Elements of Aeronautical Engineering

(R24A2105)

COURSE FILE

II B. Tech I Semester

(2025-2026)

Prepared By

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Department of Aeronautical Engineering

MALLA REDDY COLLEGE OF ENGINEERING & TECHNOLOGY
(Autonomous Institution – UGC, Govt. of India)

Affiliated to JNTU, Hyderabad, Approved by AICTE - Accredited by NBA & NAAC – 'A' Grade - ISO 9001:2015 Certified)
Maisammaguda, Dhulapally (Post Via. Kompally), Secunderabad – 500100, Telangana State, India.

MRCET VISION

- To become a model institution in the fields of Engineering, Technology and Management.
- To have a perfect synchronization of the ideologies of MRCET with challenging demands of International Pioneering Organizations.

MRCET MISSION

To establish a pedestal for the integral innovation, team spirit, originality and competence in the students, expose them to face the global challenges and become pioneers of Indian vision of modern society.

MRCET QUALITY POLICY.

- To pursue continual improvement of teaching learning process of Undergraduate and Post Graduate programs in Engineering & Management vigorously.
- To provide state of art infrastructure and expertise to impart the quality education.

PROGRAM OUTCOMES
(PO's)

Engineering Graduates will be able to:

1. **Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analysis**: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design / development of solutions**: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
4. **Conduct investigations of complex problems**: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. **Modern tool usage**: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
6. **The engineer and society**: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability**: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and team work**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **Communication**: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
11. **Project management and finance**: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multi disciplinary environments.
12. **Life- long learning**: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

DEPARTMENT OF AERONAUTICAL ENGINEERING

VISION

Department of Aeronautical Engineering aims to be indispensable source in Aeronautical Engineering which has a zeal to provide the value driven platform for the students to acquire knowledge and empower themselves to shoulder higher responsibility in building a strong nation.

MISSION

The primary mission of the department is to promote engineering education and research. To strive consistently to provide quality education, keeping in pace with time and technology. Department passions to integrate the intellectual, spiritual, ethical and social development of the students for shaping them into dynamic engineers.

QUALITY POLICY STATEMENT

Impart up-to-date knowledge to the students in Aeronautical area to make them quality engineers. Make the students experience the applications on quality equipment and tools. Provide systems, resources and training opportunities to achieve continuous improvement. Maintain global standards in education, training and services.

PROGRAM EDUCATIONAL OBJECTIVES – Aeronautical Engineering

1. **PEO1 (PROFESSIONALISM & CITIZENSHIP):** To create and sustain a community of learning in which students acquire knowledge and learn to apply it professionally with due consideration for ethical, ecological and economic issues.
2. **PEO2 (TECHNICAL ACCOMPLISHMENTS):** To provide knowledge based services to satisfy the needs of society and the industry by providing hands on experience in various technologies in core field.
3. **PEO3 (INVENTION, INNOVATION AND CREATIVITY):** To make the students to design, experiment, analyze, and interpret in the core field with the help of other multi disciplinary concepts wherever applicable.
4. **PEO4 (PROFESSIONAL DEVELOPMENT):** To educate the students to disseminate research findings with good soft skills and become a successful entrepreneur.
5. **PEO5 (HUMAN RESOURCE DEVELOPMENT):** To graduate the students in building national capabilities in technology, education and research

PROGRAM SPECIFIC OUTCOMES – Aeronautical Engineering

1. To mould students to become a professional with all necessary skills, personality and sound knowledge in basic and advance technological areas.
2. To promote understanding of concepts and develop ability in design manufacture and maintenance of aircraft, aerospace vehicles and associated equipment and develop application capability of the concepts sciences to engineering design and processes.
3. Understanding the current scenario in the field of aeronautics and acquire ability to apply knowledge of engineering, science and mathematics to design and conduct experiments in the field of Aeronautical Engineering.
4. To develop leadership skills in our students necessary to shape the social, intellectual, business and technical worlds.

SESSION PLANNER

R24A2104- ELEMENTS OF AERONAUTICAL ENGINEERING

YEAR: II **SEMESTER: I**

S. N O	UNIT NO	TOPIC	NO OF CLASSES HELD
I	UNIT-1	**History and first principles of flight:**	
1		Evolution of Flight- Hot air balloons, Airships	1
2		Heavier than air, Wright flyer to commercial transportation	2
3		Rotorcraft, missiles	1
4		Standard atmosphere, Understanding space-environment	2
5		Laws of gravitation, kepler's law,	2
6		Micro-gravity, rockets	2
7		Spacecrafts and planetory environment	2
8		Aircraft structural components and their functions.	1 Total 13
II	UNIT- II	**Aerodynamics**	
1		Aerodynamics and its importance	2
2		Flow regimes based on Mach number, forces and Moments	2
3		Derivation of Lift, Drag and moment Coefficients with pressure distribution	2
4		Variation of pressure distribution with respect to angle of attack, Airfoil-nomenclature and types.	2
5		Control surfaces, High Lift devices, Spoilers, Propeller, Rotary wing aircraft concepts	2
6		Compressible flow, shock waves, and expansion waves in high-speed aerodynamics.	2 Total 12
III		**Propulsion**	
1		Basic forces on an aircraft	1

2	**UNIT III**	Need for thrust	2
3		Types and working of air-breathing engines	3
4		Working of reciprocating engines (2/4 stroke variants), ,	2
5		Rocket engines	2
6		Types and principles, missiles and their types	2
7		Introduction to ramjet and scramjet engines.	2
			Total 14
IV	**UNIT-IV**	**Aircraft Performance** The role and design mission of an aircraft	2
2		Specification of the performance requirements and mission profile. Off-standard and design atmosphere. Measurement of air data. Air data computers.	3
3		Equations of motion for performance - the aircraft force system. The propulsive forces	2
4		The thrust production engines, power producing engines, variation of thrust, propulsive power and specific fuel consumption with altitude and flight speed.	3
			Total 10
V	**UNIT- V**	**Aircraft Measurement Instrumentation**	
1		Sensors and Instrumentation-pitot static tube	2
2		Primary flight instruments	2
3		Principles of gyro and accelerometer	2
4		Hydraulics and pneumatic systems,	3
5		High lift devices, engine and navigation instruments.	4
			Total 13
		TOTAL NO OF CLASSES HELD	**53**

R22

Code No: R22A2105

MALLA REDDY COLLEGE OF ENGINEERING & TECHNOLOGY

(Autonomous Institution – UGC, Govt. of India)

II B.Tech I Semester Regular Examinations, January 2024

Elements of Aeronautical Engineering

(ANE)

Roll No										

Time: 3 hours **Max. Marks: 60**

Note: This question paper contains two parts A and B
Part A is compulsory which carries 10 marks and Answer all questions.
Part B Consists of 5 SECTIONS (One SECTION for each UNIT). Answer **FIVE** Questions, Choosing ONE Question from each SECTION and each Question carries 10 marks.

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PART-A (10 Marks)

(Write all answers of this Part at one place)

1	A	Identify the primary lifting mechanism in hot air balloons.	**[1M]**
	B	Name the primary force that opposes the motion of an aircraft.	**[1M]**
	C	Define Mach Number.	**[1M]**
	D	Identify one control surface on an aircraft and its purpose.	**[1M]**
	E	What is the working principle of a turbofan engine?	**[1M]**
	F	Define the principles behind rocket propulsion.	**[1M]**
	G	Express the role of air data computers in processing air data	**[1M]**
	H	Give the role of an aircraft in the context of aviation.	**[1M]**
	I	List the main application of accelerometers in aviation.	**[1M]**
	J	Name one primary engine instrument used in aircraft.	**[1M]**

PART-B (50 Marks)

SECTION-I

2	A	List and describe the laws of gravitation governing celestial bodies.	**[5M]**
	B	Explain the basic working principles of a rocket engine.	**[5M]**
		OR	
3	A	Explain Kepler's laws of planetary motion.	**[5M]**
	B	Identify the key structural components of an aircraft and their functions.	**[5M]**

SECTION-II

4	A	Explain the relationship between aerodynamics and the overall performance of an aircraft.	**[5M]**
	B	How do changes in the angle of attack affect lift and drag coefficients?.	**[5M]**
		OR	
5	A	Recall the different flow regimes based on Mach number and their characteristics.	**[5M]**
	B	Summarize the key features of compressible flow in aerodynamics.	**[5M]**

SECTION-III

6	A	Discuss the engineering challenges associated with staging in multi-stage rockets.	**[2M]**
	B	Explain the working principles of a turbojet engine with diagram.	**[8M]**
		OR	
7		Recall the basic working principles of both 2-stroke and 4-stroke	**[10M]**

reciprocating engines.

SECTION-IV

8	A	Recall the primary functions and responsibilities of an aircraft in its design mission.	**[5M]**
	B	Illustrate the specific fuel consumption of an aircraft with an altitude.	**[5M]**

OR

9	A	Summarize the methods for measuring air data during flight.	**[5M]**
	B	Explain the differences between thrust-production engines and power-producing engines.	**[5M]**

SECTION-V

10	A	Discuss the principles of Pitot-static systems used to troubleshoot and calibrate air data instruments.	**[5M]**
	B	Recall the basic components of hydraulic systems in aircraft.	**[5M]**

OR

11	A	Explain the aerodynamic principles behind the operation of high-lift devices.	**[5M]**
	B	Describe the principles of navigation instruments, such as altimeters and navigation displays, to plan and execute flight routes.	**[5M]**

***

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.

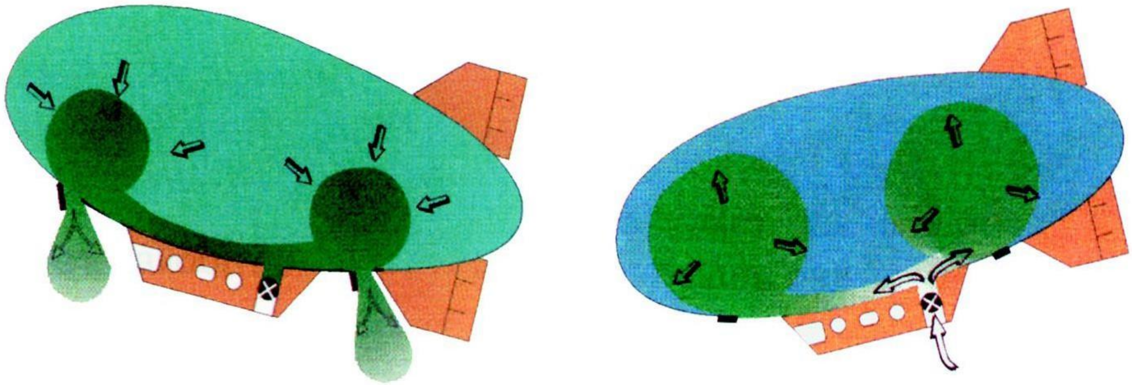
Lighter-than-aircraft: Montgolfier brothers built the first hot air balloon in Apr 1783.

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.

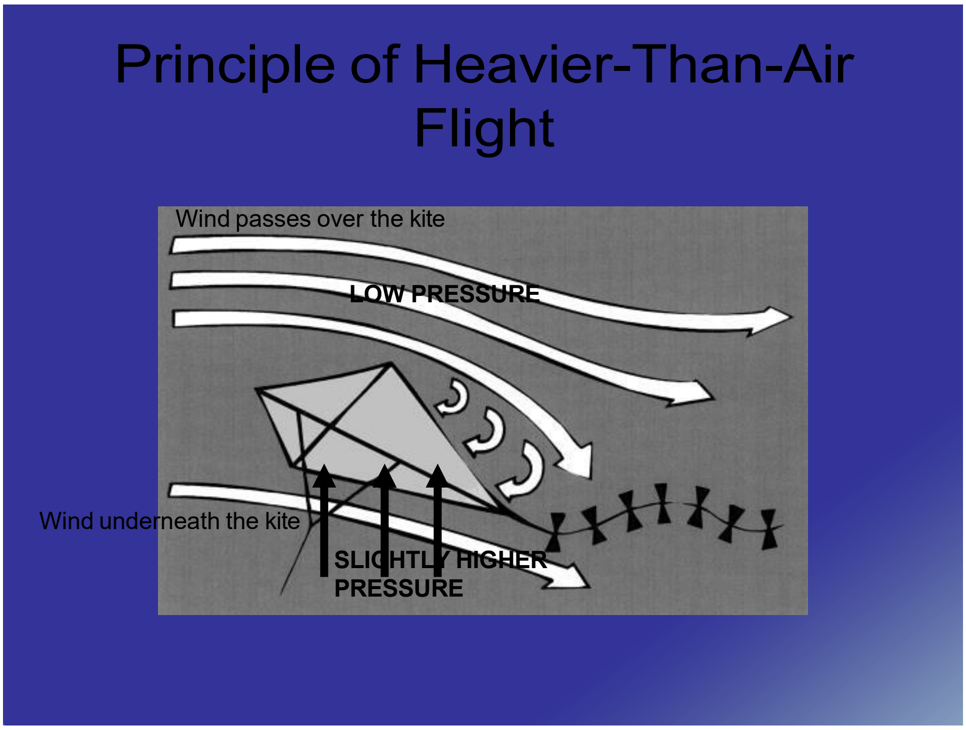
Controlling airships: Two inflatable air bags were kept inside the main balloon; these inflatable air bags, called "ballonets" are filled with helium. By varying the quantity of helium in the ballonets, the airship is controlled for maneuvering.

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.

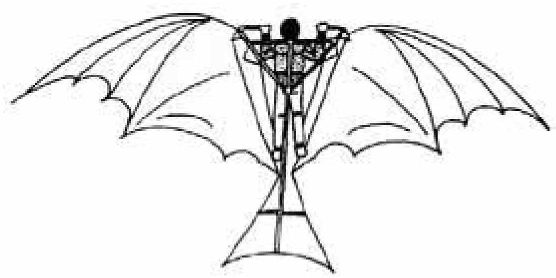


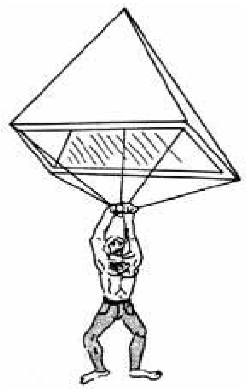
Heavier-than-air-aircraft- Principle:

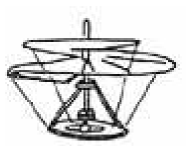
- Developed from the flight of a kite
- The shape of kite and its tail enable the kite fly at the correct angle in to the wind
- The weight of the kite is balanced by the force of the wind underneath (Lift)
- The wind passing over the top of the kite creates an area of low pressure
- The air underneath 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.

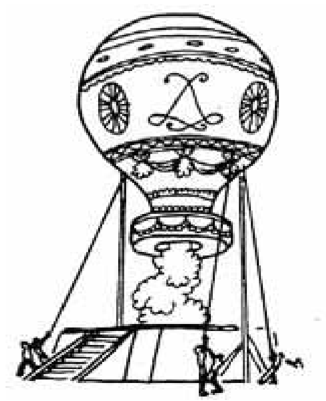


Figure 2.- Montgolfier balloon (1783).

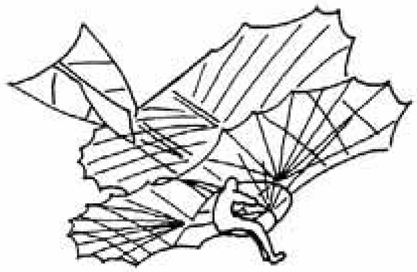


Figure 3.- Lilienthal glider (1896)

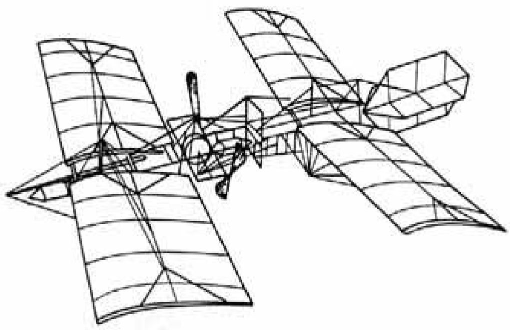
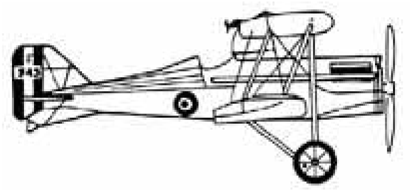


Figure 4.- Samuel Langley's "Aerodrome" (1903).

