

Elements of Aeronautical Engineering
(R20A2104)

COURSE FILE

II B. Tech I Semester

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**R20A2104- 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, micro-gravity, rockets, spacecrafts and planetary environment	2
6		Basic forces on an aircraft, aerofoil nomenclature and types and airflow distribution, types of air-breathing engines-rocket engines-missiles, loads on aircraft	2
7		Structural components and members of an aircraft-schematics and purpose.	2
8			1
			Total 13
	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	4
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
			Total 12
III		Propulsion	
1		Basic forces on an aircraft	3

2	UNIT III	Need for thrust	2
3		Types and working of air-breathing engines	2
4		Working of reciprocating engines (2/4 stroke variants), ,	1
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

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.

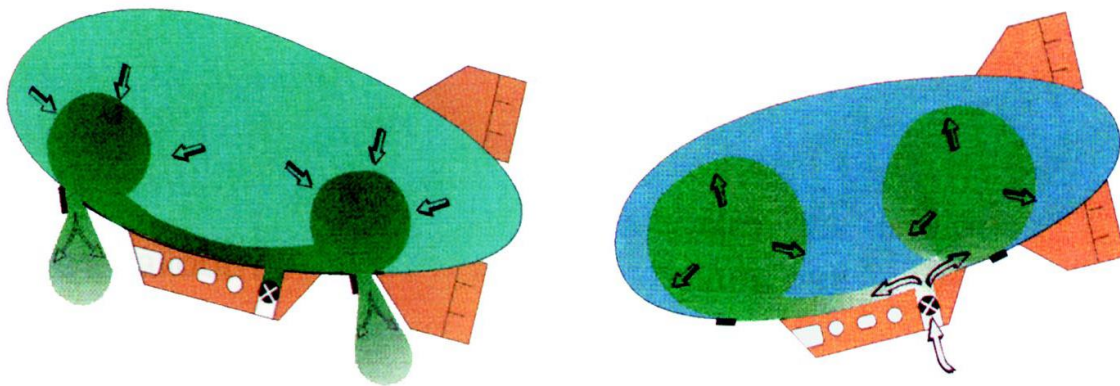


Hot air balloons were very popular till the 1900s; hydrogen was preferred as the filling gas, but, was considered unsafe, causing few explosions.

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.

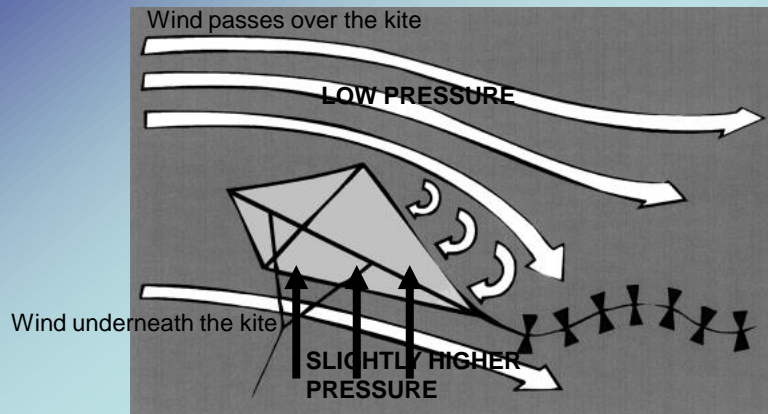
By releasing air into the ballonets or by pumping in more air into the ballonets, the helium inside ballonets is compressed or made to expand, thereby causing the airship to raise or descend.



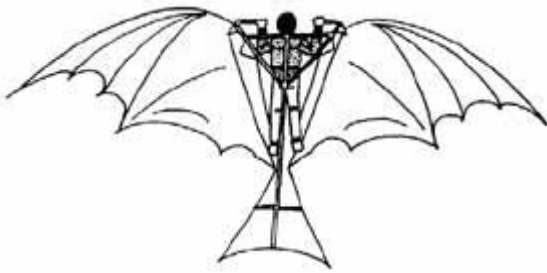
Heavier-than-air-aircraft- Principle:

- 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

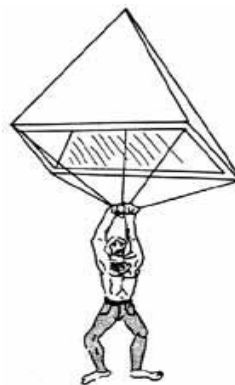
Principle of Heavier-Than-Air Flight



- In 1804, Dir George Cayley 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.

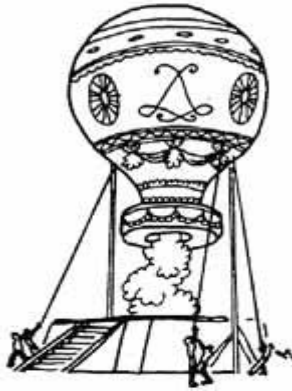
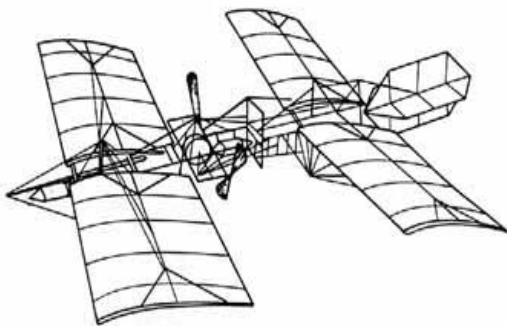


Figure 2.- Montgolfier balloon (1783).



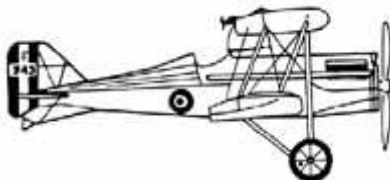
Figure 3.- Lilienthal glider (1896)



(1903).

Figure 4.- Samuel Langley's "Aerodrome"

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 Aeolipile 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.

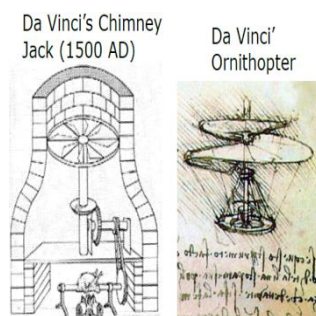
Hero mounted a sphere on top of a water kettle. A fire below the kettle turned the water into steam, and the gas traveled through the pipes to the sphere. Two L-shaped tubes on opposite sides of the sphere allowed the gas to escape. This produced a thrust to the sphere that caused it to rotate almost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

The aeolipile achieved spin speeds of at 1500 RPM.

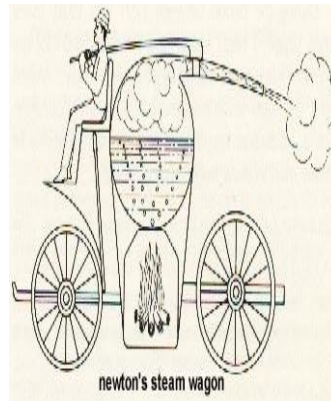
Chinese used rockets with gunpowder, around AD 1000. They attached these rocket (bamboo) tubes to arrows and launched them with bows. Soon they discovered that these gunpowder tubes could launch themselves just by the power produced from the escaping gas. The true rocket was born.

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 modern gas turbine.

Wright Brothers first Airplane "Triumph": First Flight 1903 Dec**Concept of Jet Propulsion:****Newton's Laws of Motion**Glenn
Research
Center

"Every object persists in its state of rest or uniform motion in a straight line unless it is compelled to change that state by forces impressed on it."

"Force is equal to the change in momentum (mv) per change in time. For a constant mass, force equals mass times acceleration."
 $F = m a$

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

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

M_t in a specified reference frame for the inertial motion under interest:

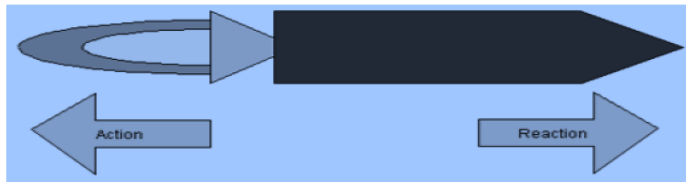
$$F = \frac{dM_t}{dt} = \frac{d(mV)}{dt} = m \frac{dv}{dt}$$

↑
For a constant mass system

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

Newton's Laws of Motion**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. Gottlieb 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:

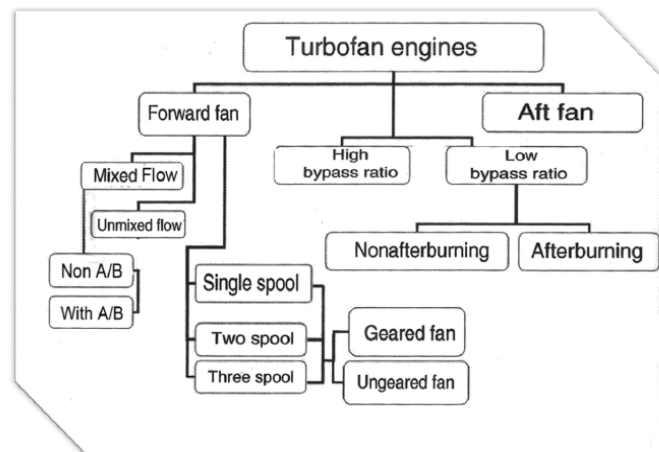
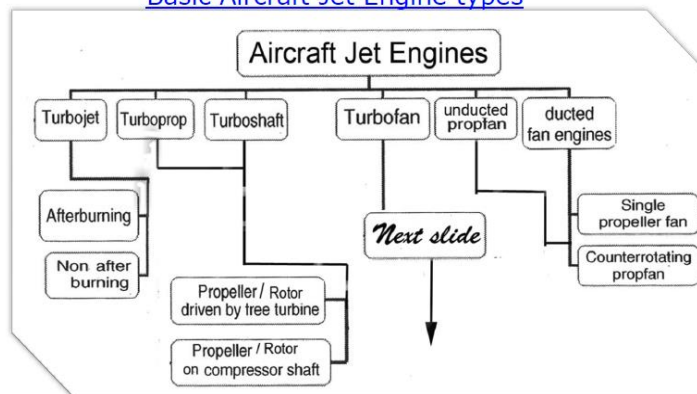
Air Breathing Systems

- 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, *unguided* munition is known as a **rocket**.

