surrounded by equipment used to erect, fuel, and maintain launch vehicles.

A spaceport, by way of contrast, is designed to facilitate winged launch vehicles and uses a long runway.

Both spaceport and launch pads are situated well away from human habitation for noise and safety reasons. Rockets run though a countdown sequence prior to Rocket launch. A launch is often restricted to certain launch windows. These windows depend upon the position of celestial bodies and orbits relative to the launch site. The biggest influence is often the rotation of the Earth itself. Once launched, orbits are normally located within relatively constant flat planes at a fixed angle to the axis of the Earth, and the Earth rotates within this orbit.

Spacecraft propulsion

Spacecraft today predominantly use rockets for propulsion, but other propulsion techniques such as ion drives are becoming more common, particularly for unmanned vehicles, and this can significantly reduce the vehicle's mass and increase its delta-v.

Outer space

Outer space, sometimes simply called *space*, refers to the relatively empty regions of the universe outside the atmospheres of celestial bodies. *Outer* space is used to distinguish it from airspace (and terrestrial locations). Contrary to popular understanding, outer space is not completely empty (i.e. a perfect vacuum) but contains a low density of particles, predominantly hydrogen plasma, as well as electromagnetic radiation.

Earth's boundary

There is no clear boundary between the Earth's atmosphere and space as the density of the atmosphere gradually decreases as the altitude increases. Nevertheless, the Federation Aeronautique Internationale has established the Kármán line at an altitude of 100 km(62 miles) as a working definition for the boundary between atmosphere and space. This is used because, as Karman calculated, above an altitude of roughly 100 km, a vehicle would have to travel faster than orbital velocity in order to derive sufficient aerodynamic lift from the atmosphere to support itself. The United States designates people who travel above an altitude of 80 km (50 statute miles) as astronauts. During re-entry, roughly 120 km (75 miles) marks the boundary where atmospheric drag becomes noticeable, depending on the ballistic coefficient of the vehicle.

Solar System

Outer space within the solar system is called interplanetary space, which passes over into interstellar space at the heliopause. The vacuum of outer space is not really empty; it is sparsely filled with several dozen types of organic molecules discovered to date by microwave spectroscopy. According to the Big bang theory, 2.7 K blackbody radiation was left over from the 'big bang' and the origin of the universe, and cosmic rays, which include ionized atomic nuclei and various subatomic particles. There is also gas, plasma and dust, and small meteors and material left over from previous manned and unmanned launches that are a potential hazard to spacecraft. Some of this debris re-enters the atmosphere periodically.

The absence of air makes outer space (and the surface of the Moon) ideal locations for astronomy at all wavelengths of the electromagnetic spectrum, as evidenced by the spectacular pictures sent back by the Hubble Space Telescope, allowing light from about 13.7 billion years ago - almost to the time of the Big Bang - to be observed. Pictures and other data from unmanned space vehicles have provided invaluable information about the planets, asteroids and comets in our solar system.

Satellites

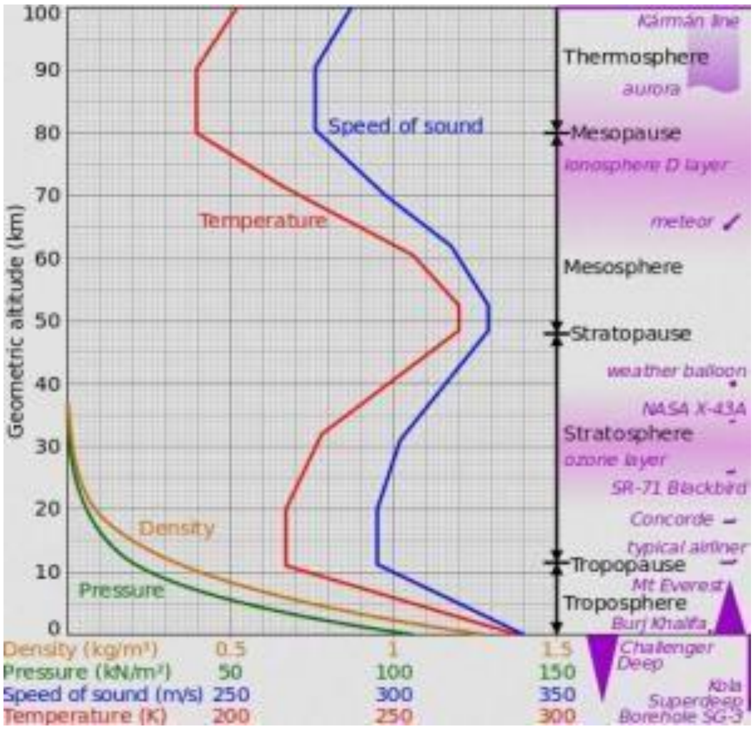
There are many artificial satellites orbiting the Earth, including geosynchronous communication satellites 35,786 km (22,241 miles) above mean sea level at the Equator. There is also increasing reliance, for both military and civilian uses, on satellites which enable the Global Positioning System (GPS). A common misconception is that people in orbit are outside Earth's gravity because they are obviously "floating". They are floating because they are in "free fall": the force of gravity and their linear velocity is creating an inward centripetal force which is stopping them from flying out into space. Earth's gravity reaches out far past the Van Allen belt and keeps the Moon in orbit at an average distance of 384,403 km (238,857 miles). The gravity of all celestial bodies drops off toward zero with the inverse square of the distance.