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.

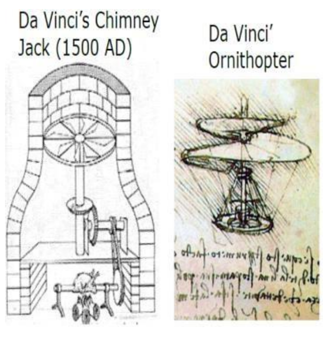
Hero mounted a sphere on top of a water kettle. A fire below the kettle turned the water into steam, and the gas traveled through the pipes to the sphere. Two L-shaped tubes on opposite sides of the sphere allowed the gas to escape. This produced a thrust to the sphere that caused it to rotate almost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

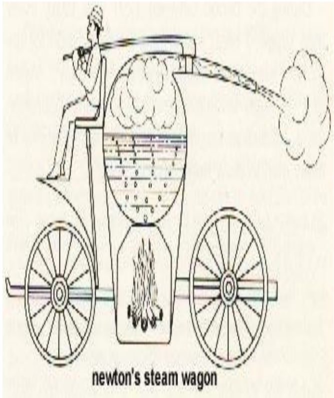
Gunpowder changed the methods of war forever.

Da Vinci visualized flight vehicles as early as 1500 AD



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:

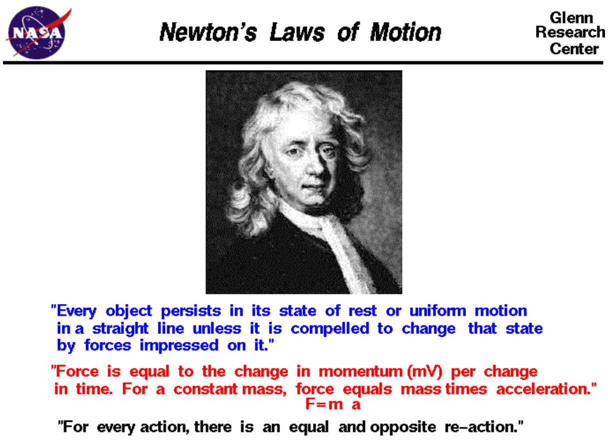


In 1687, Jacob Govesand, a Dutchman designed and built a carriage driven by steam power. Sir Isaac Newton was believed to have supplied the idea in an attempt to put his laws of motion to test.

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.

$$F = M A$$

From Newton's 2nd law of motion

The second law states that the net force on a body is equal to the time rate of change of its linear momentum **Mt** 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

Newton's third law

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:

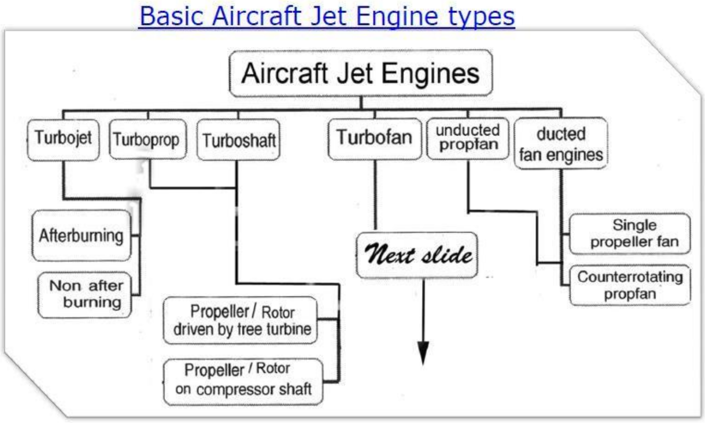
Air Breathing Systems

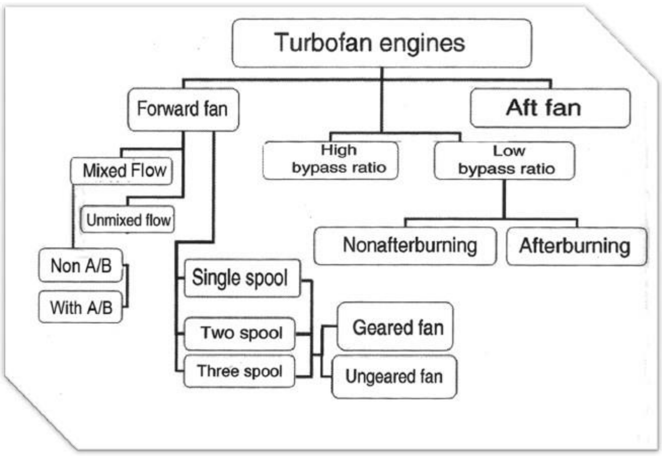
- Reciprocating Engines
- Gas Turbine Engines
- Ram Jets, Pulse Jets & Scram Jets

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**.

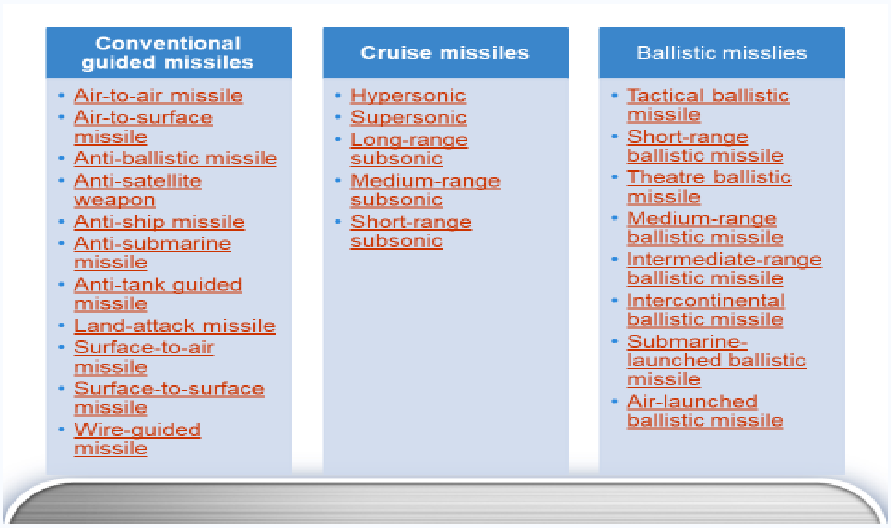
TECHNOLOGY :

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

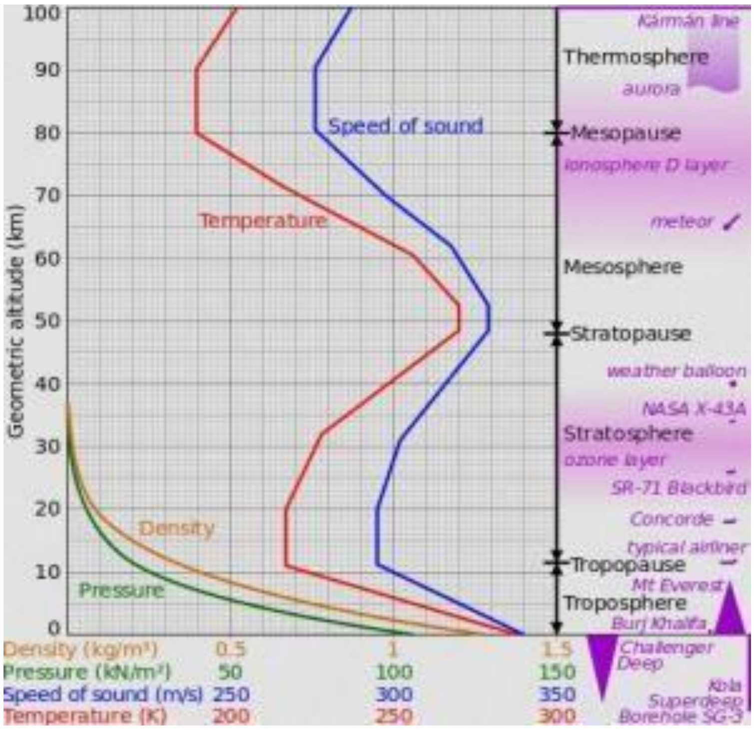
There are many artificial satellites orbiting the Earth, including geosynchronous communication satellites 35,786 km (22,241 miles) above mean sea level at the Equator. There is also increasing reliance, for both military and civilian uses, on satellites which enable the Global Positioning System (GPS). 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.

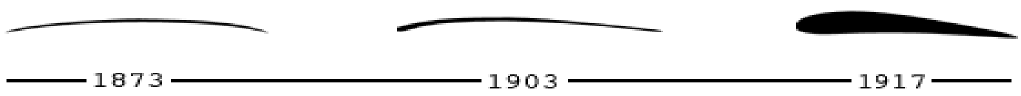
UNIT II: Aerodynamics

Aerfoil – Nomenclature and types:

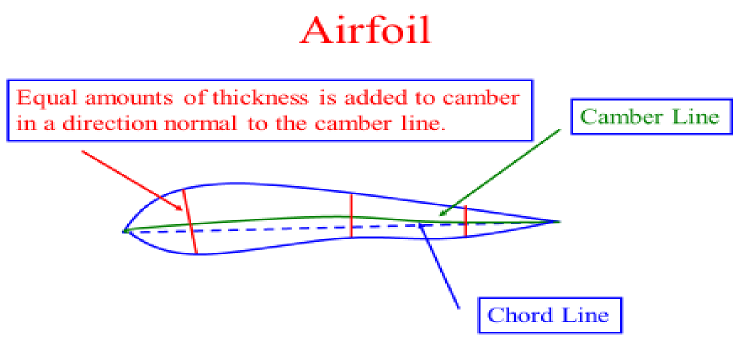
Use of aerfoil:

- Wings
- Propellers and Turbofans
- Helicopter Rotors
- Blade profiles of Compressors and Turbines
- Hydrofoils (wing-like devices which can lift up a boat above waterline)
- Wind Turbines

Evolution of aerfoil profile:



Early Designs - Designers mistakenly believed that these airfoils with sharp leading edges will have low drag.
In practice, they stalled quickly, and generated considerable drag

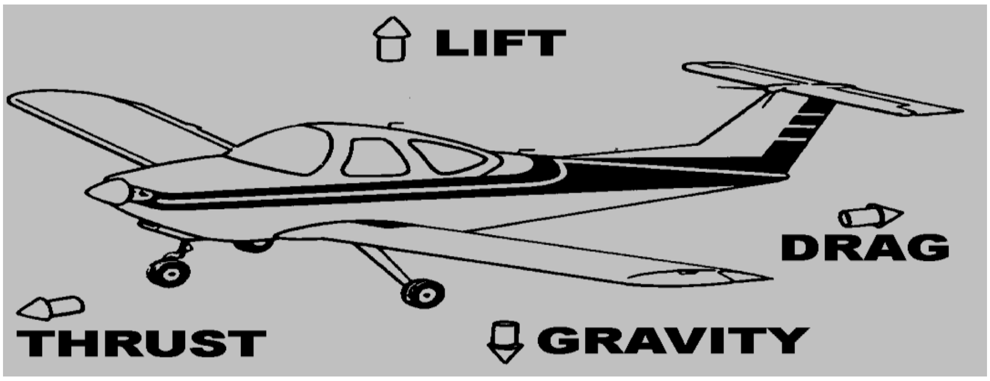


Aerodynamic forces on wings; Generation of lift; Sources of drag:

Aerfoil is defined by the following characteristics:

- Chord Line
- Camber line drawn with respect to the chord line.
- Thickness Distribution which is added to the camber line, normal to the camber line.
- Symmetric airfoils have no camber.

Aerodynamic Forces:



Lift (force)

Lift is the sum of all the fluid dynamic forces on a body perpendicular to the direction of the external flow approaching that body.

Sometimes the term **dynamic lift** or **dynamic lifting force** is used for the perpendicular force resulting from motion of the body in the fluid, as in an aerodyne, in contrast to the static lifting force resulting from buoyancy, as in an aerostat.

Lift is commonly associated with the wing of a aircraft. However there are many other examples of lift such as propellers on both aircraft and boats, rotors on helicopters, sails and keels on sailboats, hydrofoils, wings on auto racing cars, and wind turbines. While the common meaning of the term "lift" suggests an upward action, the lift force is not necessarily directed up with respect to gravity.

Physical explanation

There are several ways to explain lift which are equivalent — they are different expressions of the same underlying physical principles:

Reaction due to deflection

Lift is created as the fluid flow is deflected by an airfoil or other body. The force created by this acceleration of the fluid creates an equal and opposite force according to Newton's third law of motion. Air deflected downward by an aircraft wing, or helicopter rotor, generating lift is known as downwash.

It is important to note that the acceleration of air flowing over an aircraft wing does not just involve the air molecules "bouncing off" the lower surface. Rather, air molecules closely follow both the top and bottom surfaces, and the airflow is deflected downward when the wing is producing lift. The acceleration of the air during the creation of lift can also been described as a "turning" of the airflow.

Many shapes, such as a flat plate set at an angle to the flow, will produce lift. This can be demonstrated simply by holding a sheet of paper at an angle in front of you as you move forward. However, lift generation by most shapes will be very inefficient and create a great deal of drag. One of the primary goals of airfoil design is to devise a shape that produces the most lift while producing the least Form drag.

Circulation

Another way to calculate lift is to determine the mathematical quantity called circulation; (this concept is sometimes applied approximately to wings of large aspect ratio as "lifting-line theory"). Again, it is mathematically equivalent to the two explanations above. It is often used by practising aerodynamicists as a convenient quantity, but is not often useful for a layperson's understanding. (That said, the vortex system set up round a wing is both real and observable, and is one of the reasons that a light aircraft cannot take off immediately after a jumbo jet.)

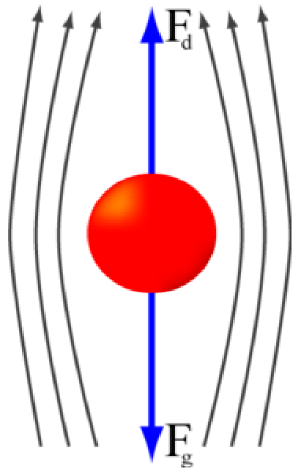
The circulation is the line integral of the velocity of the air, in a closed loop around the boundary of an airfoil. It can be understood as the total amount of "spinning" (or vorticity) of air around the airfoil. When the circulation is known, the section lift can be calculated using the following equation:

$$l = \rho V \times \Gamma$$

Where ρ is the air density, V is the free-stream airspeed, and Γ is the circulation. This is sometimes known as the **Kutta - Joukowski Theorem.**

A similar equation applies to the sideways force generated around a spinning object, the Magnus effect, though here the necessary circulation is induced by the mechanical rotation, rather than aerfoil action.

Sources of Drag:



An object falling through a gas or liquid experiences a force in direction opposite to its motion. Terminal velocity is achieved when the drag force is equal to force of gravity pulling it down.

In fluid dynamics, **drag** is the force that resists the movement of a solid object through a fluid (a liquid or gas). Drag is made up of friction forces, which act in a direction parallel to the object's surface (primarily along its sides, as friction forces at the front and back cancel themselves out), plus pressure forces, which act in a direction perpendicular to the object's surface. For a solid object moving through a fluid or gas, the drag is the sum of all the aerodynamic or hydrodynamic forces in the direction of the external fluid flow. (Forces perpendicular to this direction are considered lift). It therefore acts to oppose the motion of the object, and in a powered vehicle it is overcome by thrust.