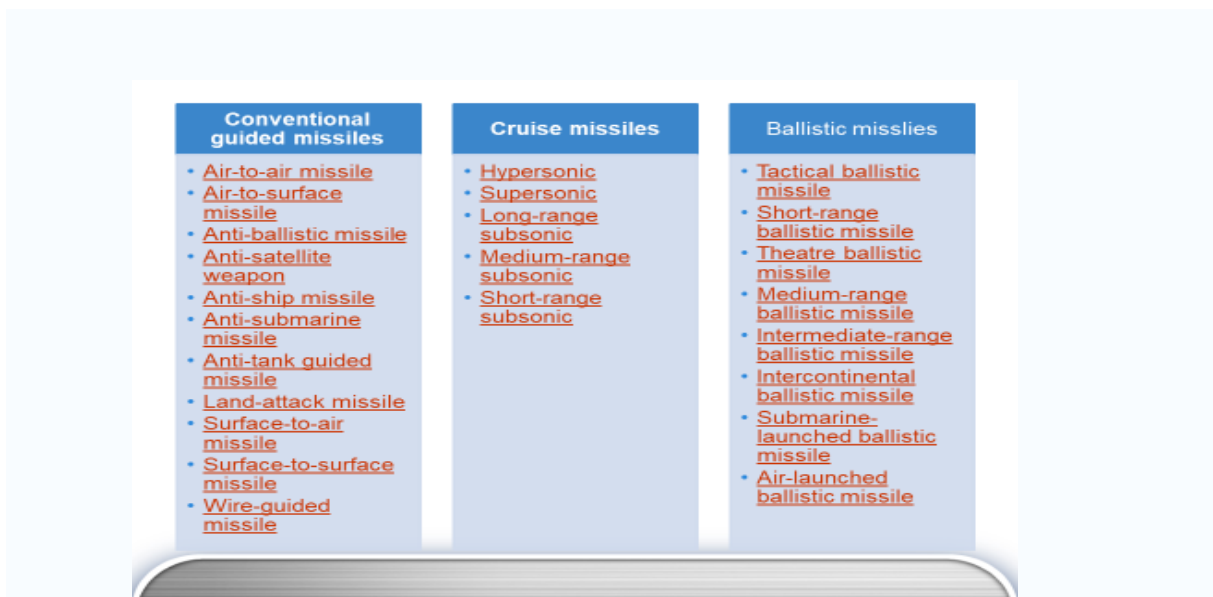
TECHNOLOGY :

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 is 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 through 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 Fédération Aéronautique 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.

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 continuous 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, accelerated 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.

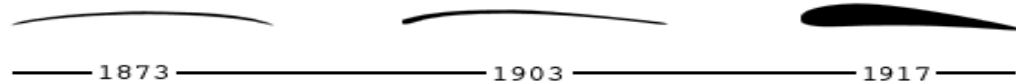
UNIT II: Aerodynamics

Aerfoil – Nomenclature and types:

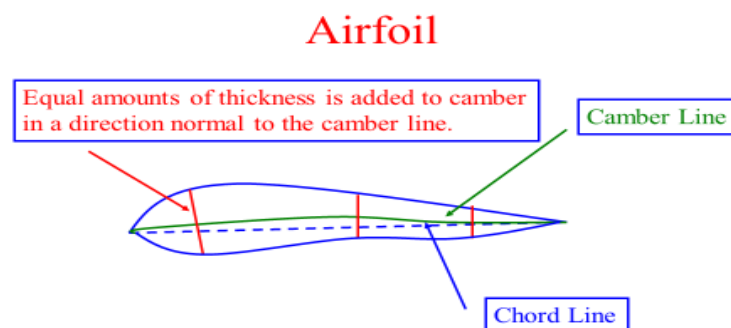
Use of aerfoil:

- 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:



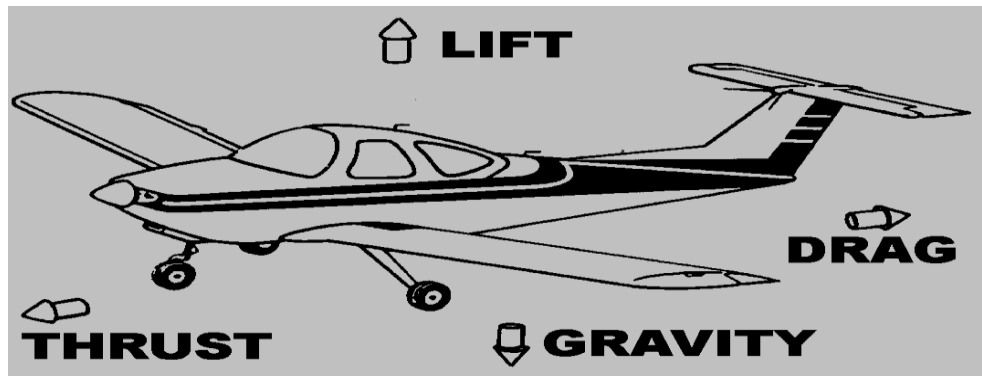
Early Designs - Designers mistakenly believed that these airfoils with sharp leading edges will have low drag. In practice, they stalled quickly, and generated considerable drag



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 an 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 be 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.)

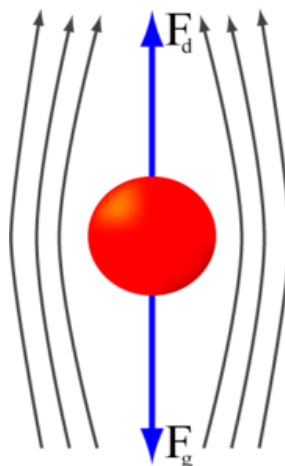
The circulation is the line integral of the velocity of the air, in a closed loop around the boundary of an airfoil. It can be understood as the total amount of "spinning" (or vorticity) of air around the airfoil. When the circulation is known, the section lift can be calculated using the following equation:

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

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.

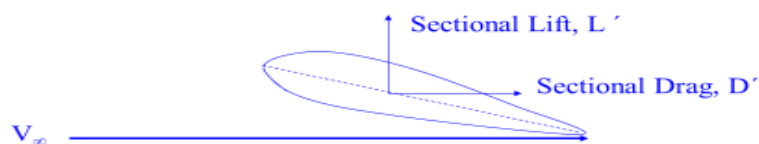
- Parasitic drag includes form drag, skin friction and interference drag.
- Lift-induced drag is only relevant when wings or a lifting body are present, and is therefore usually discussed only in the aviation perspective of drag.
- Wave drag occurs when a solid object is moving through a fluid at or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

Lift and Drag Forces acting on a Wing Section



The component of aerodynamic forces normal to the freestream, per unit length of span (e.g. per foot of wing span), is called the sectional lift force, and is given the symbol L' .

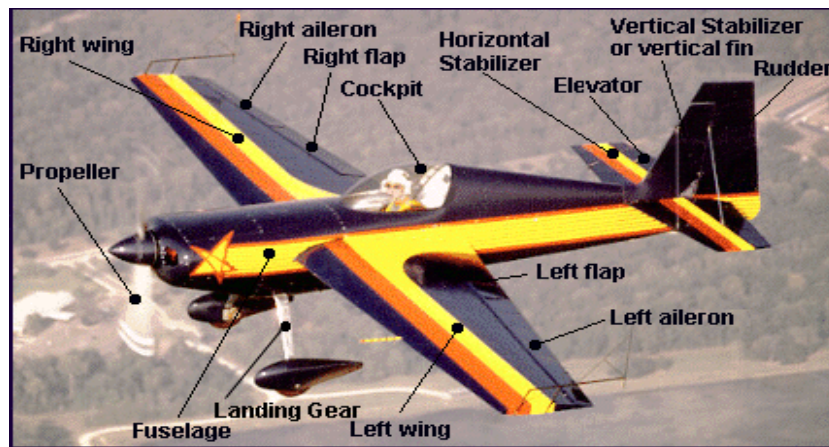
The component of aerodynamic forces along the freestream, per unit length of span (e.g. per foot of wing span), is called the sectional drag force, and is given the symbol D' .

Sectional Lift and Drag Coefficients

- The sectional lift coefficient C_l is defined

as:
$$C_l = \frac{L'}{\frac{1}{2} \rho V_\infty^2 c}$$

- 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:
$$C_d = \frac{D'}{\frac{1}{2} \rho V_\infty^2 c}$$



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

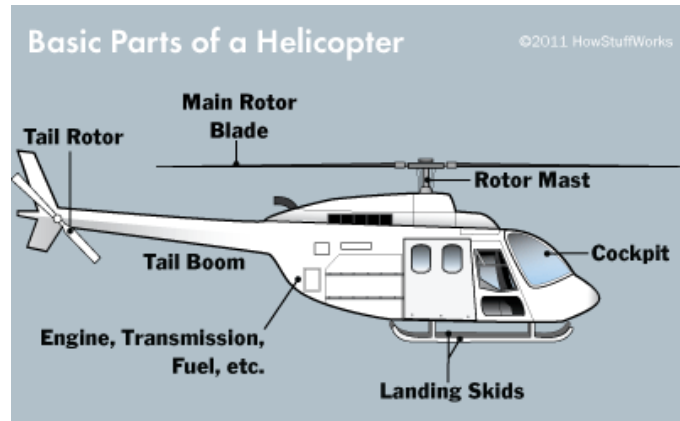
The helicopter rotor is powered by the engine, through the transmission, to the rotating mast. The mast is a cylindrical metal shaft which extends upward from—and is driven by—the transmission. At the top of the mast is the attachment point for the rotor blades called the hub. The rotor blades are then 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



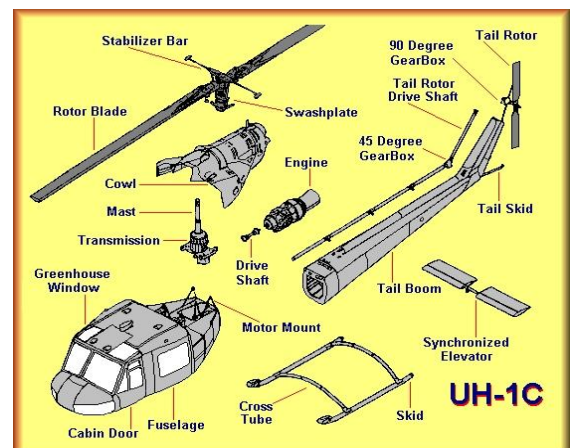
Main rotor

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

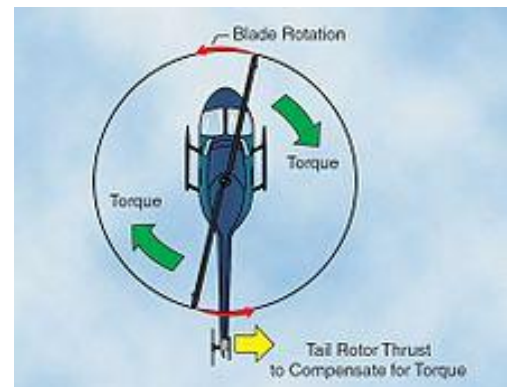


Types

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).