Earth’s atmosphere, standard atmosphere

Variation of Pressure, temperature and density with altitude:

As the altitude increases, the pressure and density decreases so does the thrust. However, as altitude increases, temperature decreases, the thrust increases. The pressure and density decreases faster than the temperature, so the net effect on thrust is to reduce up to an altitude of 11000 (troposphere).

After 11000 mt, the temperature stops falling, but pressure continues to drop with altitude. Consequently, above 11000 mt, thrust will drop off more rapidly.



This makes 11000 mt as optimum altitude for long range cruise.

Laws of gravitation, low earth orbit, microgravity, benefits of microgravity

Gravity Effects (*Weightlessness and Microgravity)*

Gravity is one of the four **forces of nature**, along with the electromagnetic force and the strong and weak nuclear forces. It is an invisible force that is all-pervading. According to Newton's law :

$$F = G \times \frac{m_1 \times m_2}{r^2}$$

To get a better understanding of gravity and weightlessness, we must now focus our attention on what happens when you let an object fall freely. When an object is in**continuous free-fall** and there are no external forces acting on it, then the object can be described as being **weightless**. In this case, all gravity effects disappear and only the internal forces inside the object remain. Free-fall can be implemented in ground-based facilities called **drop towers**, in special aircraft which fly **parabolic flights**, as well as in **sounding rockets**. With these kinds of techniques we can achieve near-weightless conditions, more precisely known as **microgravity**.. For longer durations of microgravity we must devise more sophisticated free-fall methods. Coming back to the Newton's equation above, one can see that the further an object is transported from the Earth, the less it will be attracted. The equation to calculate the attractive force (F) of an object as a function of its altitude is as follows:

$$F = M \times g \times \frac{R^2}{(R+H)^2}$$

- From this equation, it can be seen that at an altitude of 400 km above the Earth's surface a stationary object would still have about 89% of its terrestrial weight. An adult male with mass 80 kg (or weight 785 Netwons) would appear to weigh about 71 kg (actually 699 Netwons), which is far from being weightless ! The trick to achieving weightlessness is to propel an object using a rocket engine with an initial velocity parallel to Earth's surface, while simultaneously allowing the object to fall freely. In this way, the object will be in continous free-fall but will never hit the Earth. In practice, it is almost impossible to attain absolute weightlessness because a number of secondary effects disturb the gravity environment of an orbiting spacecraft. Although these secondary effects are generally very small indeed they cannot be neglected completely. These effects include the **tidal acceleration** on the spacecraft as a result of different parts of a spacecraft having slightly different circular orbits, **residual aerodynamic drag** from high-altitude gases and the **solar radiation pressure** on the surface of the spacecraft, as photons collide with it.

- Weightlessness or 0g and microgravity or 10^{-6} g complicates many fluid and gas dynamic processes, including thermal convection, compared with ground experience. The situation is particularly exacerbated when one is designing for human presence.
- Gravity dictates the size and shape of a spacecraft's orbit. Launch vehicles must first overcome gravity to fling spacecraft into space. Once a spacecraft is in orbit, gravity determines the amount of propellant its engines must use to move between orbits or link up with other spacecraft.
- It is common to assume that orbital flight provides a weightless environment for a spacecraft and its contents. To some level of approximation this is true, but as with most absolute statements, it is inexact. A variety of effects result in acceleration levels (i.e., "weight" per unit mass) between 10^{3} g and 10^{11} g , where 1g is the acceleration due to gravity at the Earth's surface**.**
- Measurements of gravity aboard the **International Space Station** have shown that *g* is approximately 1 millionth of that on Earth, which is where the term microgravity comes from (scientifically speaking micro means one millionth or 10^{-6}). This is why astronauts are able to float around so effortlessly

Microgravity:

The term **micro-g environment** is more or less a synonym of *weightlessness* and *zero-G*, but indicates that g-forces are not quite zero, just very small.