In astrodynamics, depending on the situation, **atmospheric drag** can be regarded as inefficiency requiring expense of additional energy during launch of the space object or as a bonus simplifying return from orbit.

Types of drag:

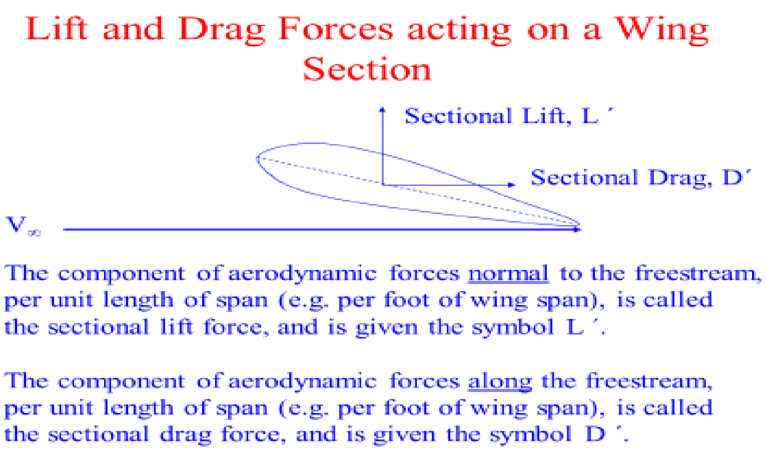
Types of drag are generally divided into three categories: parasitic drag, lift-induced drag and wave drag.

- Parasitic drag includes form drag, skin friction and interference drag.
- Lift-induced drag is only relevant when wings or a lifting body are present, and is therefore usually discussed only in the aviation perspective of drag.
- Wave drag occurs when a solid object is moving through a fluid at or near the speed of sound in that fluid.

The overall drag of an object is characterized by a dimensionless number called the drag coefficient, and is calculated using the drag equation. Assuming a constant drag coefficient, drag will vary as the square of velocity. Thus, the resultant power needed to overcome this drag will vary as the cube of velocity.

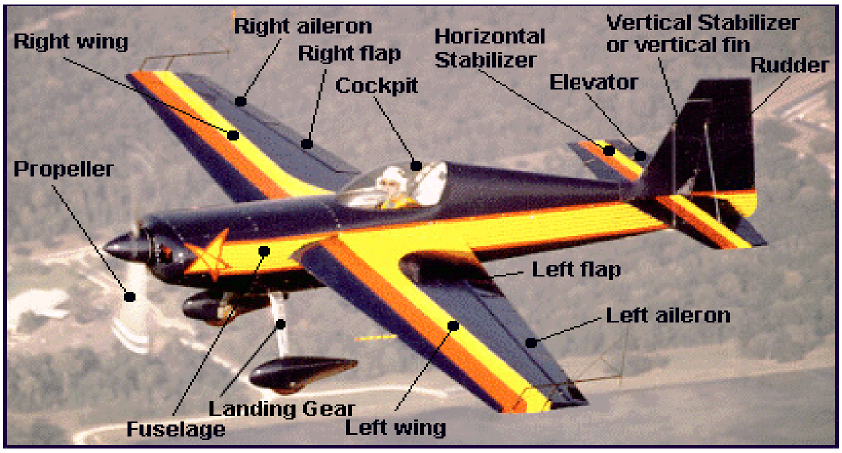
Wind resistance is a layman's term used to describe drag. Its use is often vague, and is usually used in a relative sense (e.g. A badminton shuttlecock has more *wind resistance* than a squash ball).

Force and moment coefficients, Centre of Pressure. Control surfaces:



Sectional Lift and Drag Coefficients

- The sectional lift coefficient C_l is defined as: $C_l = \dfrac{L'}{\frac{1}{2}\rho V_\infty^2 c}$
- Here c is the airfoil chord, i.e. distance between the leading edge and trailing edge, measured along the chordline.
- The sectional drag force coefficient C_d is likewise defined as: $C_d = \dfrac{D'}{\frac{1}{2}\rho V_\infty^2 c}$



Rotary Wing Aircraft Concepts – Propellor Theory:

HELICOPTERS

A helicopter main rotor or rotor system is a type of fan that is used to generate both the aerodynamic lift force that supports the weight of the helicopter, and thrust which counteracts aerodynamic drag in forward flight. Each main rotor is mounted on a vertical mast over the top of the helicopter, as opposed to a helicopter tail rotor, which is connected through a combination of drive shaft(s) and gearboxes along the tail boom. A helicopter's rotor is generally made up of two or more rotor blades. The blade pitch is typically controlled by a swash plate connected to the helicopter flight controls. Rotors are sometimes referred to as rotary wings, for they are the wings (as well as propellers) of a rotary-wing aircraft.

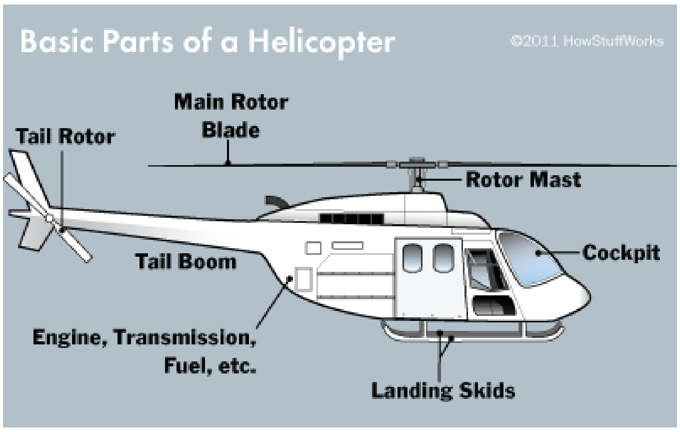
Design

The helicopter rotor is powered by the engine, through the transmission, to the rotating mast. The mast is a cylindrical metal shaft which extends upward from—and is driven by—the transmission. At the top of the mast is the attachment point for the rotor blades called the hub. The rotor blades are then attached to the hub. Main rotor systems are classified according to how the main rotor blades are attached and move relative to the main rotor hub. There are three basic classifications: rigid, semi-rigid, or fully articulated, although some modern rotor systems use an engineered combination of these classifications. The rotors are designed to operate in a narrow range of RPM.

Unlike the small diameter fans used in turbofan jet engines, the main rotor on a helicopter has a quite large diameter, permitting a large volume of air to be accelerated. This permits a lower downwash velocity for a given amount of thrust. As it is more efficient at low speeds to accelerate a large amount of air by a small degree than a small amount of air by a large degree, a low disc loading (thrust per disc area) greatly increases the aircraft's energy efficiency and this reduces the fuel use and permits reasonable range.

Parts and functions

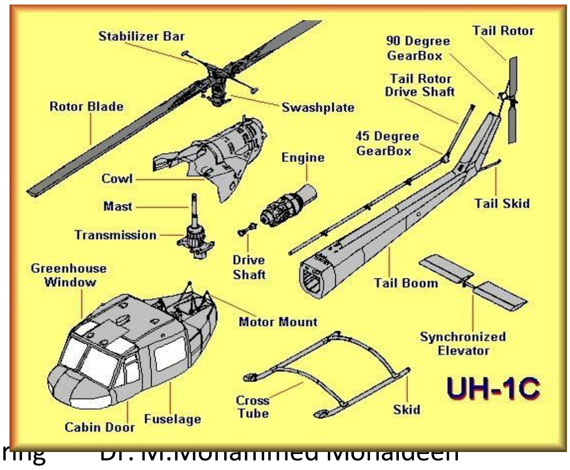
- The simple rotor (Main Rotor), rotor head with mast
- Tail Rotor, Tail Boom
- Swash plate
- Cockpit, Fuselage, Cabin
- Landing skids



Main rotor

The main rotor serves to provide lift and propulsion to the helicopter. The main rotor blade performs the same function as an airplane's wings, providing **lift** as the blades rotate -- lift being one of the critical aerodynamic forces that keeps aircraft aloft. A pilot can affect lift by changing the rotor's revolutions per minute (rpm) or its **angle of attack**, which refers to the angle of the rotary wing in relation to the oncoming wind.

1. **Rotor mast** -- Also known as the rotor shaft, the mast connects the transmission to the rotor assembly. The mast rotates the upper swash plate and the blades.
2. **Stabilizer** -- The stabilizer bar sits above and across the main rotor blade. Its weight and rotation dampen unwanted vibrations in the main rotor, helping to stabilize the craft in all flight conditions. Arthur Young, the gent who designed the Bell 47 helicopter, is credited with inventing the stabilizer bar.
3. **Transmission** -- Just as it does in a motor vehicle, a helicopter's transmission transmits power from the engine to the main and tail rotors. The transmission's main gearbox steps down the speed of the main rotor so it doesn't rotate as rapidly as the engine shaft. A second gearbox does the same for the tail rotor, although the tail rotor, being much smaller, can rotate faster than the main rotor.



Fuselage

The fuselage holds the aircraft together and accommodates passengers and cargo, as appropriate.

Cockpit

The cockpit, at the front end of the fuselage, is the control and command centre, where the pilots sit and all the instrumentation is located.

Cabin

The cabin serves to accommodate passengers and cargo.

Landing skids

The skids serve to stand the helicopter while on the ground.

Tail boom

The tail boom holds the tail rotor for stabilizing the aircraft.

Tail rotor

The tail rotor prevents the helicopter from spinning as well as turns the aircraft.

Engine

The engine generates power for the aircraft. Early helicopters relied on reciprocating gasoline engines, but modern helicopters use gas turbine engines like those found in commercial airliners.

Swash plate

The pitch of main rotor blades can be varied cyclically throughout its rotation in order to control the direction of rotor thrust vector (the part of the rotor disc where the maximum thrust will be developed, front, rear, right side, etc.). Collective pitch is used to vary the magnitude of rotor thrust (increasing or decreasing thrust over the whole rotor disc at the same time). These blade pitch variations are controlled by tilting and/or raising or lowering the swash plate with the flight controls. The vast majority of helicopters maintain a constant rotor speed (RPM) during flight, leaving only the angle of attack of the blades as the sole means of adjusting thrust from the rotor.

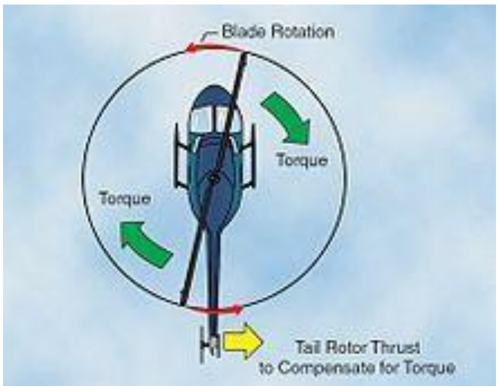
The swash plate is two concentric disks or plates, one plate rotates with the mast, connected by idle links, while the other does not rotate. The rotating plate is also connected to the individual blades through pitch links and pitch horns. The non-rotating plate is connected to links which are manipulated by pilot controls, specifically, the collective and cyclic controls. The swash plate can shift vertically and tilt. Through shifting and tilting, the non-rotating plate controls the rotating plate, which in turn controls the individual blade pitch.

HELICOPTERS CAN BE USED FOR VARIOUS PURPOSE LIKE

Types

Helicopter arrangements

Rotor configurations



Most helicopters have a single, main rotor but require a separate rotor to overcome torque. This is accomplished through a variable pitch, anti-torque rotor or tail rotor. When viewed from above, the main rotors of helicopter designs from Germany, United Kingdom, The United States and Canada rotate counter-clockwise, all others rotate clockwise. This can make it difficult when discussing aerodynamic effects on the main rotor between different designs, since the effects may manifest on opposite sides of each aircraft.

Anti-torque: Torque effect on a helicopter

With a single main rotor helicopter, the creation of torque as the engine turns the rotor creates a torque effect that causes the body of the helicopter to turn in the opposite direction of the rotor. To eliminate this effect, some sort of antitorque control must be used, with a sufficient margin of power available to allow the helicopter to maintain its heading and provide yaw control. The three most common controls used today are the traditional tail rotor, Eurocopter's Fenestron (also called a fantail), and MD Helicopters' NOTAR.

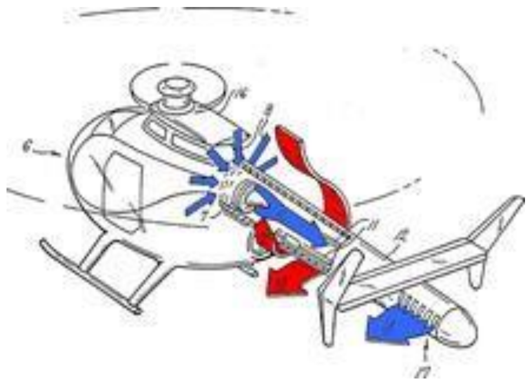
Tail rotor

The tail rotor is a smaller rotor mounted so that it rotates vertically or near-vertically at the end of the tail of a traditional single-rotor helicopter. The tail rotor's position and distance from the center of gravity allow it to develop thrust in a direction opposite of the main rotor's rotation, to counter the torque effect created by the main rotor. Tail rotors are simpler than main rotors since they require only collective changes in pitch to vary thrust. The pitch of the tail rotor blades is adjustable by the pilot via the anti-torque pedals, which also provide directional control by allowing the pilot to rotate the helicopter around its vertical axis (thereby changing the direction the craft is pointed).

Ducted fan

Fenestron and FANTAIL are trademarks for a ducted fan mounted at the end of the tail boom of the helicopter and used in place of a tail rotor. Ducted fans have between eight and 18 blades arranged with irregular spacing, so that the noise is distributed over different frequencies. The housing is integral with the aircraft skin and allows a high rotational speed, therefore a ducted fan can have a smaller size than a conventional tail rotor.

NOTAR



NOTAR, an acronym for NO-TAil Rotor, is a helicopter anti-torque system that eliminates the use of the tail rotor on a helicopter. Although the concept took some time to refine, the NOTAR system is simple in theory and works to provide antitorque the same way a wing develops lift using the Coandă effect. A variable pitch fan is enclosed in the aft fuselage section immediately forward of the tail boom and driven by the main rotor transmission. This fan forces low pressure air through two slots on the right side of the tailboom, causing the downwash from the main rotor to hug the tailboom, producing lift, and thus a measure of antitorque proportional to the amount of airflow from the rotorwash. This is augmented by a direct jet thruster (which also provides directional yaw control) and vertical stabilizers.

Tip jets

Another single main rotor configuration without a tail rotor is the tip jet rotor, where the main rotor is not driven by the mast, but from nozzles on the rotor blade tips; which are either pressurized from a fuselage-mounted gas turbine or have their own turbojet, ramjet or rocket thrusters. Although this method is simple and eliminates torque, the prototypes that have been built are less fuel efficient than conventional helicopters and produced more noise. The Percival P.74 was underpowered and was not able to achieve flight, while the Hiller YH-32 Hornet had good lifting capability but performed poorly otherwise.

Dual rotors (counter-rotating)

Counter-rotating rotors are rotorcraft configurations with a pair or more of large horizontal rotors turning in opposite directions to counteract the effects of torque on the aircraft without relying on an anti-torque tail rotor. This allows the power normally required to drive the tail rotor to be applied to the main rotors, increasing the aircraft's lifting capacity. Primarily, there are three common configurations that use the counter-rotating effect to benefit the rotorcraft.

A. Tandem

Tandem rotors are two horizontal main rotor assemblies mounted one behind the other. Tandem rotors achieve pitch attitude changes to accelerate and decelerate the helicopter through a process called differential collective pitch. To pitch forward and accelerate, the rear rotor increases collective pitch, raising the tail and the front rotor decreases collective pitch, simultaneously dipping the nose. To pitch upward while decelerating (or moving rearward), the front rotor increases collective pitch to raise the nose and the rear rotor decreases collective pitch to lower the tail. Yaw control is developed through opposing cyclic pitch in each rotor; to pivot right, the front rotor tilts right and the rear rotor tilts left, and to pivot left, the front rotor tilts left and the rear rotor tilts right.