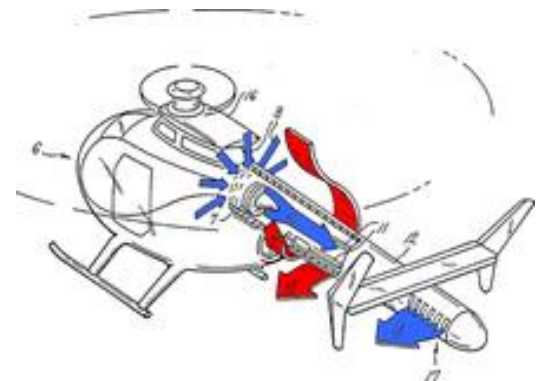
Ducted fan

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:

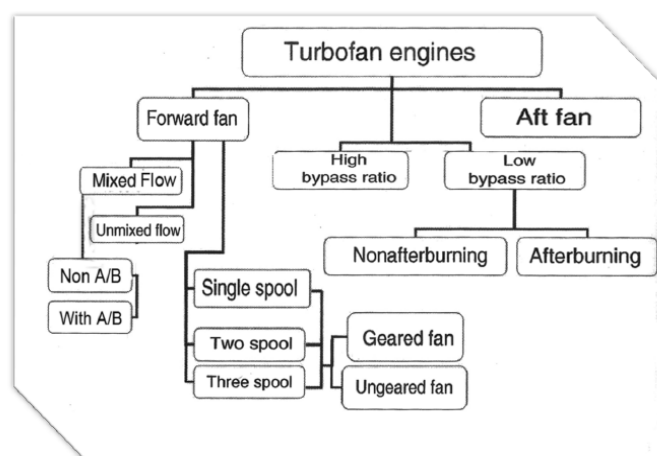
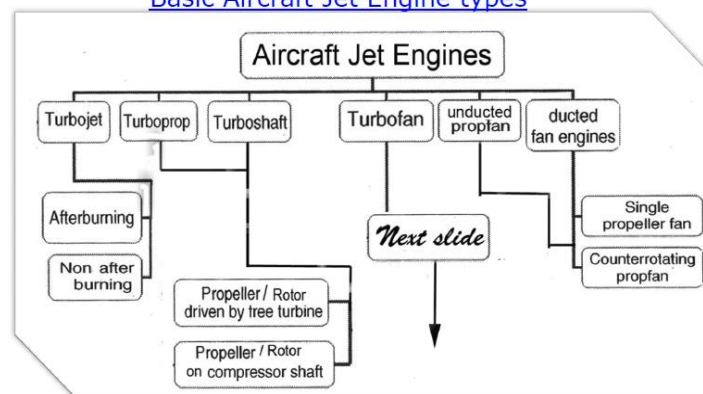
Air Breathing Systems: Broadly grouped as - Reciprocating & Jet Propulsion Engines.

- 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

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

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 p 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:-

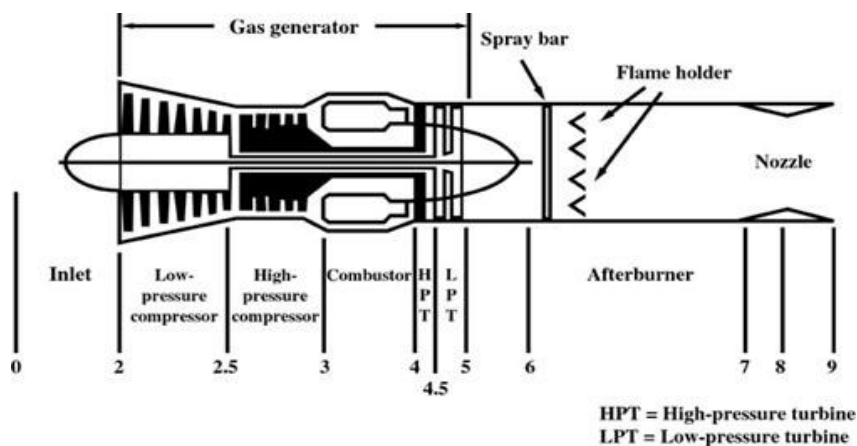
- (a) Turbojet engines

- (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 to 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:

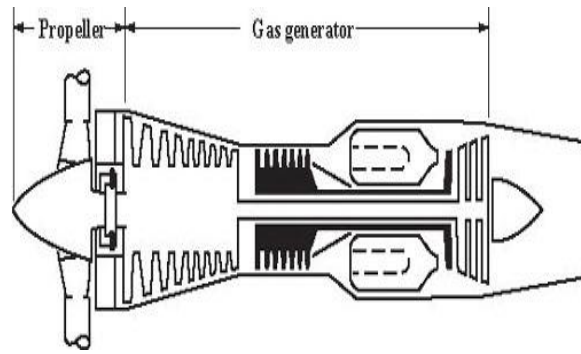
- **Mechanical Efficiency:** Mechanical efficiency of gas turbine engines is higher than reciprocating engines. This is mainly due to high friction losses in reciprocating engines.
- **Balancing:** Due to absence of reciprocating mass in gas turbine engines, balancing can be near perfect. Torsional vibrations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

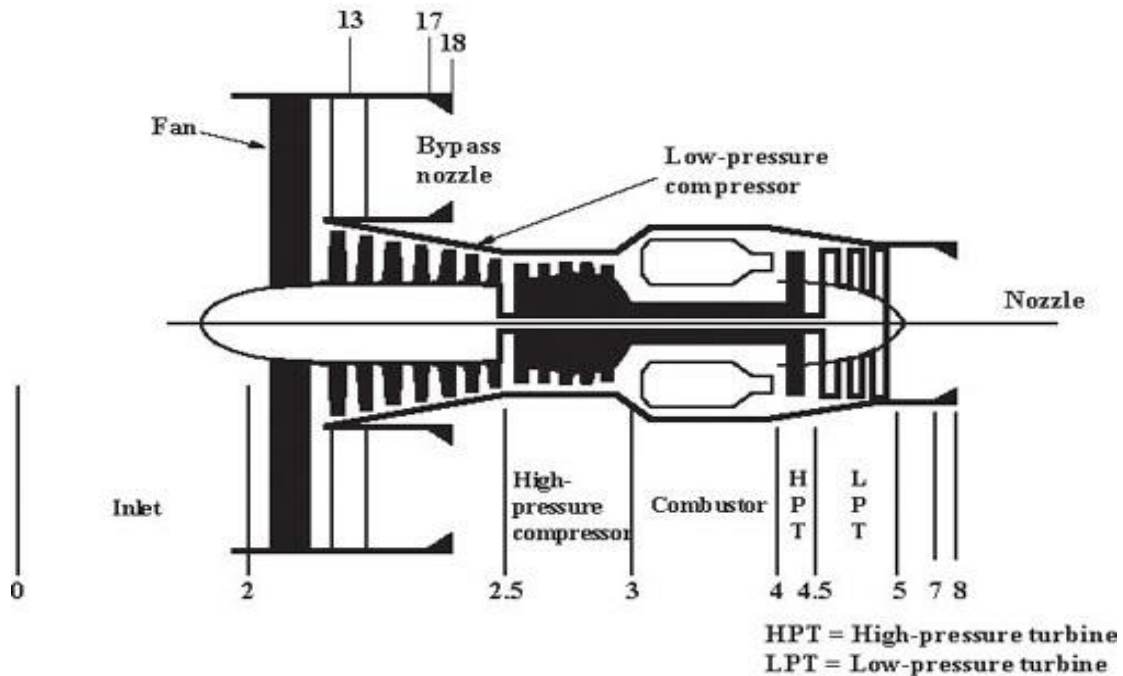
The turbine speeds need to be reduced through a suitable reduction gearing so that propeller runs at lower speeds, which adds to weight.

Applications:

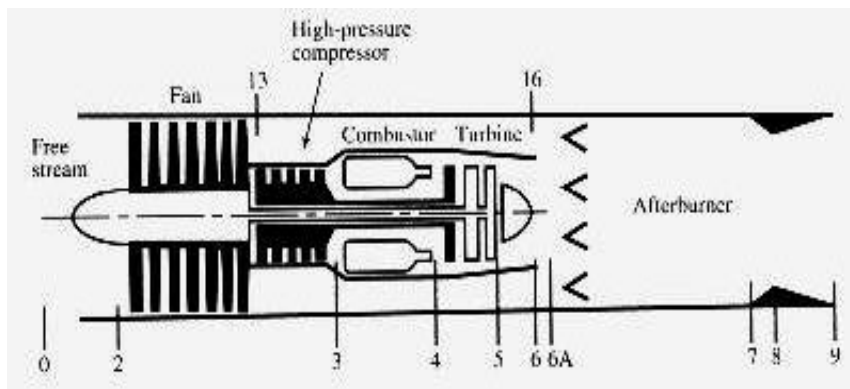
The turboprop engine is widely used in commercial and military aircraft due to its flexibility of operation and good fuel economy.

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.

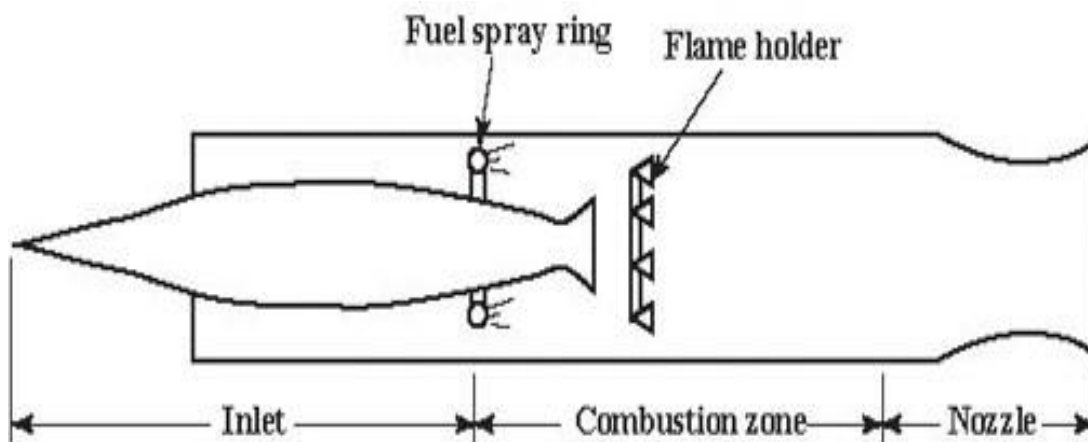
A **geared fan** connected to turbine reduces power consumed by the fan. It also produces low sound.

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 further 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 gases 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 13:1 which 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.

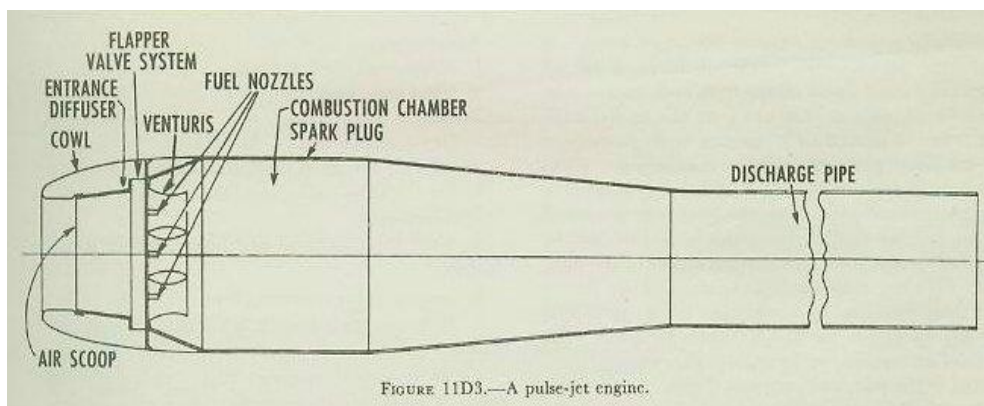
Used in high speed military aircraft, in a combined cycle engine (Turbojet-Ramjet combination).

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:



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 or turbine, it can be used in high temperatures.
4. Can be used for military applications.