Absence of Gravity:

1. A stationary micro-g environment would require travelling far enough into deep space so as to reduce the effect of gravity by attenuation to almost zero.
2. For example, to reduce the gravity of the Earth by a factor of one million one needs to be at a distance of 6 million km from the Earth,
3. But to reduce the gravity of the Sun to this amount one has to be at a distance of even 3700 million km.
4. To reduce the gravity to one thousandth of that on Earth one needs to be at a distance of 200,000 km.

The near-earth radiative environment. The magnetosphere. Environmental impact on spacecraft:

Space environment is a branch of astronautics, aerospace engineering and astronomy that seeks to understand and address conditions existing in space that would impact both the operation of spacecraft and also affect our planet's atmosphere and geomagnetic field.

Problems for spacecraft can include radiation, space debris, upper atmospheric drag, and the solar wind. Effects on Earth of space environmental conditions can include ionospheric storms, temporary decreases in ozone densities, disruption to radio communication, to GPS signals and submarine positioning. Some scientists also theorize links between sunspot activity and ice ages.

Solutions explored by scientists and engineers in the area of space environment study include, but are not limited to, spacecraft shielding, various collision detection systems, and atmospheric models to predict drag effects encountered in lower orbits and during re entry.

The field often overlaps with the disciplines of astrophysics, atmospheric science, space physics, and geophysics, albeit with a stronger emphasis on application.

The United States government maintains a Space Environment Center at Boulder, Colorado. The Space Environment Center (SEC) is part of the National Oceanic and Atmospheric Administration (NOAA). SEC is one of the National Weather Service's (NWS) National Centers for Environmental Prediction (NCEP).

SPACE WEATHER

Space weather is the concept of changing environmental conditions in outer space. It is distinct from the concept of weather within an atmosphere, and generally deals with the interactions of ambient radiation and matter within interplanetary and occasionally interstellar space. From the definition of the National Academy of Science: "Space weather describes the conditions in space that affect Earth and its technological systems. Our space weather is a consequence of the behavior of the sun, the nature of Earth's magnetic field, and our location in the solar system."

Within our own solar system, space weather is greatly influenced by the speed and density of the solar wind and the interplanetary magnetic field (IMF) carried by the solar wind plasma. A variety of physical phenomena are associated with space weather, including geomagnetic storms and substorms, energization of the Van Allen radiation belts, ionospheric disturbances and scintillation, aurora and geomagnetically induced currents at Earth's surface. Coronal Mass Ejections and their associated shock waves are also important drivers of space weather as they can compress the magnetosphere and trigger geomagnetic storms. Solar Energetic Particles, acclerated by Coronal Mass Ejections or solar flares are also an important driver of space weather as they can damage electronics onboard spacecraft and threaten the life of astronauts.

Space weather exerts a profound influence in several areas related to space exploration and development. Changing geomagnetic conditions can induce changes in atmospheric density causing the rapid degradation of spacecraft altitude in Low Earth orbit. Geomagnetic storms due to increased solar activity can potentially blind sensors aboard spacecraft, or interfere with on-board electronics. An understanding of space environmental conditions is also important in designing shielding and life support systems for manned spacecraft. There is also some concern that geomagnetic storms may also expose conventional aircraft flying at high latitudes to increased amounts of radiation.

Meteoroids and micrometeoroids, space debris. Planetary environments:

Meteoroids:

1. A meteoroid is a sand- to boulder-sized particle of debris in the Solar System.
2. The visible path of a meteoroid that enters Earth's (or another body's) atmosphere is called a *meteor*, or colloquially a *shooting star* or *falling star*.
3. If a meteoroid reaches the ground and survives impact, then it is called a *meteorite*.
4. Many meteors appearing seconds or minutes apart are called a meteor shower

Micrometeoroids:

1. A **micrometeoroid** is a tiny meteoroid; a small particle of rock in space, usually weighing less than a gram.
2. A **micrometeor** or **micrometeorite** is such a particle that enters the Earth's atmosphere or falls to Earth.

Effect of environment on Spacecraft:

- Micrometeoroids pose a significant threat to space exploration.
- Their velocities relative to a spacecraft in orbit can be on the order of kilometers per second, and resistance to micrometeoroid impact is a significant design challenge for spacecraft and space suit designers
- While the tiny sizes of most micrometeoroids limits the damage incurred, the high velocity impacts will constantly degrade the outer casing of spacecraft in a manner analogous to sandblasting.
- Long term exposure can threaten the functionality of spacecraft systems.