B. Coaxial

Coaxial rotors are a pair of rotors mounted one above the other on the same shaft and turning in opposite directions. The advantage of the coaxial rotor is that, in forward flight, the lift provided by the advancing halves of each rotor compensates for the retreating half of the other, eliminating one of the key effects of dissymmetry of lift: retreating blade stall. However, other design considerations plague coaxial rotors. There is an increased mechanical complexity of the rotor system because it requires linkages and swashplates for two rotor systems.

C. Intermeshing

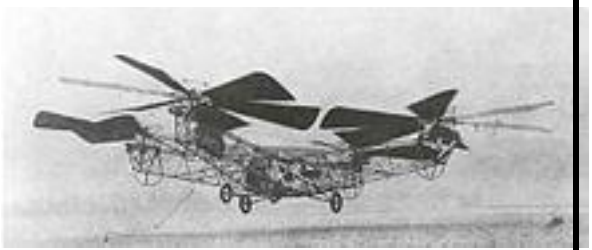
Intermeshing rotors on a helicopter are a set of two rotors turning in opposite directions, with each rotor mast mounted on the helicopter with a slight angle to the other so that the blades intermesh without colliding. This configuration is sometimes referred to as a synchropter. Intermeshing rotors have high stability and powerful lifting capability. The arrangement was successfully used in Nazi Germany for a small anti-submarine warfare helicopter, the Flettner Fl 282 Kolibri. During the Cold War, an American company, Kaman Aircraft, produced the HH-43 Huskie for the USAF

firefighting and rescue missions. The latest Kaman model, the Kaman K-MAX, is a dedicated sky crane design.

Transverse

Transverse rotors are mounted on the end of wings or outriggers, perpendicular to the body of the aircraft. Similar to tandem rotors and intermeshing rotors, the transverse rotor also uses differential collective pitch. But like the intermeshing rotors, the transverse rotors use the concept for changes in the roll attitude of the rotorcraft. This configuration is found on two of the first viable helicopters, the Focke-Wulf Fw 61 and the Focke-Achgelis Fa 223, as well as the world's largest helicopter ever built, the Mil Mi-12. It is also the configuration found on tiltrotors, such the Bell-Boeing V-22 Osprey and the Agusta Westland AW609.

Quadrotor:



A quadrotor helicopter has four rotors in an "X" configuration designated as front-left, front-right, rear-left, and rear-right. Rotors to the left and right are in a transverse configuration while those in the front and to the rear are in a tandem configuration.

The main attraction of quadrotors is their mechanical simplicity—a quadrotor helicopter using electric motors and fixed-pitch rotors has only four moving parts.

Blade design

The blades of a helicopter are long, narrow airfoils with a high aspect ratio, a shape which minimises drag from tip vortices (see the wings of a glider for comparison). They generally contain a degree of washout to reduce the lift generated at the tips, where the airflow is fastest and vortex generation would be a significant problem. Rotor blades are made out of various materials, including aluminium, composite structure and steel or titanium with abrasion shields along the leading edge. Rotorcraft blades are traditionally passive, but research into active blade control trailing edge flaps is performed.

Limitations and hazards

Helicopters with teetering rotors, for example the two-blade system on the Bell, Robinson and others, must not be subjected to a low-g condition because such rotor systems do not control the fuselage attitude. This can result in the fuselage assuming an attitude controlled by momentum and tail rotor thrust that causes the tail boom to intersect the main rotor tip-path plane, or result in the blade roots contacting the main rotor drive shaft causing the blades to separate from the hub (mast bumping).

Performance requirements of Civil and Military aircraft:

Airframe:

The structural backbone of an aircraft that balances the internal and external loads acting upon the craft is called airframe. These loads consist of internal mass inertia forces (equipment, payload, stores, fuel, and so forth), flight forces (propulsion thrust, lift, drag, maneuver, wind gusts, and so forth), and ground forces (taxi, landing, and so forth).

The strength capability of the airframe must be predictable to ensure that these applied loads can be withstood with an adequate margin of safety throughout the life of the airplane.

In addition to strength, the airframe requires structural stiffness to prevent excessive deformation under load and to provide a satisfactory natural frequency of the structure (the number of times per second the structure will vibrate when a load is suddenly imposed or changed).

The aerodynamic loads on the airframe can oscillate in magnitude under some circumstances, and if these oscillations are near the same rate as the natural frequency of the structure, runaway deflections (called flutter) and failure can occur. Consequently, adequate structural stiffness is needed to provide a natural frequency far above the danger range.

The overall airframe structure is made up of a number of separate components, each of which performs discrete individual functions. The fuselage provides the accommodations of crew, passengers, cargo, fuel, and environmental control systems.

The empennage consists of the vertical and horizontal stabilizers, which are used, respectively, for turning and pitching flight control. The wing passing through the air provides lift to the aircraft. Its related control devices, leading-edge slats and trailing-edge flaps, are used to increase this lift at slow airspeeds, such as during landing and takeoff, to prevent stalling and loss of lift. The ailerons increase lift on one side of the wing and reduce lift on the other in order to roll the airplane about its fore-and-aft axis.

Performance requirements (range, payload, speed, altitude, landing and takeoff distance, and so forth) dictate that the airframe be designed and constructed so as to minimize its weight. All the airframe material must be arranged and sized so that it is utilized as near its capacity as possible, and so that the paths between applied loads and their reactions are as direct and as short as possible. The accomplishment of these goals, however, is compromised by constraints such as maintenance of the aerodynamic shape, the location of equipment, minimum sizes or thicknesses that are practical to manufacture, and structural stability, among others.

To maintain structural efficiency (minimum weight), the material that forms the aerodynamic envelope of the airplane is also utilized as a primary load-carrying member of the airframe. For example, the thin sheets that are commonly used for outer fuselage skins are very efficient in carrying in-plane loads like tension and shear when they are stabilized (prevented from moving or deflecting out of the way when loads are applied). This structural support is provided by circumferential frames and longitudinal primary members called longerons.

The compression loads are also carried in the longerons and the thin skins when they are additionally stabilized by multiple secondary longitudinal stiffeners that are normally located between the frames. Illustration *a* shows a typical fuselage primary load path structure indicating the frames and longerons. This skeleton will be covered by thin skins.

UNIT III: Propulsion:

Thrust for Flight- Reciprocating Engines; Jet Engines:

Types of Aerospace Propulsion:

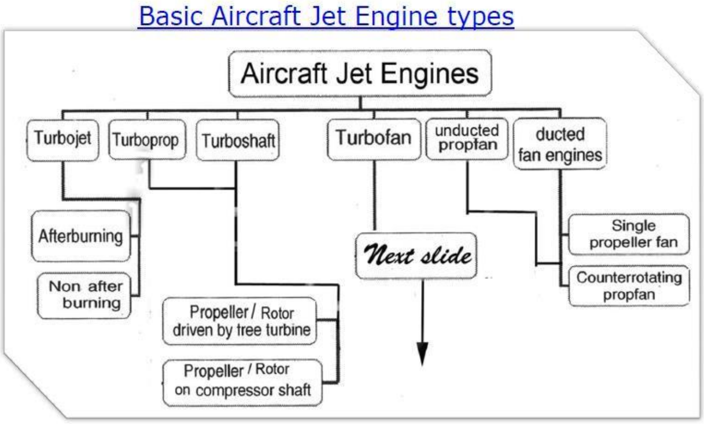
Air Breathing Systems: Broadly grouped as - Reciprocating& Jet Propulsion Engines.

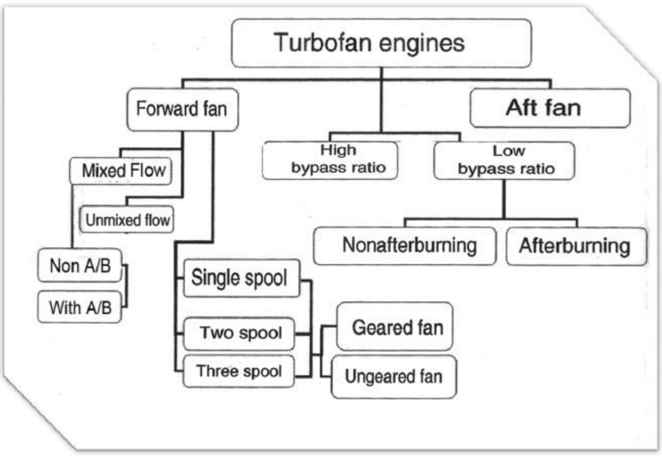
- Reciprocating Engines
- Gas Turbine Engines
- Ram Jets, Pulse Jets & Scram Jets

Non Air Breathing Systems

- Rockets

Basic Aircraft Jet Engine types





Working Principles, Advantages/Disadvantages & Applications:

Reciprocating Engines (I.C Engine): Working Principle: The four strokes of an Internal Combustion (I.C) engine are Intake, Compression, Power and Exhaust strokes.

During intake stroke, the piston moves downwards and the mixture of fuel and air (charge) is admitted in to the cylinder. At the completion of intake stroke, the inlet valve closes.

During the compression stroke, the piston moves up, compressing the charge. At the end of compression stroke, the electric spark ignites the charge.

On ignition, combustion of air fuel mixture releases thermal energy, exerting high force on the piston. This commences the power stroke.

During the power stroke, the piston is driven downwards.

Once the power stroke is completed, the exhaust valve opens. While the piston is moving up, the combustion gases are driven out of the cylinder through the exhaust valve. This creates a suction in the cylinder, that initiates the next cycle of operations.

The reciprocating movement of piston is transmitted to the crankshaft and converted into rotary motion. The crankshaft is connected to the propeller, which produces the forward thrust force for the aircraft.

The rotating output shaft of the I.C engine can be connected to a propeller, ducted fan, or helicopter rotor.

The propeller displaces a large mass of air rearwards, accelerating it in the process.

Reciprocating engines can produce up to 4000 KW power. Power to weight ratio (P/W) of up to 1.4 is produced.

The power produced by an I.C engine is given by

$P = \frac{KNV_c\rho_{air} f Q_f \eta_o}{60}$ where

K = constant; either 1.0 for 2 stroke engine or 0.5 for 4 stroke engine

N = rpm (around 5000-9000 rpm)

V_c = Volume of the cylinder

ρ_{air} = density of air

f = fuel air ratio (usually 13 to 15 ie one part fuel to 15 parts of air to burn the fuel completely)

Q_f = Calorific value of fuel (kerosene- 42 MJ/kg)

η_o = overall efficiency (usually 0.25 to 0.35)

$KNV_c\rho_{air}$ is the mass flow rate ingested in to the engine

- Multiplying mass flow rate with f gives the amount of fuel
- Multiplying with Q_f gives the heat energy released

To increase the power of the I.C engine, we need to

- Increase N –increases P
- As altitude increases ρ decreases, and P reduces. To offset this, turbo superchargers are used.

Advantages of Reciprocating Engines:

- Reciprocating engines provide excellent fuel economy and good take-off characteristics within their range of operations
- Highly suitable for small aircraft flying up to 500 km/hr and operating at low altitudes
- Components of reciprocating engines are subjected less thermal stresses than gas turbine-propeller combination
- Aircraft fitted with reciprocating engines need short runways
- Mainly used for business travel, farming & agriculture, air-taxi/ambulance, pilot training and unmanned aerial vehicles

Disadvantages of Reciprocating Engines:

- Reciprocating engines suffer drop in power at altitudes
- Difficulty in cooling and lubrication
- Low Power/Weight ratios compared to gas turbine engines
- Need high octane fuels to improve power output
- Increase in power output require larger number of cylinders, thereby increasing the frontal area and weight
- Use of reciprocating engines is limited to low speeds and altitudes
- Development reached a saturation stage as far as maximum power is concerned
- Maintenance requirement of piston-prop engines is more than turbojet aircraft
- Exhaust gases have less impurities in turbojet engines

Aircraft gas turbine Engines

All modern aircraft are fitted with gas turbine engines. Gas turbine engines can be classified into the following:-

(a) Turbojet engines

(b) Turbofan engines

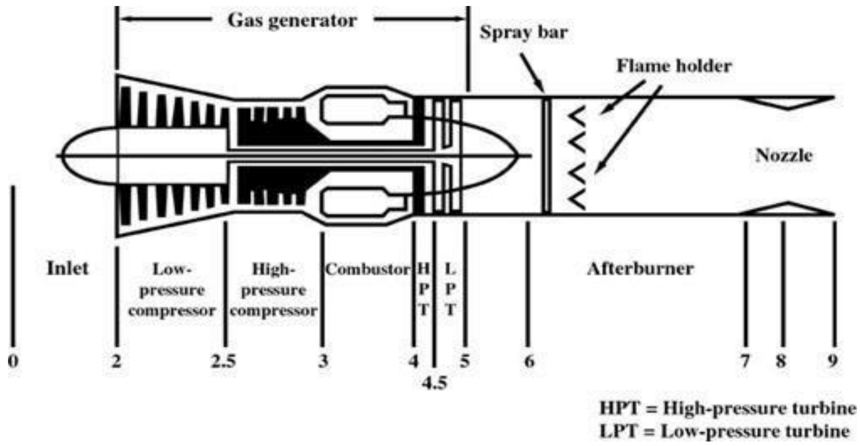
(c) Turbo-shaft engines

(d) Turboprop engines

Taken in the above order they provide propulsive jets of increasing mass flow and decreasing jet velocity. Therefore, in that order, it will be seen that the turbojet engines can be used for highest cruising speed whereas the turboprop engine will be useful for the lower cruising speed at low altitudes.

In practice the choice of power plant will depend on the required cruising speed, desired range of the aircraft and maximum rate of climb.

Turbojet Engine: Schematic diagram of a turbojet engine with station numbering is given below:



Working Principle:

1. The thrust of a turbojet engine is developed by compressing the free stream air in the diffuser or inlet and compressor. The diffuser converts the kinetic energy of the entering air into pressure rise which is achieved by ram effect. Diffusion in the inlet occurs due the geometric shaping of the inlet.
2. The compressor is driven by the turbine. It rotates at high speed, adding energy to the airflow and at the same time squeezing (compressing) it into a smaller space. Compressing the air increases its pressure and temperature
3. Compressor types used in turbojets were typically axial or centrifugal.
4. Use of axial flow compressors enable high pressure ratios. Modern axial compressors are split into low pressure and high pressure spools, driven by corresponding two stage turbine. High compressor ratios of 15:1 or more can be achieved while improving stability of operation at off-design conditions. The high pressure air is then mixed with fuel and burnt in the combustion chamber under constant pressure condition.

5. The combustion gasses at high temperature and pressure are expanded in the turbine and the exhaust nozzle. The expansion of gasses in the turbine provides power to drive the compressor while the exhaust nozzle expands the gasses to atmospheric pressure, thereby producing propulsive force, thrust.
6. The net thrust delivered by the engine is the result of converting internal energy to kinetic energy.
7. The exhaust products downstream of the turbine still contain adequate amount of oxygen. Additional thrust augmentation can be achieved by providing an afterburner in the jet pipe in which additional amounts of fuel can be burnt.
8. Turbojet engines are most suitable for speeds above 800 km/hr and up to 3.0 mach number

Advantages of Turbojet:

1. Power to Weight ratio is about 4 times that of Piston-Prop combination
2. Simple, easy to maintain, requires lower lubricating oil consumption. Complete absence of liquid cooling reduces frontal area
3. Turbojets allow faster supersonic speeds up to 3.0 M
4. There is no limit to power output while piston engines reached their peak power, beyond which any increase will result in high complexity and greater weight/frontal area.
5. Speed of turbojet is not limited by the propeller.
6. Turbojets can attain higher speeds than turboprop aircraft

Disadvantages-Turbojet:

- Fuel economy at low operational speeds is very poor
- It has low take-off thrust and hence poor starting characteristics
- High operating temperatures and engine parts are subjected to thermal stresses

Application: Turbojet engine is highly suited for aircraft at speeds above 800 km/hr.