Disadvantages:

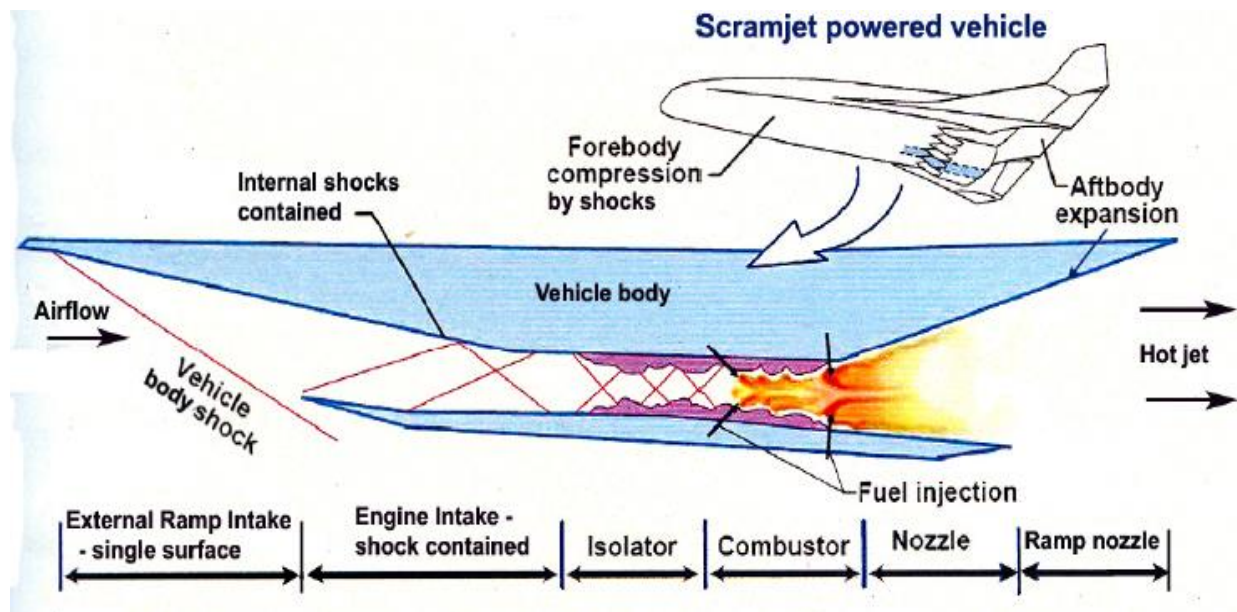
1. It is having limited flight speed only.
2. Limited flying altitude.
3. High vibration and noise due to the pulses of thrust produced

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:

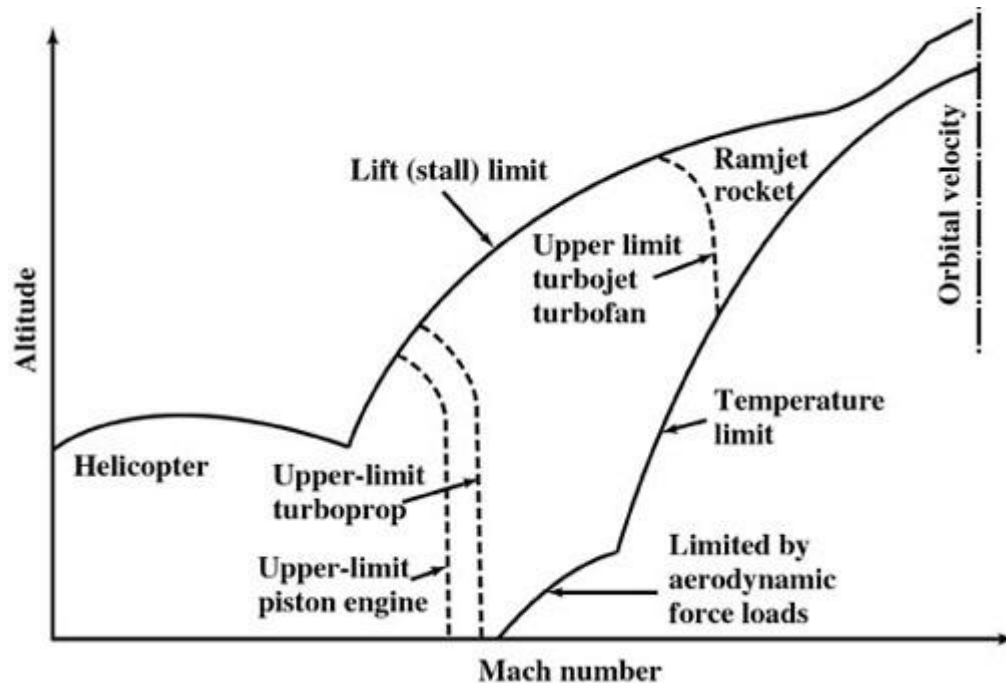
- Weapons systems -hypersonic cruise missiles
- Aircraft systems - global strike / reconnaissance
- Space access systems that will take off and land horizontally like commercial Airplanes
- Using these Scramjet technologies, along with additional ground-and flight-test experiments, will pave the way 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, *unguided* 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

Conventional guided missiles	Cruise missiles	Ballistic missiles
<ul style="list-style-type: none"> • <u>Air-to-air missile</u> • <u>Air-to-surface missile</u> • <u>Anti-ballistic missile</u> • <u>Anti-satellite weapon</u> • <u>Anti-ship missile</u> • <u>Anti-submarine missile</u> • <u>Anti-tank guided missile</u> • <u>Land-attack missile</u> • <u>Surface-to-air missile</u> • <u>Surface-to-surface missile</u> • <u>Wire-guided missile</u> 	<ul style="list-style-type: none"> • <u>Hypersonic</u> • <u>Supersonic</u> • <u>Long-range subsonic</u> • <u>Medium-range subsonic</u> • <u>Short-range subsonic</u> 	<ul style="list-style-type: none"> • <u>Tactical ballistic missile</u> • <u>Short-range ballistic missile</u> • <u>Theatre ballistic missile</u> • <u>Medium-range ballistic missile</u> • <u>Intermediate-range ballistic missile</u> • <u>Intercontinental ballistic missile</u> • <u>Submarine-launched ballistic missile</u> • <u>Air-launched ballistic missile</u>

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.

UNIT-4 AIRCRAFT PERFORMANCE

The Role and Design Mission of an Aircraft

Civil Aircraft

- ❖ Agriculture
- ❖ Sports
- ❖ Trainer
- ❖ Air Transport
- ❖ Cargo
- ❖ Early warning and control (AEW&C)
- ❖ Chartered Aircraft
- ❖ Etc...

Military Aircraft

- ❖ Fighter
- ❖ Interceptor
- ❖ Bomber
- ❖ Spying
- ❖ Electronic warfare (EW)
- ❖ Maritime patrol
- ❖ Expérimental
- ❖ Reconnaissance
- ❖ Surveillance
- ❖ Tanker
- ❖ Trainer
- ❖ Transport

Civil Aircraft

- ❖ Agriculture
- ❖ Sports
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- ❖ Trainer
- ❖ Early warning and control (AEW&C)
- ❖ Chartered Aircraft
- ❖ Photo Etc...

Agriculture Aircraft spreading Manure

Agriculture Aircraft used for spreading Manure on the fields which takes lesser time and efficient to undertake more area



Agriculture aircraft in Grassy Runway

These aircraft are used for landing in fields of grassy areas
Which can be used for agricultural activities.



Kite Type Sports Aircraft

These aircrafts are used for sports and recreational activities. This is the part of general aviation activities.



FAA Light Sport Aircraft

- ❖ Max. Gross Takeoff Weight: 1,320 lbs (600 kg) or 1,430 lbs for seaplanes (650 kg)
- ❖ Max. Stall Speed: 45 knots (83 km/h; 52 mph) CAS
- ❖ Max. Speed in Level Flight (at sea level In the US Standard Atmosphere): 120 knots (220 km/h; 140 mph) CAS
- ❖ Max. Seats: Two
- ❖ Max. Engines / Motors: One (if powered)
- ❖ Propeller: Fixed-pitch or ground adjustable
- ❖ Cabin: Unpressurized
- ❖ Fixed-pitch, semi-rigid, teetering, two-blade rotor system, if a gyroplane.
- ❖ Landing Gear: Fixed (except for seaplanes and gliders)

Aircraft data

Manufacturer	Engine	Max. cruise	Max. range	Type
<u>3Xtrim</u>	<u>100 HP Rotax 912 S</u>	104 kn (193 km/h)	747 NM	Certified
<u>Advanced Composites Solutions</u>		120 kn (222 km/h)		<u>Kit</u>
<u>Aeropro / fly-Aerotrek.com</u>	<u>Rotax 912 A/ 912 S</u>	115 kn (213 km/h)	570 NM (1056 km)	Certified
<u>AeropraktManufacturing</u>	<u>Rotax 912UL, Rotax 912ULS or Rotax 912 iS</u>	110 kn (210 km/h)	594 NM (950 km)	Certified
<u>The Airplane Factory</u>	<u>Rotax 912S or 912 ULS</u>	110 kn (201 km/h)	880 NM (1600 km)	Certified,
<u>Aviasud Engineering</u>	<u>Rotax 582DCDI</u>	65 kn (120 km/h)	270 NM, 500 km	Certified

Trainer aircraft

Trainer Aircraft and its different types

A trainer is a class of aircraft designed specifically to facilitate flight training of pilots and aircrews. The use of a dedicated trainer aircraft with additional safety features

- ❖ Tandem

- ❖ Side By Side

Trainer Aircraft

- ❖ Basic training
- ❖ Advanced training
- ❖ Lead-in fighter training
- ❖ Multi-engine trainers
- ❖ Navigation trainers
- ❖ Combat use of trainers

Tandem Trainer Aircraft

Tandem Trainer Aircraft used to train the pilot

In tandem, usually with the pilot in front and the instructor behind.



Side by side trainer aircraft

Side By Side

The *two* seating configurations for trainer aircraft are: pilot and instructor side by side



Transport Aircraft

Transport Aircraft

- Airliners, aircraft, usually large and most often operated by airlines, intended for carrying multiple passengers or cargo in commercial service
- Cargo aircraft or freighters, fixed-wing aircraft designed or converted for the carriage of goods, rather than passengers, lacking in passenger amenities and generally featuring one or more large doors for loading cargo; also known as freight aircraft, freighters, airlifters, or cargo jets.

Transport Aircraft

- Mail planes, airplanes used for carrying mail
- Military transport aircraft, airplanes or helicopters used to deliver troops, weapons. and military equipment, usually outside of the commercial flight routes in uncontrolled airspace, and employed historically to deliver airborne forces and tow military gliders; sometimes also called military cargo aircraft.

Passenger Transport Aircraft

Passenger Transport Aircrafts are shown below with two different airplane



Cargo Transport Aircraft

Two different types of cargo aircraft are shown with loading a big helicopter like Chinook and troops from one place to another.



Military Transport Aircraft

These helicopters can be used for military and civil use to lift heavy loads to carry in hilli terrain.



DRDO AEW&CS

The DRDO Airborne Early Warning and Control System (AEWACS) is a project of India's Defence Research and Development Organisation to develop an airborne early warning and control system for the Indian Air Force. It is also referred to as DRDO NETRA AEW&CS system.



Chartered Aircraft

A charter flight is an unscheduled flight that is not part of a regular airline routing. With a charter flight, you rent the entire aircraft and can determine departure/arrival locations and times. There are several types of charter flights.



Types of Military Aircraft

- ❖ Fighter
- ❖ Interceptor
- ❖ Bomber
- ❖ Spying
- ❖ Electronic warfare (EW)
- ❖ Maritime patrol
- ❖ Expérimental
- ❖ Reconnaissance
- ❖ Surveillance
- ❖ Tanker
- ❖ Trainer
- ❖ Transport

Interceptor

An interceptor aircraft, or simply interceptor, is a type of fighter aircraft designed specifically to attack enemy aircraft, particularly bombers and reconnaissance aircraft, as they approach.



Su-15, one of the principal Soviet Air Defence interceptors

Fighter

A **fighter aircraft** is a military aircraft designed primarily for air-to-air combat against other aircraft, as opposed to bombers and attack aircraft, whose main mission is to attack ground targets. The hallmarks of a fighter are its speed, maneuverability, and small size relative to other combat aircraft.



Bomber

Bomber, military aircraft designed to drop bombs on surface targets.



Spying Aircraft

A reconnaissance aircraft is a military surveillance aircraft designed or adapted to perform aerial reconnaissance with roles including collection of imagery intelligence (including using photography), signals intelligence, as well as measurement and signature intelligence. Modern technology has also enabled some aircraft and UAVs to carry out real-time surveillance in addition to general intelligence gathering.



[ScanEagle](#) reconnaissance UAV on its catapult launcher

Electronic warfare (EW)

An electronic-warfare aircraft is a military aircraft equipped for electronic warfare, that is, degrading the effectiveness of enemy radar and radio systems by using radar jamming and deception methods. In 1943, British Avro Lancaster aircraft were equipped with chaff in order to blind enemy air defence radars.



Maritime Patrol

A maritime patrol aircraft (MPA), also known as a patrol aircraft, maritime reconnaissance aircraft, or by the older American term **patrol bomber**, is a fixed-wing aircraft designed to operate for long durations over water in maritime patrol roles — in particular anti-submarine warfare (ASW), anti-ship warfare (AShW), and search and rescue (SAR).



Expérimental Aircraft

An **experimental aircraft** is an aircraft that has not yet been fully proven in flight. Often, this implies that new aerospace technologies are being tested on the aircraft, though the label is more broad.



Tanker Aircraft

Aerial refuelling, also referred to as air refuelling, in-flight refuelling, air-to-air refuelling, and tanking, is the process of transferring aviation fuel from one military aircraft to another during flight.



Performance Requirements and Mission Profile

- ❖ Takeoff and Landing Distances
- ❖ Rate of Climb
- ❖ Ceiling
- ❖ Speed
- ❖ Payload
- ❖ Fuel Economy
- ❖ Maneuvering

Aircraft Design Performance

1. Range
2. Takeoff distance
3. Stalling velocity.
4. Endurance **[imp for reconnaissance airplanes; an overall dominating factor for the new group of very high-altitude uninhabited air vehicles (UAVs)]**
5. Maximum velocity
6. Rate of climb
7. For dogfighting combat aircraft, maximum turn rate and sometimes minimum turn radius
8. Maximum load factor
9. Service ceiling
10. Cost
11. Reliability and maintainability
12. Maximum size **(so that the airplane will fit inside standard hangers and/or be able to fit in a standard gate at airline terminals)**

The International Standard Atmosphere

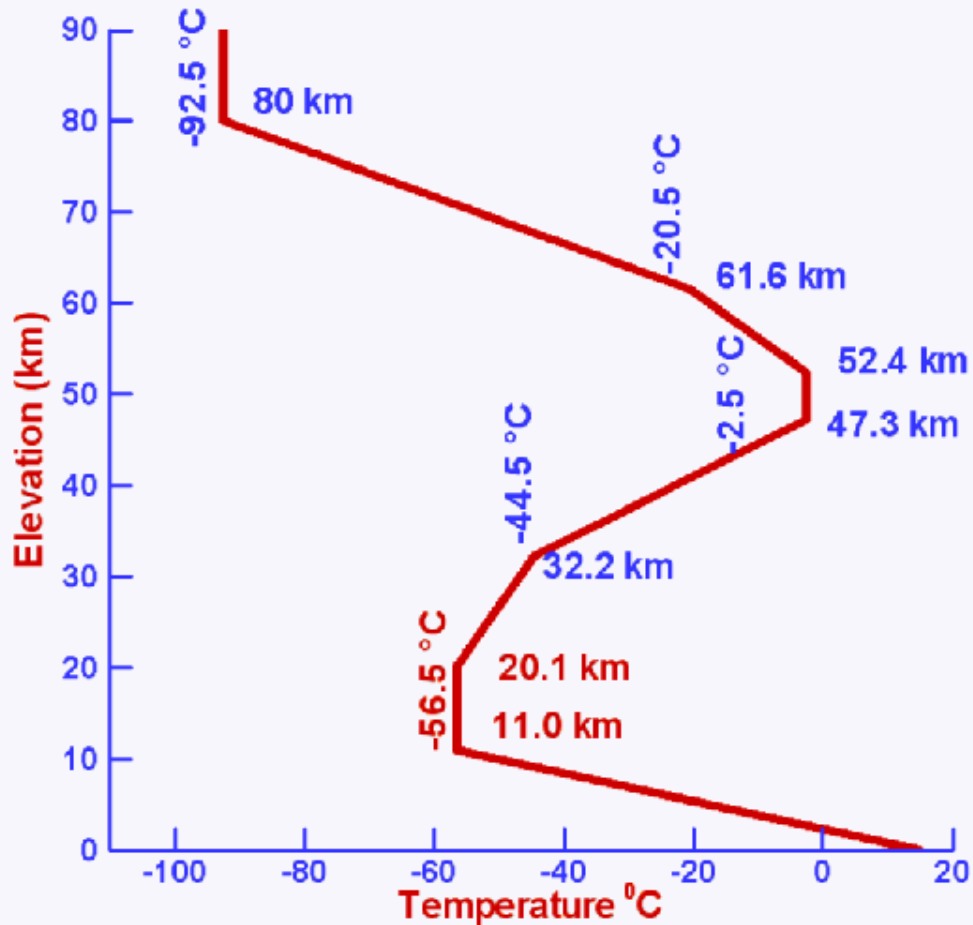
The International Standard Atmosphere (ISA) is a static **atmospheric** model of how the pressure, temperature, density, and viscosity of the Earth's **atmosphere** change over a wide range of altitudes or elevations.

AIR-BREATHING ENGINES

The International Standard Atmosphere 1976

Layer	Level Name	Base Geopotential Altitude above MSL ^[5] h (m)	Base Geometric Altitude above MSL ^[5] z (m)	Lapse Rate ($^{\circ}\text{C}/\text{km}$) ^[a]	Base Temperature T ($^{\circ}\text{C}$)	Base Atmospheric Pressure p (Pa)	Base Atmospheric Density ρ (kg/m ³)
0	Troposphere	-610	-611	+6.5	+19.0	108,900 (1.075 bar)	1.2985
1	Tropopause	11,000	11,019	0.0	-56.5	22,632	0.3639
2	Stratosphere	20,000	20,063	-1.0	-56.5	5474.9	0.0880
3	Stratosphere	32,000	32,162	-2.8	-44.5	868.02	0.0132
4	Stratopause	47,000	47,350	0.0	-2.5	110.91	0.0020
5	Mesosphere	51,000	51,413	+2.8	-2.5	66.939	
6	Mesosphere	71,000	71,802	+2.0	-58.5	3.9564	
7	Mesopause	84,852	86,000	—	-86.28	0.3734	

ISA contd--



International
Standard Atmosphere
(Temperature Profile)

AIR-BREATHING ENGINES

Off-standard and Design Atmosphere

Atmospheric Model

- ❖ Jackhia -71
- ❖ Jackhia -77
- ❖ Exponential Model

Purpose

- ❖ Re-entry of space craft
- ❖ Ballistic Missile
- ❖ Space Launch Vehicle
- ❖ Low Earth Orbiting Objects

Modelling Consideration

- ❖ Seasonal effect
- ❖ Latitude & Longitudinal Effect
- ❖ Earth Oblateness effect
- ❖ Etc...

Relation Between Geo Potential Height And Geometric Height

$$g = g_o \left(\frac{r}{h_a} \right)^2 = g_o \left(\frac{r}{r + h_g} \right)^2$$

$$dP = -\rho g dh_g$$

Relation between hg and h

Relation Between Geo Potential Height And Geometric Height

$$\frac{\rho T}{\rho_1 T_1} = \left(\frac{T}{T_1} \right)^{-\frac{g_0}{\alpha R}}$$

$$\frac{\rho}{\rho_1} = \left(\frac{T}{T_1} \right)^{-\frac{g_0}{\alpha R} - 1}$$

$$\frac{\rho}{\rho_1} = \left(\frac{T}{T_1} \right)^{-\left(\frac{g_0}{\alpha R} + 1\right)}$$

Variables	Gradient layer	Isothermal layer
Pressure	$\frac{P}{P_1} = \left(\frac{T}{T_1} \right)^{-\frac{g_0}{\alpha R}}$	$\frac{P}{P_1} = e^{-[g_0/(RT)](h-h_1)}$
Density	$\frac{\rho}{\rho_1} = \left(\frac{T}{T_1} \right)^{-\left(\frac{g_0}{\alpha R} + 1\right)}$	$\frac{\rho}{\rho_1} = e^{-[g_0/(RT)](h-h_1)}$

Measurement of Air Data

Measuring Parameters

- ❖ Temperature
- ❖ Pressure
- ❖ Density
- ❖ Moisture etc..

Measuring Techniques

- ❖ Barometer
- ❖ Thermometer
- ❖ Thermal Infra-red

Relations

- ❖ Atmospheric Pressure
- ❖ Temperature, Pressure & Density Relations

Air Data Computers

An **air data computer** (ADC) is an essential avionics component found in modern glass cockpits. This **computer**, rather than individual instruments, can determine the calibrated airspeed, Mach number, altitude, and altitude trend **data** from an aircraft's pitot-static system.