Advantages of Gas turbines over Reciprocating Engines:

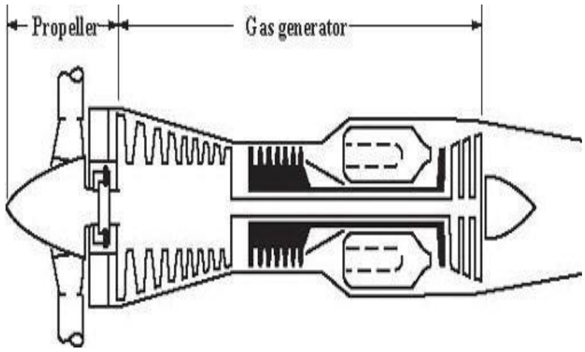
- **Mechanical Efficiency**: Mechanical efficiency of gas turbine engines is higher than reciprocating engines. This is mainly due to high friction losses in reciprocating engines.
- **Balancing**: Due to absence of reciprocating mass in gas turbine engines, balancing can be near perfect. Torsional vibrations are absent because gas turbine is a flow machine.

- **Smooth & Vibration-free operation**: Turboprop engines have fewer moving parts than piston-prop engines, offering greater reliability and time-between-overhaul (TBO).
- **Power**: The higher power of a turbo-prop engine allows it to fly at higher speeds and altitudes.
- **Shape**: Gas turbine engines have streamlined shape suitable from aerodynamic point of view.
- **Fuel**: Aviation turbine fuel is much cheaper than the high octane fuels used by reciprocating engines.
- **Lower Cost**: For a given power, gas turbine engine has lower cost and can be built faster
- **Weight:** Gas turbine engines have higher power-to-weight ratios. This means, for a given weight, gas turbine engines develop more power.
- **Lubrication:** Lubrication in gas turbine engines is much simpler than reciprocating engines. The requirement is chiefly to lubricate the main bearing, compressor shaft and bearing auxiliaries.
- **High operational speed:** Turbine can be run at much higher speed than reciprocating engine. Turbine can also be made lighter than the reciprocating engine of similar output. Therefore, for a given output, and higher speed, the torque can be lower. Gas turbine engines have better torque characteristics.
- **Silent Operation:** Since exhaust from gas turbine engines occurs under practically constant pressure conditions unlike the pulsating nature of the reciprocating engine exhaust, the usual vibrational noises will be absent in gas turbine engines.
- **Maintenance:** Relatively simpler in case of gas turbine engines.

Advantages of Reciprocating Engines over Gas turbine Engines:

- **Efficiency**: The overall efficiency of gas turbine engines is much less than the reciprocating engines.
- **Temperature Limitation**: The turbine blades in gas turbine engine are exposed to high temperature gasses continuously, and hence cannot exceed 1500 K.
- **Cooling**: We can achieve very good results by cooling the cylinder walls effectively. Cooling of turbine blades is complicated.
- **Ease of Starting**: It is more difficult to start a gas turbine than a a reciprocating engine.
- **Complexity**: Reciprocating engines are far less complex than their turbo-prop counter parts, from engineering considerations. This is primarily because of the high temperatures and forces unique to turbo-prop engine operation, which must be accommodated from materials and engine design.

Turboprop Engine: Schematic diagram is given below:



Working Principle: Turboprop engine is an intermediate between a pure jet engine and a propeller engine.

Turboprop engine provides high thrust per unit mass flow of fuel burnt by increasing mass flow of air. It offers better fuel economy. The propeller displaces a large mass of air rearwards, thereby increasing the net thrust.

The turbine extracts more power from the combustion gasses to drive the propeller. A small remaining energy is extracted by expansion in the jet nozzle.

The propeller and the compressor may be mounted on a single shaft or on separate shafts with a free turbine driving the propeller.

Advantages:

Turboprop engines have a higher thrust at take-off and better fuel economy.

The engine can operate economically over a wide range of speeds ranging from low speeds, where turbojet is uneconomical, to high speeds of about 800 km/hr where piston-prop engine cannot operate efficiently

It is easy to maintain and has lower vibration levels than piston-prop engine. The frontal area is much less than corresponding piston-prop engine.

Disadvantages:

The main disadvantage is that the propeller efficiency decreases greatly at high speeds due flow separation and shocks. The maximum speed is thus limited.

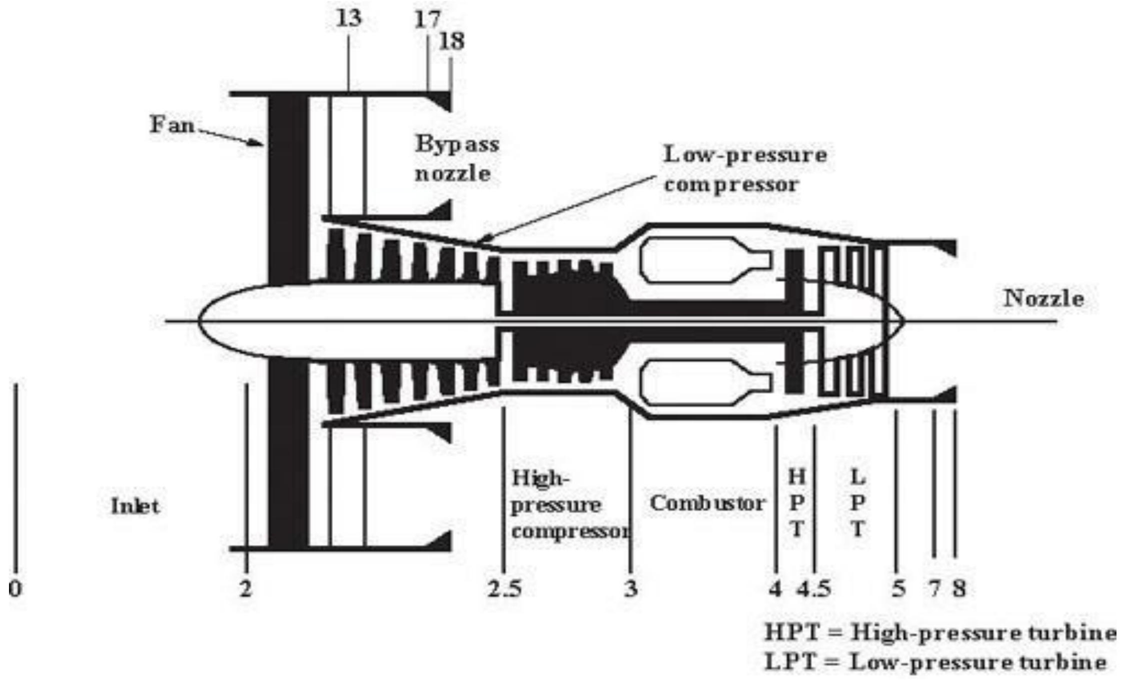
The turbine speeds need to be reduced through a suitable reduction gearing so that propeller runs at lower speeds, which adds to weight.

Applications:

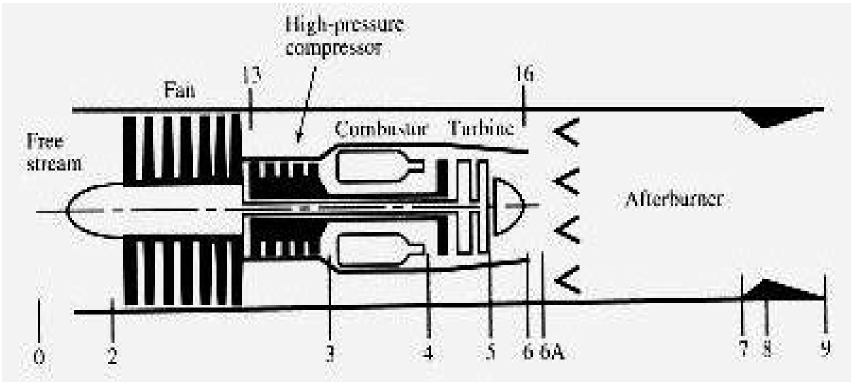
The turboprop engine is widely used in commercial and military aircraft due to its flexibility of operation and good fuel economy.

Turbofan Engine

Schematic Diagram of Turbofan (with station numbering): High by-pass ratio (used for commercial aircraft)



Turbofan with afterburner & Mixed flow: Low by-pass ratio (used for military aircraft)



Turbofan engine is designed as a compromise between turbojet and turboprop engines. The turbofan engine consists of a fan larger in diameter than the compressor, driven by the turbine. The fan displaces/bypasses free stream air around the primary engine. Two streams of air flow through the engine, primary airstream pass through the compressor and is delivered to the combustion chamber at high pressure to mix with fuel, while the other stream bypasses the primary engine to be expanded in the nozzle as a cold stream. The **hot and cold streams may be expanded through separate nozzles or combined together through a single nozzle**. The ratio of mass of cold air to the hot air is the by-pass ratio.

Thus the turbofan accelerates a larger mass of air at lower velocity than turbojet for a higher propulsive efficiency. Turbofan engines can also employ afterburner for higher thrust.

Turbofan engines can be aft-fan or forward fan (position of the fan), mixed or unmixed(hot and cold air streams) and high and low bypass ratio configuration

Advantages:

Fan is not as large as the propeller, therefore higher aircraft speeds can be attained without facing flow separation problems.

Turbofan engines do not encounter vibration problems associated with propellers. The fan could be encased in a duct/cowling to provide better aerodynamic shape.

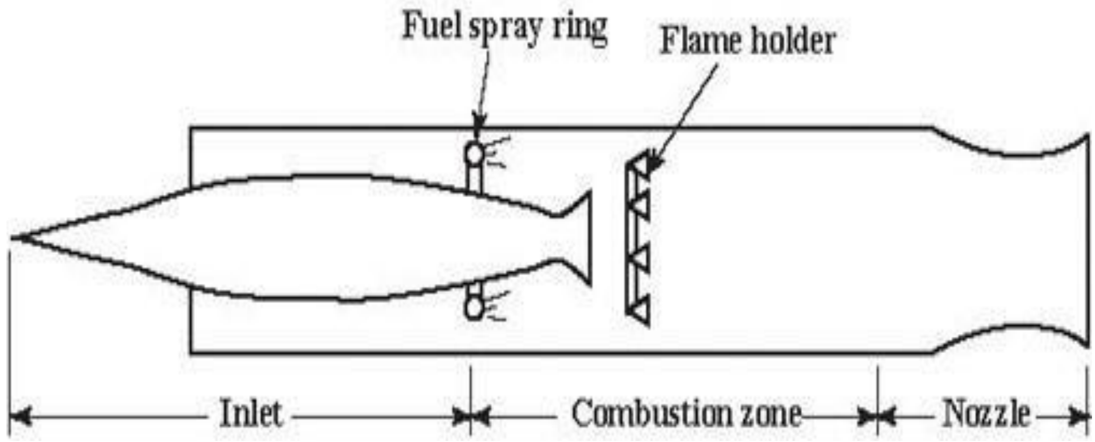
A **geared fan** connected to turbine reduces power consumed by the fan. It also produces low sound.

Turbofan is fuel efficient than turbojet, offers better propulsive efficiencies.

Lowers the sound levels of the exhaust gasses

Ramjet Engine

Schematic Diagram:



Operating Principle:

Ramjet Engine consists of supersonic diffuser, subsonic diffuser, combustion chamber and nozzle section

Air from atmosphere enters the supersonic diffuser at a very high speed. The air velocity gets reduced in the supersonic diffuser through normal and oblique shock waves.

Air velocity is furthur reduced in the subsonic diffuser.

The diffuser converts the kinetic energy of the entering air into static pressure and temperature rise which is achieved by ram effect. Diffusion in the inlet also occurs due the geometric shaping of the diffuser. The diffuser thus slows down the air enabling combustion.

Fuel is injected into the combustor through suitable injectors causing mixing of fuel with the air and the mixture is burnt

Combustion gases attain a temperature of around 1500-2000 k by continuous combustion of fuel air mixture

Fresh air supply continuously will not allow gasses towards the diffuser. Instead, gases are made to expand towards the tail pipe and nozzle, which expands the gases completely.

The gases leave the engine with a speed much higher than the air entering the engine.

The rate of increase of momentum of the working fluid produces thrust F in the direction of flight

Distinguishing Features:

Air enters the engine at supersonic speeds, must be slowed down to subsonic value, to prevent blow out of the flame in the combustor

Velocity must be low enough (approximately around 0.2-0.4 mach number) to allow mixing of fuel and stable combustion

Cycle pressure ratio depends on the diffusion pressure ratio. Very high pressure ratios of about 8 to 10 through ram compression is possible, therefore, a mechanical compressor is not required

Slowing down speeds from mach 3.0 to 0.3 will result in a pressure ratio of more than 30

As the ram pressure increases, a condition is reached where the nozzle gets choked. Thereafter, the nozzle operates at Mach 1 condition at throat

Advantages:

Ramjet is a simple machine and does not have any moving parts

Since turbine is not used, maximum temperature allowed is very high, around 2000 C, as compared to around 900 C in turbojets.

We can burn air/fuel ratios of 13:1which gives greater thrust

Specific fuel consumption is much better than other gas turbine engines, at high speeds and altitudes

Wide range of fuels can be used

It is very cheap to produce; adoptable for mass production

It is not possible to start a ramjet engine without an external launching device

The engine heavily relies on the diffuser and it is very difficult to design a diffuser which gives good pressure recovery over a wide range of speeds

Due to high air speed, the combustion chamber requires flame holders to stabilize the combustion

At very high temperatures of about 2000 C, dissociation of combustion products take place, reducing the efficiency of the plant

High fuel consumption at low speeds

Applications:

Highly suitable for propelling missiles.

Used in high speed military aircraft, in a combined cycle engine (Turbojet-Ramjet combination).

Development is in progress for a hypersonic aircraft system using turbojet-ram-scramjet combined cycle.

Subsonic ramjets are used as target weapons in conjunction with turbojet aircraft.

Pulsejet Engine:

Schematic Diagram:

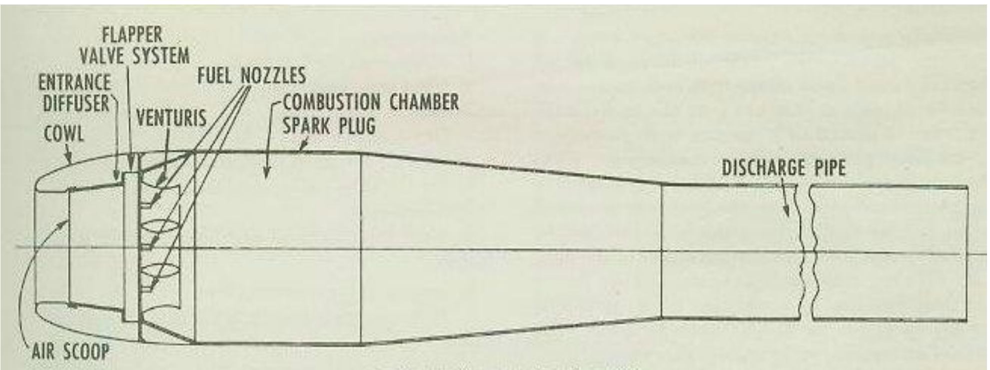


FIGURE 11D3.—A pulse-jet engine.

Basic Components are diffuser, Valve grid with spring loaded flapper valves, Combustion chamber with spark plug, tail pipe and discharge nozzle

Operation:

The diffuser converts the kinetic energy of the entering air into static pressure rise and slows down the air. Ram action also builds pressure in the diffuser.

The pressure differential opens the flapper valves which are spring loaded and the high pressure air enters the combustion chamber.