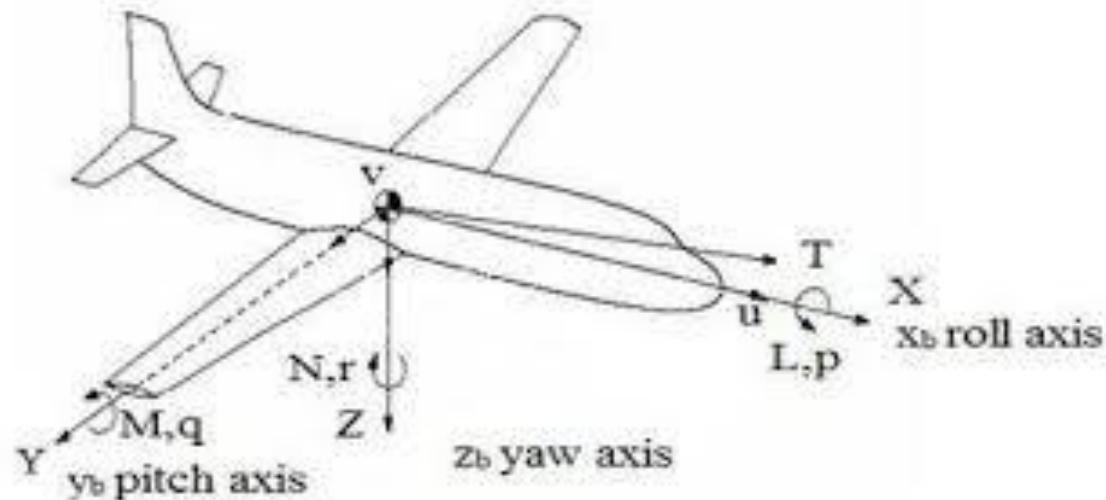


EOMs

Equations of Motion for Performance

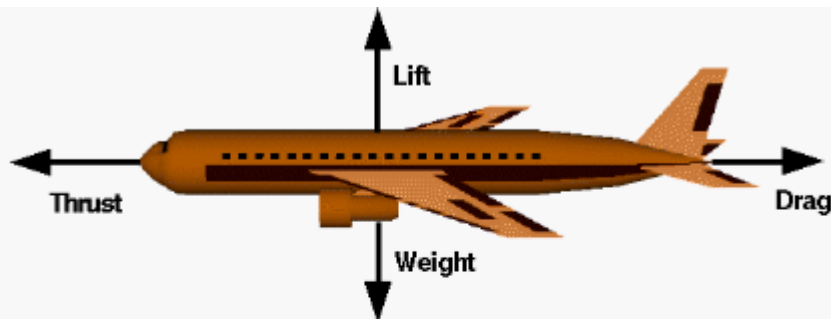
Governing Parameters

- ❖ Lift
- ❖ Drag
- ❖ Weight
- ❖ Thrust
- ❖ Velocity
- ❖ Flight path
 - Velocity & horizontal
- ❖ Pitch angle
 - Nose & horizontal



Force system of an aircraft

The Aircraft Force System



Flight Condition	Effect
Lift > Weight	Plane Rises
Weight > Lift	Plane Falls
Drag > Thrust	Plane Slows
Thrust > Drag	Plane Accelerates

A diagram of an aircraft in a climb. The 'Flight Path' is shown as a red line at an angle 'c' (climb angle) to the horizontal. Force vectors are shown: 'F' (Thrust) along the flight path forward, 'D' (Drag) along the flight path backward, 'L' (Lift) perpendicular to the flight path, and 'W' (Weight) vertically downward. A legend on the right defines: L = Lift, D = Drag, W = Weight, F = Thrust. Below the diagram, it states: m = aircraft mass, a = acceleration.

Equations:

$$L \cos(c) + F \sin(c) - D \sin(c) - W = m a_{\text{Vertical}}$$

$$F \cos(c) - L \sin(c) - D \cos(c) = m a_{\text{Horizontal}}$$

Definition of Excess Thrust: $F - D = F_{\text{ex}}$

$$L \cos(c) + F_{\text{ex}} \sin(c) - W = m a_{\text{Vertical}}$$

$$F_{\text{ex}} \cos(c) - L \sin(c) = m a_{\text{Horizontal}}$$

Total Airplane Drag Estimation

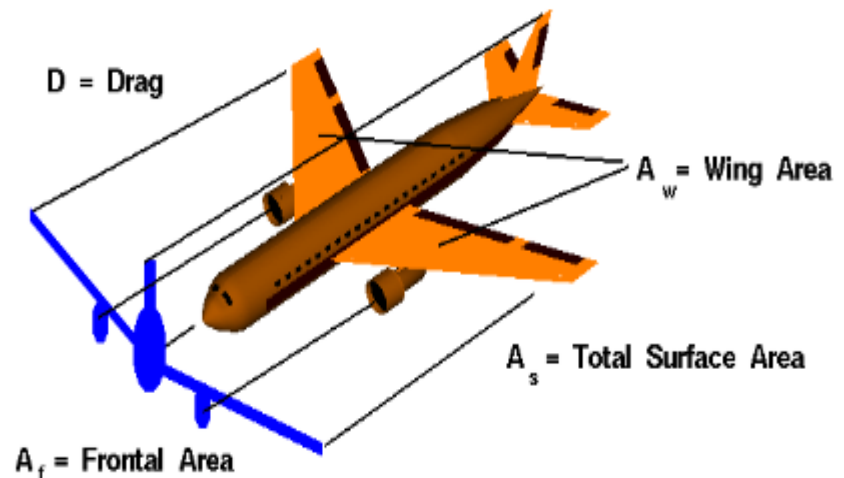


$$D = C_d \times \frac{\rho \times V^2 \times A}{2}$$

Drag = coefficient x density x velocity squared x reference area
two

Coefficient C_d contains all the complex dependencies and is usually determined experimentally.

Choice of reference area A affects the value of C_d .



$$A_s \sim A_f \sim A_w$$

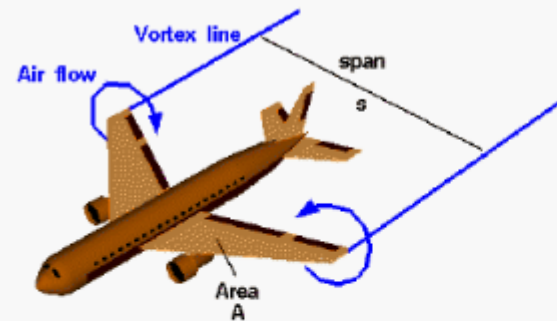
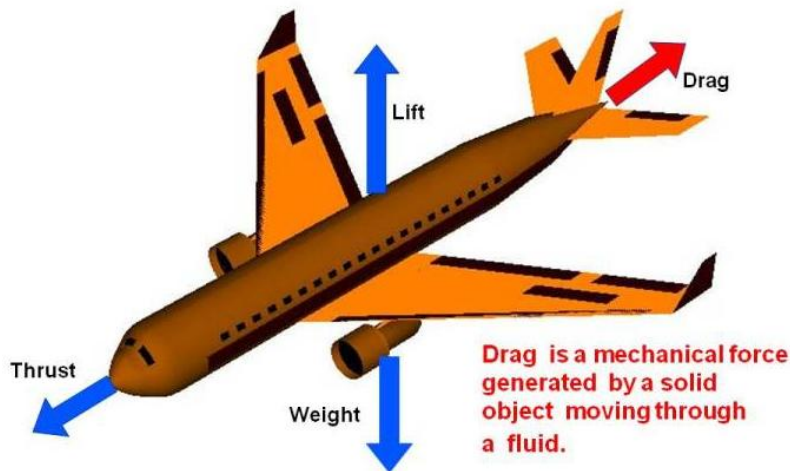
Drag is directly related to reference area

$$D = \text{Constant} \times A_{\text{ref}}$$

Double the Area \rightarrow Double the Drag

Drag calculation

Total Airplane Drag Estimation



Aspect Ratio = AR

$$AR = \frac{s^2}{A}$$

$$Cd_i = \frac{Cl^2}{\pi AR e}$$

efficiency factor = e
for an ellipse e = 1.0
in general e < 1.0

Pressure difference across wing surface causes spillage around the wing tips.

Downwash causes a local induced angle of attack with additional induced drag on a finite wing.

Total Airplane Drag Estimation

Factors Affecting Drag



Shape and size
Velocity and inclination to flow
Mass, Viscosity, Compressibility

Effects of shapes on drag estimation

Total Airplane Drag Estimation

Shape Affecting Drag

Shape	Drag Coefficient		
Sphere	0.47	Long Cylinder	0.82
Half-sphere	0.42	Short Cylinder	1.15
Cone	0.50	Streamlined Body	0.04
Cube	1.05	Streamlined Half-body	0.09
Angled Cube	0.80		

Measured Drag Coefficients

Drag Reduction Methods

SKIN FRICTION DRAG

1. Turbulent drag reduction

- A. Riblets
- B. Large eddy break-up devices
- C. Surface coatings

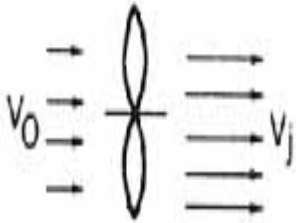
2. Laminar flow control

- A. Boundary layer suction
- B. Hybrid laminar flow concept
- C. Boundary layer flow control
- D. Wing tip devices
- E. Vortex generators

AIR-BREATHING ENGINES

The Propulsive Forces

Propeller



$$\text{force} = \text{mass} \times \text{acceleration}$$

Turbojet and Ram Jet



Heat is added

$$\begin{aligned} \text{force} &= \text{rate of change of momentum or} \\ \text{force} &= \text{mass flow rate} \cdot \text{change in fluid velocity} \end{aligned}$$

Rocket



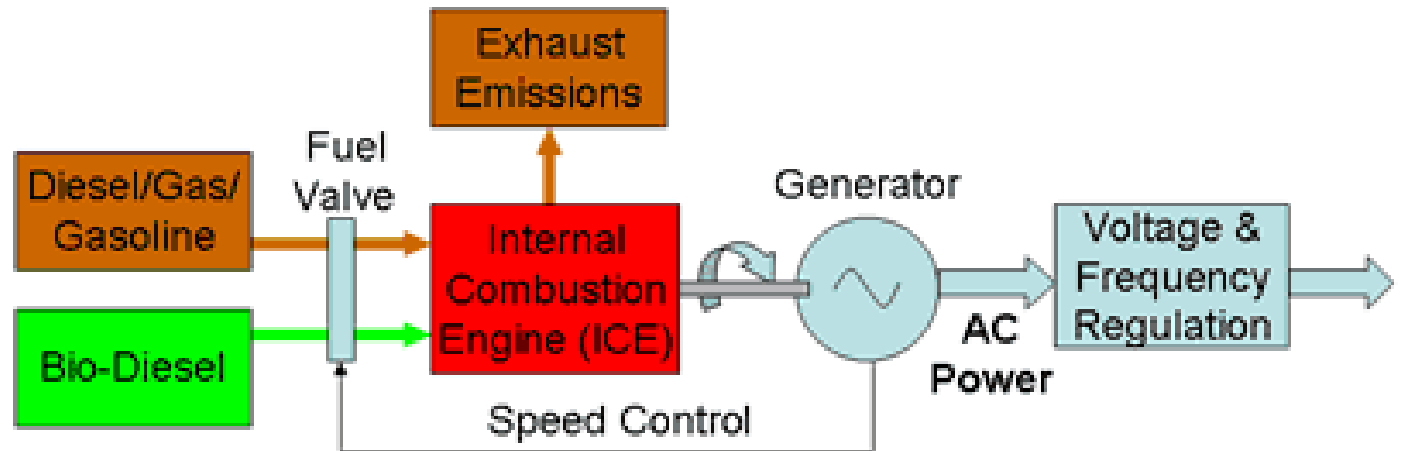
Heat is added

The Thrust Production Engines

A piston **engine** cannot **produce thrust** on its own. The exhaust gases **produced** by a propeller, jet or rocket, due to Newton's Third Law, are feeling a force opposite and equal to **the thrust**, and therefore are moved in the direction opposite to **the thrust** of the **engine**. Hence, the exhaust is the effect of **thrust**

Power Producing Engines

An **engine power plant** is a power station in which power comes from the combination of a reciprocating engine and an alternator.

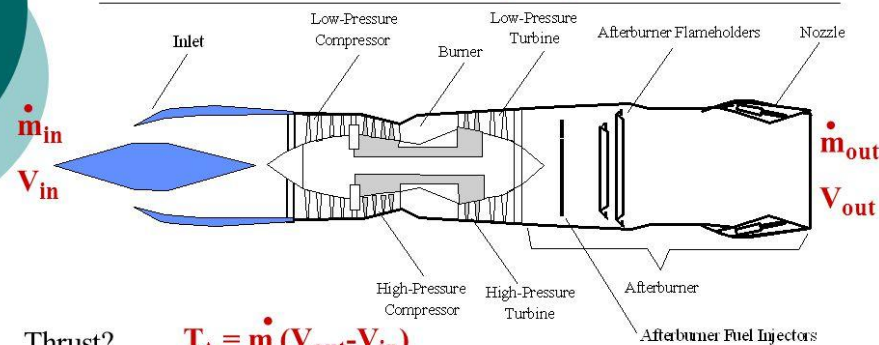


Electric Power Generation by Internal Combustion Engine (ICE)

Variation of Thrust

Thrust is produced by accelerating air. Therefore **thrust** decreases with increasing airspeed. In level flight, an aircraft could not be accelerated above the engine exhaust gas speeds because then the incoming air would be faster than the exhaust air - resulting in a deceleration.

Thrust Available (T_A)



Thrust? $T_A = \dot{m} (V_{out} - V_{in})$

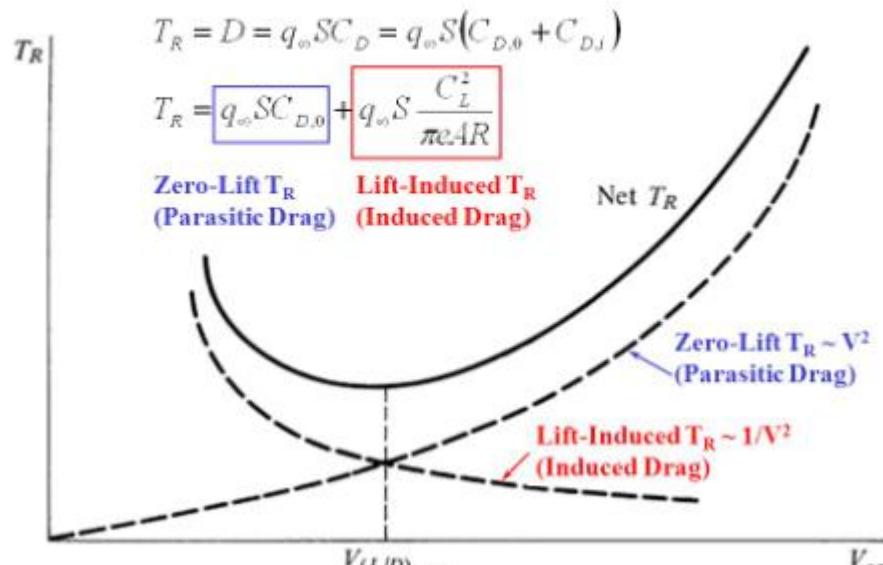
Continuity? $\dot{m}_{in} = \dot{m}_{out}$

Mass flow equation? $\dot{m} = \rho AV$

$$T_A = \rho AV (V_{out} - V_{in})$$

$$T_A = T_{SL} \left(\frac{\rho}{\rho_{SL}} \right)$$

THRUST REQUIRED VS. FLIGHT VELOCITY



Power and SFC

Propulsive power and specific fuel consumption with altitude and flight speed

Thrust Specific Fuel Consumption (TSFC)

\dot{m}_f = fuel mass flow rate

\dot{m}_a = air mass flow rate

f = fuel to air ratio (\dot{m}_f / \dot{m}_a)

F_s = specific thrust (F / \dot{m}_a)

F = net thrust

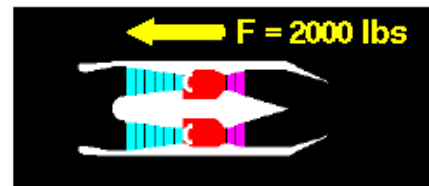
$$TSFC = \frac{f}{F_s}$$

$$TSFC = \frac{\dot{m}_f}{F} \quad \frac{(\text{lbm/hr})}{(\text{lbs})} \quad \text{or} \quad \frac{(\text{kg/hr})}{(\text{N})}$$

Low TSFC = High efficiency

High TSFC = Low efficiency

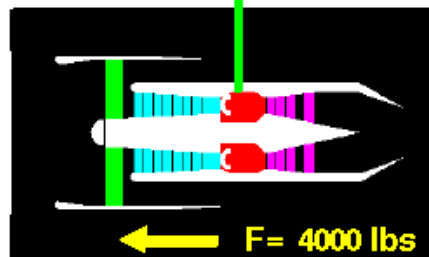
Turbojet



TSFC = 1.0

$\dot{m}_f = 2000 \text{ lbm/hr}$

TSFC = 0.5



Turbofan

To move an airplane through the air, a propulsion system is used to generate thrust. The amount of thrust an engine generates is important. But the amount of fuel used to generate that thrust is sometimes more important, because the airplane has to lift and carry the fuel throughout the flight. Engineers use an efficiency factor, called **thrust specific fuel consumption**, to characterize an engine's fuel efficiency. "Thrust specific fuel consumption" is quite a mouthful, so engineers usually just call it the engine's **TSFC**.

What does TSFC mean?

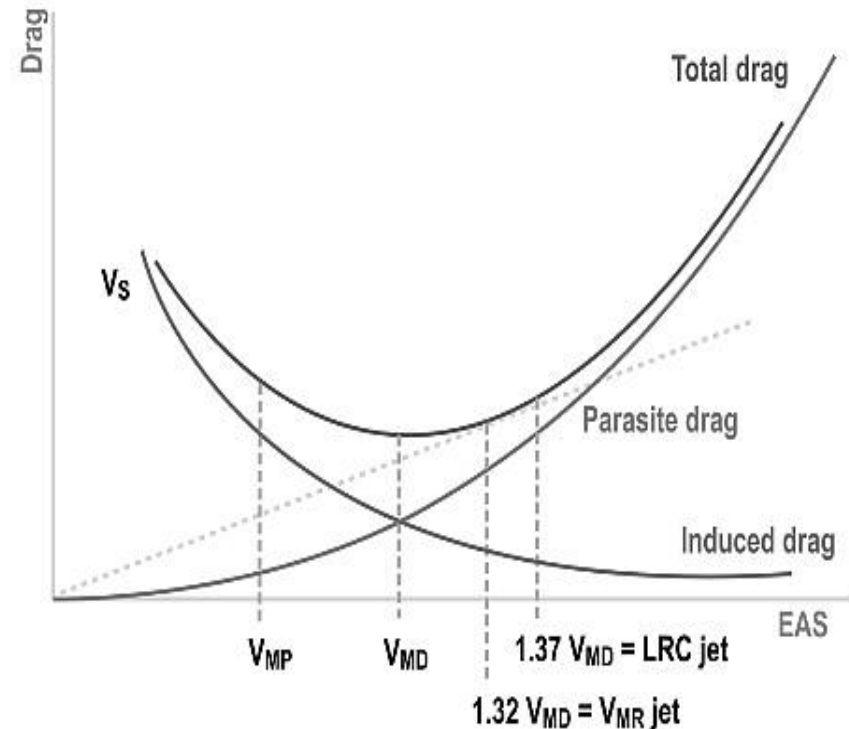
SFC and BSFC

The fuel consumption of TSFC is "how much fuel the engine burns each hour." The specific of TSFC is a scientific term meaning "divided by mass or weight." In this case, **specific** means "per pound (Newton) of thrust." The **thrust** of TSFC is included to indicate that we are talking about gas turbine engines. There is a corresponding **brake specific fuel consumption (BSFC)** for engines that produce shaft power. Gathering all the terms together, TSFC is the **mass of fuel burned by an engine in one hour divided by the thrust** that the engine produces. The units of this efficiency factor are mass per time divided by force (in English units, pounds mass per hour per pound; in metric units, kilograms per hour per Newton).

Mathematically, TSFC is a ratio of the engine fuel mass flow rate \dot{m}_f to the amount of thrust F produced by burning the fuel.

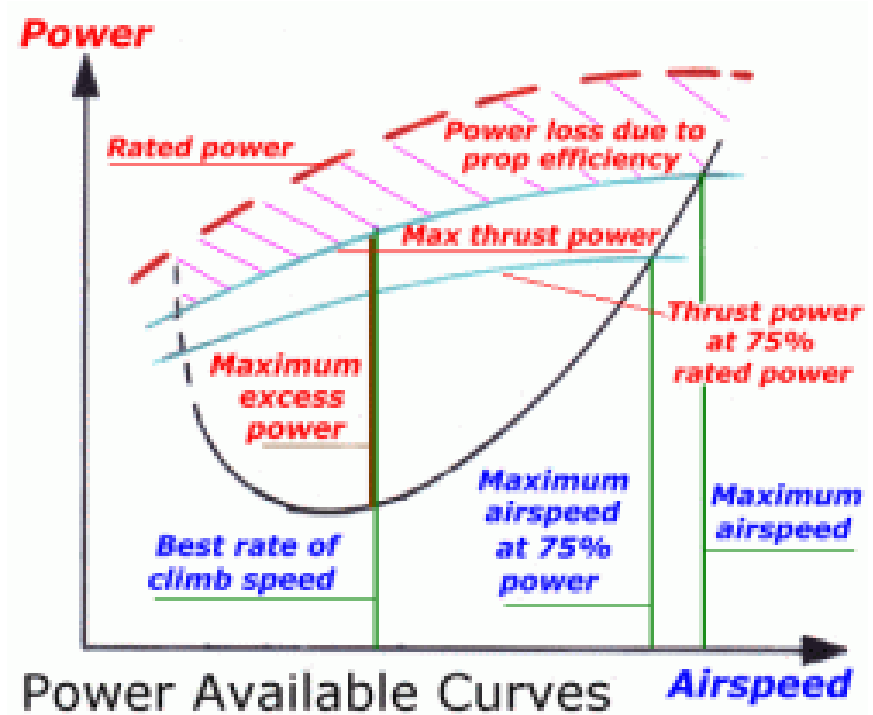
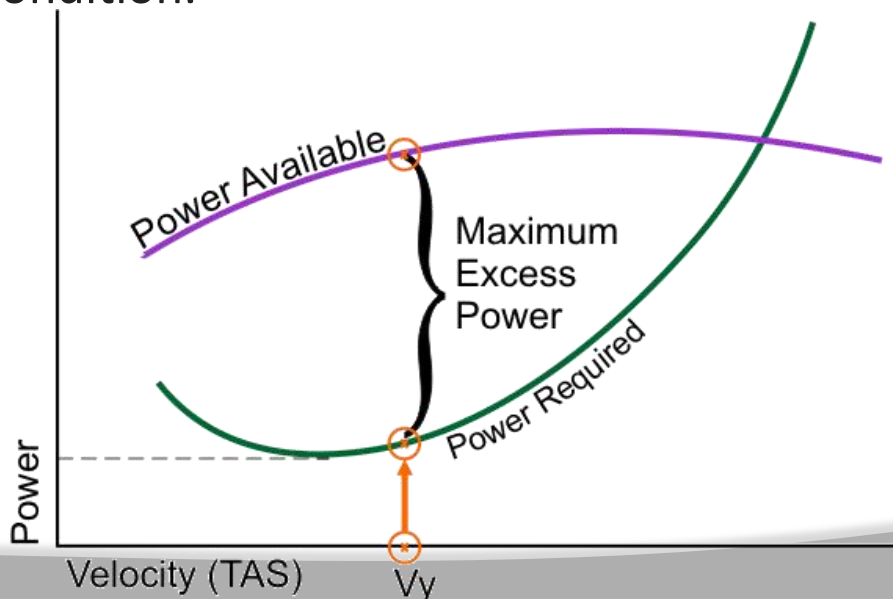
Minimum drag speed

There is a **speed** for **minimum** power required to maintain level flight (VMP) and this is where the product of **speed** and **drag** are at a **minimum** (where the two values make a square with the axes of the graph). VMP is the **speed** for **minimum** fuel consumption (max endurance) in a propeller driven aircraft.