Fuel is injected and ignited by the spark plug

Combustion proceeds at constant volume with sudden explosion.

There is a sudden pressure rises in the combustion chamber which closes the flapper valves

The combustion gasses expand in the nozzle and escape to the atmosphere at high velocity

As combustion products leave the combustion chamber, a low pressure is created which causes the valves to open and a new charge of air enters the chamber

Distinguishing feature: Since the combustion chamber builds pressure, the engine can operate in static condition also. Proper design makes the duct to fire at a given pulse rate which can be as high as 500 cycles/sec

Advantages:

1. Simple to construct and hence cheap.
2. Can be mass produced in a short time.
3. Since it does not have any moving parts like compressor of turbine, it can be used in high temperatures.
4. Can be used for military applications.

Disadvantages:

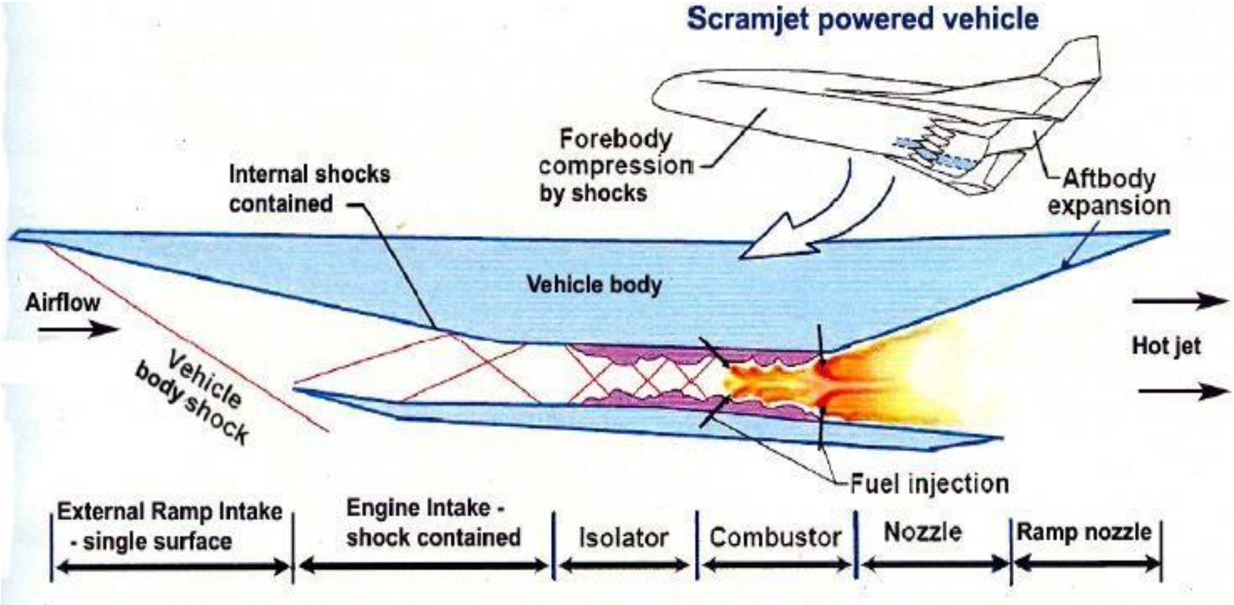
1. It is having limited flight speed only.
2. Limited flying altitude.
3. High vibration and noise due to the pulses of thrust produced

Scramjet Engine:

- Scramjet engine stands for supersonic combustion ramjet engine.
- The flow speed in the combustion chamber is supersonic
- Scramjet engine is characterized by high flow speeds ie low residence times in the engine.
- The engine needs larger combustion volumes; leading to integrated design of airframe and engine.
- In scramjet aircraft, the entire lower body of the aircraft is occupied by the engine. The front portion of the underside operates as external/internal diffuser, with rear portion providing expansion surface.

The scramjet consists of

- Diffuser (compression component) consisting of external ramp intake and engine intake
- Isolator
- Supersonic combustor
- Exhaust nozzle or aft body expansion component



Scramjet Engine- Construction: Scramjet engine is characterized by slow reaction times and high flow speeds ie low residence times in the engine. The engine needs larger combustion volumes; leading to integrated design of airframe and engine. In scramjet aircraft, the entire lower body of the aircraft is occupied by the engine. The front (fore) portion of the underside operates as external/internal diffuser, with rear (aft) portion providing expansion surface.

The scramjet consists of

- Diffuser (compression component) consisting of external ramp intake and engine intake
- Isolator
- Supersonic combustor
- Exhaust nozzle or aft body expansion component

Diffuser

- It consists of fore-body external intake and internal intake
- The fore-body provides the initial external compression and contributes to the drag and moments of the vehicle.
- The internal inlet compression provides the final compression of the propulsion cycle.

Since the flow upstream is supersonic, the geometry of the diffuser is entirely convergent.

Isolator: Isolator is constant area diffuser containing the internal shock structure, swallowed during supercritical operation of the inlet (or during operation after the inlet "started"). The isolator is inserted before the combustor to diffuse the flow further, through a shock train, producing desired flow speeds in the combustors. The function of the isolator is:

- The shock train provides a mechanism for the supersonic flow to adjust to a static back pressure higher than its inlet static pressure
- The isolator cross-sectional area may be constant or slightly divergent to accommodate boundary layer separation.
- When the combustion process begins to separate the boundary layer in the combustor, a pre-combustion shock train forms.
- The shock structure allows the required pressure rise, thus isolating the combustion process from the inlet compression process. Thus the isolator functions to prevent inlet surge or "unstart".

Combustor: Main features include:

- Avoidance of hot pockets near the walls implies that the fuel be injected from centrally located struts.
- The usual circular configuration for combustors can be sacrificed in favor of a rectangular configuration.
- Typical velocities in the combustion chamber are about 1 to 1.5 km/s and the Mach numbers will be 1.4 to 2.3 for a typical combustor entry Mach number of 2.5

Combustion limits: Two limits are very critical for the operation

- First, since when a supersonic flow is compressed, it slows down, the level of compression must be low enough (or the initial speed high enough) not to slow the gas below Mach 1. If the gas within a scramjet goes below Mach 1 the engine will "choke", transitioning to subsonic flow in the combustion chamber. Additionally, the sudden increase in pressure and temperature in the engine can lead to an acceleration of the combustion, leading to the combustion chamber exploding.
- Second, the heating of the gas by combustion causes the speed of sound in the gas to increase (through increase of $\sqrt{t}$ and hence cause Mach number to decrease) even though the gas is still travelling at the same speed. Forcing the speed of air flow in the combustion chamber under Mach 1 in this way is called "**thermal choking**".
- A thermal throat results when the flow is slowed through tailored heat for causing dual-mode operation.
- There are engine designs where a ramjet transforms into a scramjet over the Mach 3-6 range, known as dual-mode scramjets.

Expansion System:

- The expansion system, consists of
  - a. Internal nozzle
  - b. Vehicle aft body
- It completes the propulsion flow path and controls the expansion of the high pressure and temperature gas mixture to produce net thrust.

Applications of Scramjets:

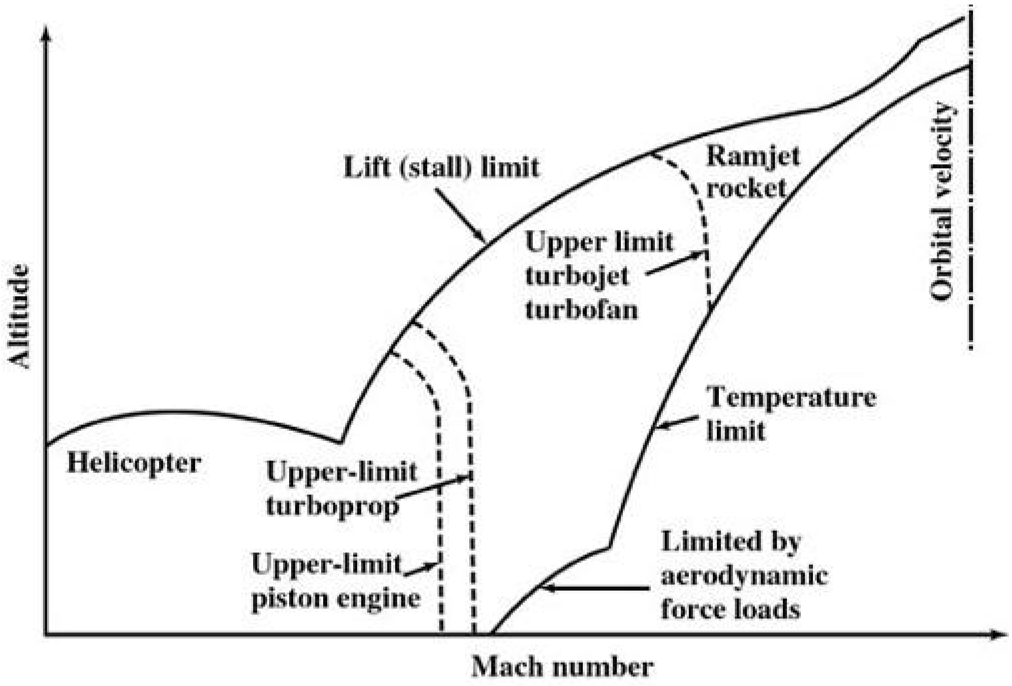
- Weapons systems -hypersonic cruise missiles
- Aircraft systems - global strike / reconnaissance
- Space access systems that will take off and land horizontally like commercial Airplanes
- Using these Scramjet technologies, along with additional ground-and flight-test experiments, will pave the way for affordable and reusable air-breathing hypersonic propulsion systems such as missiles, long range aircraft and space-access vehicles

Advantages:

1. Need not carry oxygen on board
2. No rotating parts makes it easier to manufacture than a turbojet

3. Has a higher specific impulse (change in momentum per unit of propellant) than a rocket engine; could provide between 1000 and 4000 seconds, while a rocket only provides 450 seconds or less
4. Higher speed could mean cheaper access to outer space in the future

Flight Limits/Operating Envelope:



Missiles:

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 :

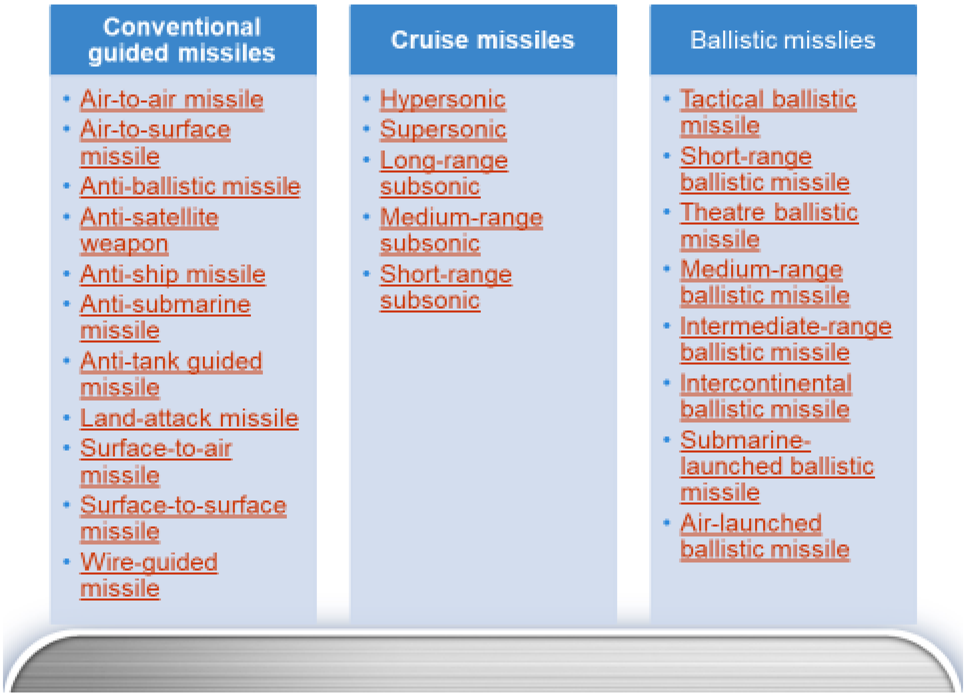
Guided missiles have a number of different system components:

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

Basic categorization

Missiles are generally categorized by their launch platform and intended target. Other kinds of military missiles are Glide- Bombs , Torpedos etc.

Their basic types are



Space Launch Vehicle:

A **launch vehicle** is the rocket we see sitting on the launch pad during countdown. In spaceflight a **launch vehicle** or **carrier rocket** is a rocket used to **carry a payload from the Earth's surface into outer space**. A **launch system** includes the launch vehicle, the launch pad and other infrastructure.

ROLE :

- It provides the **necessary velocity change** to get a spacecraft into space.
- At lift-off, the launch vehicle blasts almost straight up to gain altitude rapidly and get out of the dense atmosphere which slows it down due to drag. When it gets high enough, it slowly pitches over to gain horizontal velocity.

A launch vehicle consists of a series of smaller rockets that ignite, provide thrust, and then burn out in succession, each one handing off to the next one like runners in a relay race. These smaller rockets are **stages.** In most cases, a launch vehicle uses at least three stages to reach the mission orbit.

The Role and Design mission of an aircraft

The role and design mission of an aircraft refer to its intended purpose and the specific operational requirements it must fulfil. The role could vary from commercial transport, military operations, cargo delivery, surveillance, or specialized functions like firefighting or search and rescue. The design mission encompasses factors such as range, payload capacity, speed, endurance, altitude, and environmental conditions the aircraft must withstand. Engineers consider these parameters to optimize the aircraft's performance, ensuring it can meet mission-specific demands while maintaining efficiency, safety, and regulatory compliance. Design trade-offs are often made to balance cost, weight, and mission versatility.

The role of an aircraft defines its primary function, which directly impacts its design, systems, and performance requirements. Roles can include:

1. **Commercial aviation**: Transporting passengers (e.g., Boeing 787, Airbus A320) or cargo (e.g., Boeing 747F).
2. **Military aviation**: Roles such as fighters (e.g., F-22 Raptor), bombers (e.g., B-2 Spirit), transport (e.g., C-130 Hercules), reconnaissance (e.g., Global Hawk), and unmanned combat vehicles (e.g., MQ-9 Reaper).
3. **General aviation**: Private, business, or leisure flights (e.g., Cessna 172, Gulfstream G650).
4. **Specialized functions**: Includes roles like search and rescue (e.g., Sikorsky S-92), aerial refuelling (e.g., KC-135), firefighting (e.g., Bombardier 415), and medical evacuation.

The **design mission** outlines the operational objectives the aircraft must achieve, shaping its configuration and technology. A typical design mission defines:

1. **Range**: The distance an aircraft can travel without refuelling. For long-range aircraft (e.g., Boeing 777X), maximizing range influences fuel capacity and engine efficiency.
2. **Payload**: The weight of passengers, cargo, weapons, or equipment the aircraft is designed to carry. For a cargo plane (e.g., Antonov An-225), payload capacity defines the structure and power needed for heavy loads.
3. **Speed and manoeuvrability**: High-speed jets require aerodynamic optimizations for supersonic flight (e.g., Concorde), while slow-speed aircraft focus on fuel efficiency and stability.
4. **Endurance**: How long an aircraft can stay airborne, critical for roles like long-duration surveillance (e.g., RQ-4 Global Hawk).
5. **Altitude**: Aircraft designed for high-altitude missions, like reconnaissance planes (e.g., Lockheed U-2), need specialized pressurization and aerodynamics for thin air operations.
6. **Environmental and operational conditions**: Design accounts for temperature extremes, adverse weather, runway types, and battlefield conditions.

Balancing these factors involves trade-offs between aerodynamic efficiency, structural weight, fuel capacity, engine performance, and mission flexibility. For instance, commercial airliners prioritize fuel efficiency and passenger comfort over speed, while fighter jets focus on agility, speed, and combat readiness at the cost of higher fuel consumption.

Specification of the performance requirements and mission profile

Performance requirements and **mission profiles** are critical aspects in the design of an aircraft, directly shaping its technical specifications. These include:

1. Performance Requirements

Performance requirements ensure the aircraft can achieve its mission objectives efficiently and safely. They include:

- **Range**: The maximum distance the aircraft can fly without refuelling. Commercial aircraft may have a range of 3,000 to 8,000 nautical miles (e.g., Boeing 787 Dreamliner: ~7,530 nm).
- **Speed**: Defined as cruise speed, maximum speed, and stall speed.
  - **Cruise speed**: Optimal speed for fuel efficiency (e.g., 0.85 Mach for a long-range jet).
  - **Max speed**: Typically, higher for military jets (e.g., F-22 Raptor can exceed Mach 2).
- **Payload capacity**: The total weight of passengers, cargo, or weapons. For commercial aircraft, payload includes passengers and luggage (e.g., Boeing 777: 84,000 kg cargo). For military, it includes weapons (e.g., F-35: ~18,000 lbs external payload).
- **Endurance**: How long the aircraft can remain airborne (important for patrol or surveillance missions). The RQ-4 Global Hawk, for example, has an endurance of over 32 hours.
- **Service ceiling**: The maximum altitude an aircraft can reach and maintain. Civil airliners typically cruise at ~35,000-40,000 ft, while specialized military aircraft, such as the Lockheed U-2, can fly above 70,000 ft.
- **Take-off and landing performance**:
  - **Take-off distance**: Runway length needed to achieve liftoff.
  - **Landing distance**: Runway length required for a safe stop, both impacted by weight, configuration, and engine thrust.
  - Short take-off and landing (STOL) requirements, like for military transport aircraft, necessitate specific wing and engine designs.
- **Climb rate**: How fast the aircraft can ascend to its operational altitude, critical for military or emergency aircraft where rapid deployment is essential.

- **Fuel efficiency**: Measured as fuel consumption per nautical mile (specific fuel consumption, SFC). This is a key consideration for commercial aircraft aiming to reduce operational costs.

2. Mission Profile

A mission profile is a detailed description of the operational scenario the aircraft is designed for. It includes:

- **Phases of flight**:
  - **Takeoff**: Includes aircraft weight, engine thrust, and runway length considerations.
  - **Climb**: Altitude and speed profiles for ascending.
  - **Cruise**: Optimal flight level, speed, and fuel consumption for the longest segment of the mission.
  - **Descent**: Planned descent rate and procedures to minimize fuel consumption and maximize safety.
  - **Landing**: Involves deceleration, approach speed, and runway conditions.
- **Mission duration**: For military aircraft, it may involve flying to a target, completing an operation (e.g., strike, surveillance), and returning. For commercial, it's the duration from departure to arrival including potential layovers.
- **Operational conditions**:
  - **Weather**: Ability to operate in adverse conditions like storms, high winds, or icing.
  - **Runway type and length**: Some aircraft are designed for rugged terrain (e.g., military transports like C-130 can operate on unpaved runways).
- **Payload and range trade-offs**: The mission profile often defines how much payload (passengers, cargo, or weapons) an aircraft can carry over a specific range. More payload usually means reduced range due to higher fuel consumption.
- **Combat radius** (for military aircraft): The distance an aircraft can fly from a base to complete a mission and return without refuelling. This may include engaging in combat operations, which requires extra fuel reserves.
- **Special requirements**: Certain missions require unique configurations like:
  - **Aerial refuelling**: Extending the range by refuelling mid-flight.
  - **Loiter time**: How long the aircraft can stay over a target area, important for surveillance drones or aircraft like the E-3 AWACS.
  - **Manoeuvrability**: Military aircraft require high agility for dogfights or evasive manoeuvres.

For example, a fighter jet's mission profile might include:

- Rapid take-off.
- A high-speed supersonic dash to the target.
- Engagement in combat or weapon delivery.
- Evasive manoeuvres or air combat operations.
- Returning to base with enough fuel reserves for emergencies.

By defining performance requirements and mission profiles, engineers ensure that the aircraft meets all operational needs while remaining efficient, safe, and cost-effective.

Off-standard and design atmosphere

In aircraft design, understanding atmospheric conditions is crucial for predicting performance. Typically, engineers use **standard atmosphere models**, but real-world conditions often deviate from this, referred to as **off-standard atmosphere**. Here's an explanation of both **standard atmosphere** and **off-standard atmosphere**, as well as how design is adapted for these conditions.

1. Standard Atmosphere

The **International Standard Atmosphere (ISA)** is a reference model used to simulate atmospheric conditions. It provides standard values for temperature, pressure, and density at various altitudes. The standard atmosphere assumes:

- **Sea-level conditions**:
  - Temperature: 15°C (59°F)
  - Pressure: 1013.25 hPa (hectopascals)
  - Density: 1.225 kg/m³
- **Temperature lapse rate**: A decrease of 6.5°C per kilometer of altitude up to 11 km (36,089 feet), beyond which the temperature remains constant in the tropopause (~56°C).

This model is useful for performance calculations and design under "ideal" conditions.

2. Off-Standard Atmosphere

Off-standard atmosphere refers to real-world atmospheric conditions that deviate from the ISA. These deviations arise due to:

- **Temperature variations**: Warmer or colder air than standard values.
- **Pressure anomalies**: Higher or lower atmospheric pressure at a given altitude.
- **Humidity effects**: Increased humidity alters air density and engine performance.

These off-standard conditions can significantly affect aircraft performance, including:

- **Lift**: As air density decreases in warmer or higher-altitude conditions, lift is reduced, requiring adjustments in wing design or operational procedures.
- **Engine thrust**: Jet engines produce less thrust in hot and high-altitude environments (often referred to as "hot and high" conditions).
- **Fuel efficiency**: Different temperatures and densities affect fuel burn rates, which can change the expected range and endurance of the aircraft.

For instance, an aircraft operating in a tropical region where the temperature is significantly higher than the ISA would experience a reduction in engine thrust and lift. This would require more runway length for take-off and potentially reduced payload.

3. Design Atmosphere

Designers often create aircraft to perform optimally under **non-standard atmospheric conditions** expected in specific regions or missions. For example:

- **High-altitude designs**: Aircraft like the U-2 spy plane are designed to operate efficiently at altitudes above 70,000 feet, where the atmosphere is much thinner than the standard model predicts.
- **Hot and high operations**: Aircraft designed to operate from airports in hot climates and high elevations (like Denver or Johannesburg) require engines and wing configurations optimized for low-density air. Pilots may need to reduce payload or adjust flight paths to compensate for reduced performance.

4. Factors Considered for Off-Standard Atmosphere

In designing for off-standard atmospheres, the following adjustments are made:

- **Wing design**: For low-density environments, larger wings or high-lift devices like slats and flaps are used to increase lift.
- **Engine power**: High-altitude or high-temperature performance requires more powerful engines or engines with better performance retention in hot conditions.
- **Cooling systems**: In hotter climates, additional cooling might be required for engines and avionics.
- **Fuel capacity adjustments**: Aircraft flying in off-standard atmospheres may require different fuel consumption models, increasing fuel storage to account for less efficient engine performance.

Example: Hot and High Operation

An aircraft designed for an airport like **La Paz, Bolivia**, at 13,325 feet (4,061 meters) above sea level, operates in much thinner air than standard. Here’s how design compensates:

- **Thrust-to-weight ratio**: Engines with high thrust output or additional performance features (e.g., afterburners in military jets).
- **Wing design**: Larger surface area or high-lift devices to compensate for reduced lift in thin air.

- **Operational procedures**: Pilots may use longer take-off rolls, higher climb rates, or reduced payload for safety and performance.

In summary, while the **standard atmosphere** provides a baseline for aircraft performance, real-world conditions (off-standard atmospheres) require aircraft to be designed and operated with flexibility. This ensures that they perform reliably in varied environments, from the dense air at sea level to the thin, warm air at high altitudes.

Measurement of air data

The **measurement of air data** is crucial for determining an aircraft's flight parameters such as altitude, airspeed, and atmospheric conditions. This data is essential for safe and efficient flight operations. Air data is measured using specialized sensors and instruments that provide accurate readings of pressure, temperature, and other relevant atmospheric variables. Here's an overview of the key air data measurements and systems used in aircraft:

1. Types of Air Data Measurements

1. **Static Pressure**:
   - **What it is**: The atmospheric pressure at the altitude where the aircraft is flying.
   - **How it's measured**: Measured using a **static port**, which is typically located on the side of the fuselage to avoid airflow disturbances.
   - **Purpose**: Used to calculate altitude and vertical speed.
2. **Dynamic Pressure**:
   - **What it is**: The difference between the total pressure (impact pressure from the airflow) and static pressure, representing the pressure due to the aircraft's motion through the air.
   - **How it's measured**: Measured by a **Pitot tube**, which captures the total pressure (dynamic + static) at the aircraft's forward-facing surface.
   - **Purpose**: Used to determine airspeed.
3. **Total Pressure** (or **Pitot Pressure**):
   - **What it is**: The pressure felt by the aircraft due to both its motion (dynamic pressure) and the ambient air pressure (static pressure).
   - **How it's measured**: Also by the Pitot tube.
   - **Purpose**: Serves as the raw data for calculating true airspeed.
4. **Temperature**:
   - **What it is**: The temperature of the air surrounding the aircraft.

- **How it's measured**: Sensors called **air temperature probes** or **thermometers** are mounted in the airstream but shielded to avoid direct heating from the aircraft structure.
- **Purpose**: Used for engine performance, calculating true airspeed, and assessing environmental conditions (e.g., icing).

5. **Altitude**:
    - **What it is**: The height of the aircraft above a given reference, usually sea level.
    - **How it's measured**: Based on static pressure using an **altimeter**, which compares the static pressure to the standard atmospheric pressure to determine altitude.
    - **Purpose**: Crucial for navigation and maintaining separation from other aircraft.
6. **Airspeed**:
    - **What it is**: The speed of the aircraft relative to the air around it.
    - **How it's measured**: Calculated using data from the Pitot tube and static port. There are different types of airspeed measurements:
        - **Indicated Airspeed (IAS)**: The airspeed shown by the airspeed indicator, uncorrected for temperature or pressure deviations.
        - **True Airspeed (TAS)**: The actual speed of the aircraft through the air, corrected for altitude and temperature.
        - **Groundspeed**: The speed of the aircraft over the ground, calculated using TAS and wind data.
7. **Angle of Attack (AoA)**:
    - **What it is**: The angle between the chord line of the wing and the relative airflow.
    - **How it's measured**: Measured using specialized **angle of attack sensors** or vanes mounted on the fuselage.
    - **Purpose**: Critical for preventing aerodynamic stall and optimizing lift.
8. **Mach Number**:
    - **What it is**: The ratio of the aircraft's speed to the speed of sound at its current altitude.
    - **How it's measured**: Calculated using the airspeed and the temperature (which affects the speed of sound).
    - **Purpose**: Used in high-speed aircraft to ensure flight remains within safe aerodynamic limits (e.g., avoiding shock waves in transonic/supersonic flight).

2. Air Data Systems

Modern aircraft use integrated **Air Data Systems (ADS)** that consolidate inputs from various sensors to provide accurate real-time data. These systems include:

- **Pitot-Static System**:
  - Combines the Pitot tube and static port to measure airspeed, altitude, and vertical speed. The **Pitot tube** measures total pressure, while the **static port** measures the static pressure.
- **Air Data Computer (ADC)**:
  - Collects and processes the inputs from the Pitot-static system, angle of attack sensors, and temperature probes. It computes parameters like airspeed, altitude, vertical speed, and Mach number, which are displayed on cockpit instruments.

3. Air Data Instrumentation

- **Altimeter**: Displays altitude by comparing static pressure to the standard atmospheric pressure. Can be set to different pressure references (e.g., sea level, local field elevation).
- **Airspeed Indicator**: Shows indicated airspeed based on the dynamic pressure from the Pitot tube and static port readings.
- **Vertical Speed Indicator (VSI)**: Shows the rate of climb or descent, derived from changes in static pressure over time.
- **Machmeter**: Displays the Mach number, important in high-speed flight regimes.
- **Total Air Temperature (TAT) Sensor**: Measures the total temperature of the air including the rise in temperature due to compression at the aircraft's speed. This helps in calculating the true airspeed and assessing engine performance.
- **Electronic Flight Instrument System (EFIS)**: In modern aircraft, traditional air data instruments are replaced by EFIS displays, where air data is shown digitally on **Primary Flight Displays (PFD)** and **Multi-Function Displays (MFD)**.

4. Calibration and Errors

- **Position error**: Distortions caused by the placement of the Pitot tube or static port on the airframe. This is corrected during the aircraft's design or via calibration charts.
- **Instrument error**: Minor inaccuracies inherent in the instruments, generally corrected or minimized through maintenance.
- **Compressibility error**: At high speeds, air compresses before entering the Pitot tube, leading to slightly inaccurate readings. Air data computers correct this for more accurate airspeed measurements.

5. Advanced Air Data Measurement

Some modern systems, especially on high-performance military or commercial aircraft, use advanced methods such as:

- **Laser Doppler Anemometry**: Measures airflow speed using lasers without relying on physical probes.
- **Inertial Navigation Systems (INS)**: Combined with GPS, INS can assist in calculating groundspeed and position more accurately, complementing traditional air data.

In summary, **air data measurement** is fundamental for ensuring an aircraft's flight performance, navigation, and safety. It involves precise measurement of atmospheric pressures, temperature, airspeed, and altitude through sophisticated sensors and systems, all integrated to provide real-time flight information to pilots and onboard computers.

Performance analysis, estimation, measurement, operational safety, and economy

The performance analysis, estimation, measurement, operational safety, and economy of an aircraft are critical to ensure its efficient and effective operation, addressing several key areas:

1. **Performance Analysis**: This involves understanding how an aircraft behaves under various conditions, such as during take-off, cruise, and landing. It helps in optimizing aerodynamic efficiency, fuel consumption, and mission capabilities. Accurate performance analysis ensures the aircraft meets design requirements and operational needs.
2. **Estimation**: Estimating parameters like range, endurance, payload capacity, and fuel efficiency is vital during the design and planning stages. It allows for informed decision-making regarding mission planning, route selection, and aircraft suitability for specific tasks.
3. **Measurement**: Real-time measurement of performance metrics, including speed, altitude, thrust, and fuel flow, ensures that the aircraft operates within safe and efficient limits. It also provides critical data for maintenance and improvement.
4. **Operational Safety**: Ensuring safety involves monitoring the aircraft's systems and performance to avoid failures and accidents. Safety measures include regular inspections, adherence to maintenance schedules, and compliance with aviation standards and regulations.
5. **Economy**: Aircraft operational costs are a significant factor in the aviation industry. Optimizing fuel efficiency, minimizing wear and tear, and extending the life cycle of components contribute to reducing costs. Performance and economy are interconnected, as efficient operations lead to lower operational expenditures.

Together, these aspects enable the development, operation, and maintenance of aircraft that are reliable, safe, and cost-effective, thereby ensuring sustainable and efficient aviation operations.

Equations of motion for performance - the aircraft force system

The equations of motion for aircraft performance are derived from Newton's Second Law, accounting for the forces acting on the aircraft in the flight environment. These forces include thrust (T), drag (D), lift (L), and weight (W). The system considers the aircraft in various flight conditions, such as level, climbing, or descending flight.

1. Forces in the Longitudinal Plane

For simplicity, we assume steady flight, and the primary forces acting are along and perpendicular to the flight path.

a) **Along the flight path (x-axis):**

$$T \cos\alpha - D - W \sin\gamma = m\frac{dV}{dt}$$

Where:

- T: Thrust
- D: Drag
- W: Weight (mg, where m is the aircraft mass and g is gravity)
- α: Angle of attack
- γ: Flight path angle
- V: Velocity of the aircraft

In steady flight ($\frac{dV}{dt} = 0$), the forces along the flight path are balanced.

b) **Perpendicular to the flight path (z-axis):**

$$L + T \sin\alpha - W \cos\gamma = m\frac{dV}{dt} \cdot \tan\gamma$$

Where:

- L: Lift
- The term $T \sin \alpha$ accounts for thrust with a vertical component.

In steady flight ($\gamma = 0$), the lift balances the weight.

2. Special Cases

- **Level Flight** ($\gamma = 0$):

$$T = D \quad \text{and} \quad L = W$$

  Thrust balances drag, and lift balances weight.

- **Climb or Descent** ($\gamma \neq 0$):

$$T \cos \alpha = D + W \sin \gamma \quad \text{and} \quad L = W \cos \gamma$$

- **Accelerated Flight**: Non-zero acceleration in the direction of the flight path requires:

$$T \cos \alpha - D - W \sin \gamma = m \frac{dV}{dt}$$

3. Components of Forces

- **Lift (L)**: $L = C_L \frac{1}{2} \rho V^2 S$
- **Drag (D)**: $D = C_D \frac{1}{2} \rho V^2 S$
- **Thrust (T)**: Provided by the propulsion system and depends on engine type.

Here:

- C_L and C_D: Lift and drag coefficients
- ρ: Air density
- V: Aircraft velocity
- S: Wing area

These equations are the foundation for analyzing the performance of aircraft under various flight conditions, including range, endurance, climb, and glide.

The propulsive forces - the thrust production engines, power producing engines

1. Thrust-Producing Engines

Thrust-producing engines directly generate force to propel the aircraft forward by accelerating a mass of air. The main types include:

a) Turbojet Engines

- **Principle:** Operate on the Brayton cycle.
- **Thrust Production:**

$$T = \dot{m}_{\text{air}}(V_{\text{exit}} - V_{\text{inlet}}) + (P_{\text{exit}} - P_{\text{ambient}})A_{\text{exit}}$$

  - T: Thrust
  - $\dot{m}_{\text{air}}$: Mass flow rate of air
  - $V_{\text{exit}}, V_{\text{inlet}}$: Exit and inlet velocities of the engine
  - $P_{\text{exit}}, P_{\text{ambient}}$: Pressure at engine exit and ambient conditions
  - A_{exit}: Exit area of the nozzle
- **Key Applications:** Supersonic aircraft, military jets.

b) Turbofan Engines

- **Principle:** Similar to turbojets but with a large fan that accelerates bypass air.
- **Thrust Production:** Combines core thrust from the jet and bypass thrust from the fan.

$$T_{\text{total}} = T_{\text{core}} + T_{\text{bypass}}$$

  - Higher bypass ratios improve fuel efficiency.
- **Key Applications:** Commercial airliners, transport aircraft.

c) Ramjet and Scramjet Engines

- **Principle:** Operate at high speeds using compression from forward motion.
- **Thrust Production:**

$$T = \dot{m}_{\text{air}}(V_{\text{exit}} - V_{\text{inlet}})$$

  - No moving parts; rely on supersonic or hypersonic speeds.
- **Key Applications:** High-speed missiles, hypersonic aircraft.

2. Power-Producing Engines

Power-producing engines generate mechanical power to drive a propeller, rotor, or fan, which produces thrust indirectly. The main types include:

a) Turboprop Engines

- **Principle:** Combine a gas turbine engine with a propeller.
- **Thrust Production:**

$$T = \frac{\eta_p P_{\text{shaft}}}{V_{\text{aircraft}}}$$

  - η_p: Propeller efficiency
  - P_{shaft}: Shaft power delivered to the propeller
  - V_{aircraft}: Aircraft velocity
- **Key Applications:** Regional and cargo aircraft requiring efficient operation at lower speeds.

b) Piston Engines

- Principle: Internal combustion engines that power a propeller.
- Thrust Production: Similar to turboprops but less powerful.
- Key Applications: Small aircraft, general aviation.

c) Turboshaft Engines

- Principle: Similar to turboprops but optimized for rotorcraft.
- Thrust Production: Drive rotors in helicopters instead of fixed propellers.
- Key Applications: Helicopters, tiltrotor aircraft.

3. Propulsive Efficiency

- **Thrust-Producing Engines:** Higher efficiency at high speeds due to direct thrust generation.
- **Power-Producing Engines:** Higher efficiency at low to moderate speeds due to better propeller efficiency.

4. Key Factors for Engine Selection

- **Mission profile:** Speed, altitude, range.
- **Fuel efficiency:** Bypass ratio, thermodynamic cycle.
- **Reliability and maintenance requirements.**

Understanding the balance between thrust and efficiency is crucial for optimizing aircraft performance for specific applications.

Variation of thrust, propulsive power, and specific fuel consumption (SFC) with altitude and flight speed

The variation of thrust, propulsive power, and specific fuel consumption (SFC) with altitude and flight speed is influenced by several factors, including changes in air density, temperature, and pressure at different altitudes. Let's discuss these variations:

1. Thrust is a force that propels an aircraft in the forward direction. In aircraft, thrust is generated by engines, typically either jet engines or propeller engines. The primary purpose of thrust is to overcome aerodynamic drag and propel the aircraft through the air.
2. Propulsive power in aircraft refers to the force generated by the aircraft's engines to overcome drag and propel the aircraft forward. It is a crucial aspect of aviation and directly influences an aircraft's performance, speed, and efficiency.
3. Specific fuel consumption (SFC) is a measure of the efficiency of an engine in converting fuel into thrust or power. It is commonly used in the context of aircraft engines and rocket propulsion systems. SFC is defined as the amount of fuel consumed per unit of thrust or power produced. The units of SFC are typically expressed in terms of mass of fuel per unit of thrust or power and are commonly given in units such as Newton-seconds per kilowatt (Ns/kW) for rocket engines.

1. **Thrust:**
   - **Altitude:** As an aircraft ascends to higher altitudes, the air density decreases. Thrust is directly proportional to air density, so as altitude increases, the thrust produced by the engines decreases. This is because there is less air for the engines to work with.
   - **Flight Speed:** Thrust is also influenced by flight speed. At higher speeds, the drag on the aircraft increases, requiring more thrust to maintain or increase speed.
2. **Propulsive Power:**
   - **Altitude:** Propulsive power is the product of thrust and flight speed. As altitude increases, the reduction in thrust may be compensated by an increase in flight speed to maintain a constant power level.
   - **Flight Speed:** Propulsive power increases with the cube of the velocity. Therefore, at higher speeds, the power required to overcome drag increases significantly.
3. **Specific Fuel Consumption (SFC):**
   - **Altitude:** SFC is generally lower at higher altitudes due to the lower air density. Jet engines are more efficient in terms of fuel consumption at

higher altitudes because they can generate the same thrust with less fuel. However, there are other factors to consider, such as the efficiency of the specific engine design.

- **Flight Speed:** SFC tends to increase with higher speeds. At higher speeds, the engine may need to operate less efficiently, leading to higher fuel consumption per unit of thrust produced.

It's important to note that the specific characteristics can vary depending on the type of aircraft, engine technology, and design specifications. Additionally, modern aircraft may have systems that can automatically adjust parameters to optimize performance at different altitudes and speeds. Engineers use aerodynamic and thermodynamic principles, as well as data from engine performance charts, to design and optimize aircraft for various flight conditions.

UNIT-5

Pitot-Static Tube

The **Pitot-static tube** is a fundamental instrument used in aircraft to measure **airspeed**, **altitude**, and **vertical speed** by sensing air pressure.

- **Principle of Operation:**

It works based on **Bernoulli's Principle**, which states that the total pressure (also called **stagnation pressure**) is the sum of **static pressure** and **dynamic pressure**.

$$\text{Total Pressure } (\text{P}_t) = \text{Static Pressure } (\text{P}_s) + \text{Dynamic Pressure}$$

$$\text{Dynamic Pressure} = \frac{1}{2} \cdot \rho \cdot V^2$$

So, the airspeed can be calculated as:

$$V = \sqrt{\frac{2(P_t - P_s)}{\rho}}$$

Where:

- V = True Airspeed
- P_t = Total Pressure (from pitot tube)
- P_s = Static Pressure (from static port)
- ρ = Air density

- **Components:**

Component	Description
Pitot Tube	Faces into the airstream and measures **total (stagnation) pressure**.
Static Port	Located on the side of the aircraft, measures **static pressure** (ambient atmospheric pressure).
Drain Hole	Allows water to drain and prevents pressure errors.
Heater (optional)	Used in high-altitude jets to prevent icing of pitot tube.

🔹 **Instruments Using Pitot-Static System:**

Instrument	Uses
Airspeed Indicator (ASI)	Measures the **dynamic pressure** to determine airspeed.
Altimeter	Uses **static pressure** to calculate altitude above sea level.
Vertical Speed Indicator (VSI)	Measures **rate of change** in static pressure to give vertical speed (climb/descent rate).

🔹 **Error Sources:**

- **Position Error:** Caused by incorrect placement of static port.
- **Density Error:** Airspeed varies with altitude (air density changes).
- **Instrument Error:** Caused by internal mechanical imperfections.
- **Icing:** Can block pitot or static lines, leading to dangerous misreadings.

🔹 **Applications:**

- Aircraft (all types)
- Drones and UAVs
- Wind tunnels
- Meteorological balloons

Primary Flight Instruments

Primary Flight Instruments (also known as the "six-pack") provide critical information to pilots for **attitude, speed, altitude, heading, and aircraft motion**. They ensure safe navigation, especially during low visibility or instrument flight rules (IFR) conditions.

Instrument	Measured Quantity	Sensor Type	Data Source
1. Airspeed Indicator (ASI)	Forward airspeed	Pressure sensor	Pitot-static system
2. Attitude Indicator (AI)	Pitch and roll	Gyroscope	Gyro or MEMS
3. Altimeter	Altitude (MSL)	Aneroid barometer	Static pressure
4. Turn Coordinator	Rate of turn & roll	Gyroscope	Electrical gyro
5. Heading Indicator (Directional Gyro)	Heading (direction)	Gyroscope	Magnetic + Gyro
6. Vertical Speed Indicator (VSI)	Climb or descent rate	Pressure sensor	Static pressure (rate of change)

1. Airspeed Indicator (ASI):

- **Function**: Displays the speed of the aircraft relative to surrounding air.
- **Principle**: Uses **dynamic pressure** (difference between pitot and static pressure).
- **Markings**: Colored arcs (white for flap range, green for normal, red line for max).

2. Attitude Indicator (Artificial Horizon):

- **Function**: Shows aircraft orientation with respect to the horizon (pitch and bank).
- **Working**: Uses a **gyroscope** aligned with the Earth's gravity.
- **Display**: Shows horizon bar, sky (blue), ground (brown), pitch ladder.

3. Altimeter:

- **Function**: Measures altitude above mean sea level.
- **Working**: Contains sealed **aneroid capsules** that expand or contract with pressure changes.
- **Setting**: Uses barometric pressure (QNH/QFE setting) to calibrate altitude.

4. Turn Coordinator:

- **Function**: Indicates rate and quality of turn (coordination).
- **Working**: Uses an electrically-driven **rate gyro**.
- **Display**: Airplane symbol banked in direction of turn; inclinometer ball indicates coordination.

5. Heading Indicator:

- **Function**: Displays aircraft's heading.
- **Working**: Uses a **gyroscopic compass**, aligned with magnetic compass.
- **Advantage**: More stable and accurate than magnetic compass, which is subject to oscillations.

6. Vertical Speed Indicator (VSI):

- **Function**: Measures **rate of climb or descent** in ft/min or m/s.
- **Working**: Senses **rate of change of static pressure** using a diaphragm and calibrated leak.

Applications:

- Used in all aircraft: light trainers to commercial jets.
- Vital for **Instrument Flight Rules (IFR)** operations.
- Enhanced in modern aircraft by **EFIS** (Electronic Flight Instrument Systems) or **Glass Cockpits**.

Gyroscope (Gyro)

A gyroscope is a device that maintains orientation based on the principles of angular momentum. It senses rotational motion.

1. **Rigidity in Space:**
   - A spinning mass (rotor) remains in a fixed position in space unless acted upon by an external torque.
   - This property allows a gyro to provide a stable reference direction.
2. **Precession:**
   - When a force is applied, the gyro responds **90° later in the direction of rotation**.
   - Used for detecting changes in pitch, roll, and yaw.

Type	Description	Usage
Mechanical Gyro	Rotor spinning on gimbals	Traditional attitude/heading indicators
Ring Laser Gyro (RLG)	Uses laser beams and Sagnac effect	Inertial Navigation Systems
Fiber Optic Gyro (FOG)	Uses interference of light in fiber coils	High-precision aircraft systems
MEMS Gyro	Micro-Electro-Mechanical System, vibrational sensing	Drones, smartphones, modern avionics

Applications:

- **Attitude Indicator** (shows pitch and bank)
- **Heading Indicator** (direction of aircraft)
- **Inertial Navigation Systems (INS)**

<u>Accelerometer</u>

- An accelerometer is a device that measures linear acceleration in one or more axes. It detects changes in speed or direction.
  - Based on **Newton's Second Law**: $F = ma$
  - Contains a **suspended mass (proof mass)** inside a housing.
  - When acceleration occurs, the mass moves slightly, and the movement is converted into an **electrical signal** (using capacitive, piezoelectric, or resistive sensing).
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Type	Description	Usage
Mechanical	Uses spring-mass system	Traditional g-sensors
MEMS	Uses silicon microstructures	UAVs, autopilot, flight control
Capacitive	Measures change in capacitance due to mass shift	Precision flight data
Piezoelectric	Generates voltage from pressure	Used in vibration analysis

- **Measured Parameters:**
- Linear acceleration (in **g** or **m/s²**)
- Tilt angle (based on gravitational acceleration)

- Vibration and shock

Applications:

- **Inertial Measurement Unit (IMU)**: Combines 3-axis gyro + 3-axis accelerometer
- Flight Data Recorders (Black Box)
- Autopilot and flight control
- Structural Health Monitoring (detecting vibrations)

Integration with Navigation:

- **INS (Inertial Navigation System)** uses data from gyros and accelerometers to calculate position, orientation, and velocity **without GPS**.
- Essential in high-speed aircraft, missiles, and spacecraft.

Hydraulic Systems

- Hydraulic systems use incompressible fluid (usually oil) to transmit power. They are ideal for operations that require high force with precise control.
- Based on **Pascal's Law**:
- "Pressure applied to a confined fluid is transmitted equally in all directions."
- F=P×AF = P \times AF=P×A

Component	Function
Reservoir	Stores hydraulic fluid
Pump	Pressurizes the fluid (engine or electrically driven)
Actuators	Convert pressure into motion (e.g., cylinders)
Valves	Control direction, pressure, and flow
Filters	Remove contaminants
Accumulators	Store pressurized fluid for emergency use

Applications in Aircraft:

- Landing Gear Retraction/Extension
- Flap Operation
- Braking Systems
- Thrust Reversers

Advantages:

- High power-to-weight ratio
- Precise and smooth control
- Ability to hold loads without constant power

Pneumatic Systems

Pneumatic systems use compressed air or gas to transmit and control power. Best for applications that need fast and lightweight operations.

Uses **compressible gas** (usually air or nitrogen) to push against pistons or drive turbines for actuation

Component	Function
Compressor/Bleed Air	Supplies compressed air
Reservoir/Tank	Stores compressed air
Pressure Regulator	Maintains system pressure
Actuators (pneumatic cylinders)	Convert pressure into motion
Valves	Control flow and direction
Moisture Separators	Remove water vapor from air

Applications in Aircraft:

- Door Operation (cargo/passenger)
- De-icing Systems (wing or engine inlet)
- Air Brakes (in small aircraft)

Advantages:

- Light weight
- Fast response
- Cleaner (no fluid leakage)