Minimum Power Speed

The **minimum power** required (maximum endurance) occurs when is a maximum. Thus the **minimum power**(maximum endurance) condition occurs at a **speed** which is $3^{-1/4} = 76\%$ of the **minimum drag** (maximum range) condition.



Parabolic drag polar

Aerodynamic relationships for a parabolic drag polar

The relationship between the drag coefficient and the lift coefficient is called drag polar.

The usual method to estimate the drag of an airplane is to add the drags of the major components of the airplane and then apply correction for the interference effects.

The major components of the airplane which contribute to drag are wing, fuselage, horizontal tail, vertical tail, nacelles and landing gear

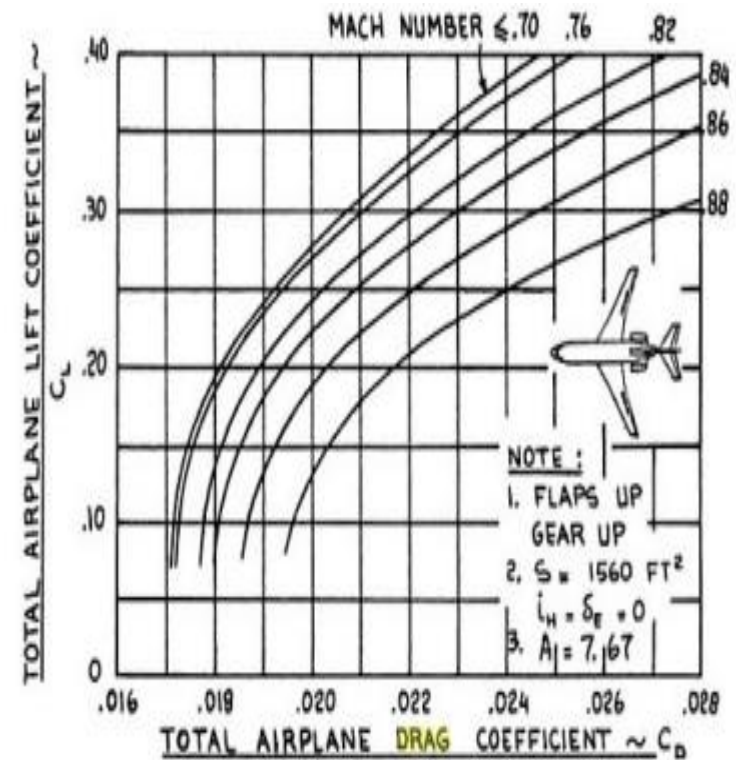
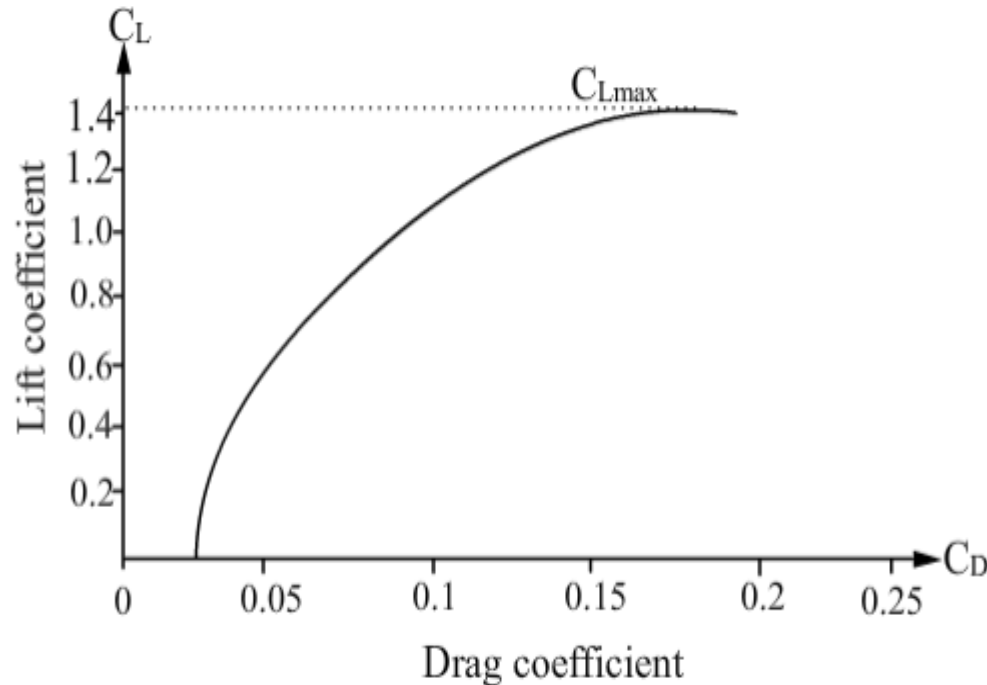
$$\text{Thus, } D = D_{\text{wing}} + D_{\text{fuse}} + D_{\text{ht}} + D_{\text{vt}} + D_{\text{nac}} + D_{\text{lg}} + D_{\text{etc}}$$

includes the drag of items like external fuel tanks, bombs, struts etc..

Equation for drag polar

- ❖ Drag polar with Varying AR
- ❖ Drag polar with Varying C_{D0}

$$C_D = C_{D0} + \frac{C_L^2}{\pi A e}$$



UNIT - V

AIRCRAFT INSTRUMENTS

INTRODUCTION

- Enable an airplane to be **operated** with **maximum performance** and **enhanced safety**
- **Manufacturers** provide the necessary flight instruments
- Pilots **need to understand** how they operate

Types

- **Flight Instruments**

- Altimeter, Airspeed Indicator, Mach meter, Vertical Speed Indicator, Attitude Indicator (Artificial Horizon), Turn and Bank Indicator , Heading Indicator

- **Navigation Instruments**

- Accelerometer, Horizontal Situation Indicator

- **Engine Instruments**

- Electrical Tachometer, Oil Pressure Indicator, Exhaust Gas Temperature,

- **Pressure Gauges**

- Bourdon Tube , Diaphragm Type ,Hydraulic

Flight Instruments

- They provide the pilot with information about the flight situation of that aircraft, such as altitude, speed and direction.
- Used in conditions of poor visibility, such as in clouds, when such information is not available from visual reference outside the aircraft.

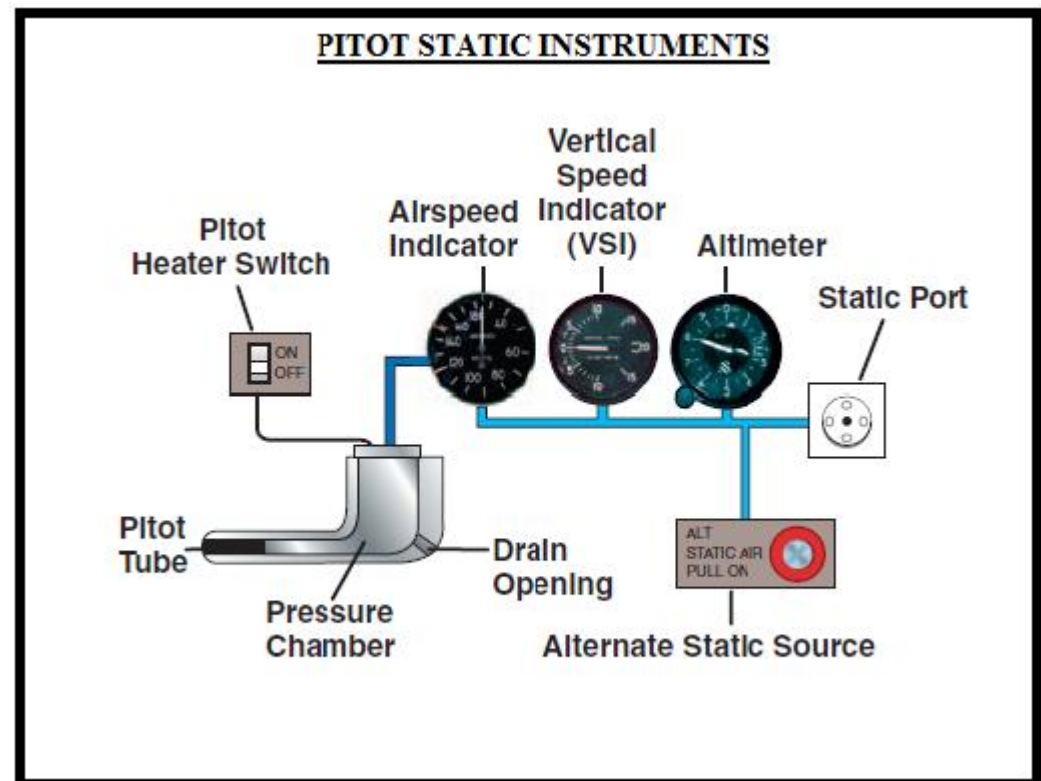
Flight Instruments



Airspeed Indicator, Attitude Indicator, Altimeter,
Turn and Bank Indicator, Heading Indicator, Vertical Speed Indicator

Pitot-Static Flight Instruments

- Two Major Parts:
 - Impact Pressure Chamber and Lines
 - Static Pressure Chamber and Lines



Blockage of Pitot-Static System

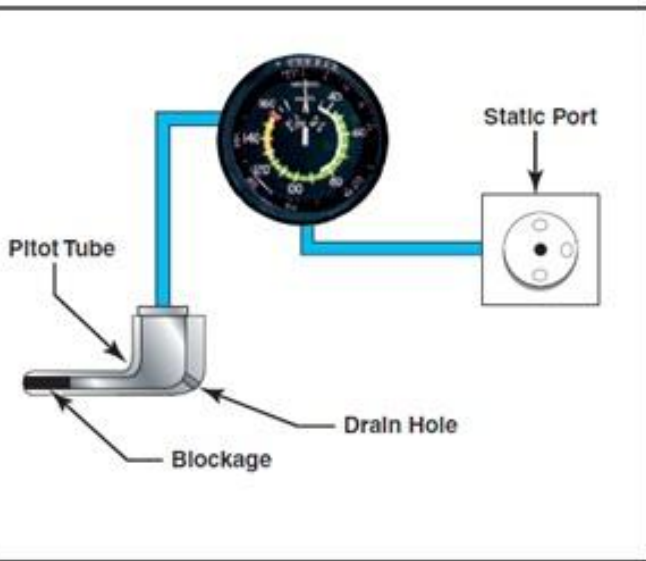


Figure A blocked pitot tube, but clear drain hole.

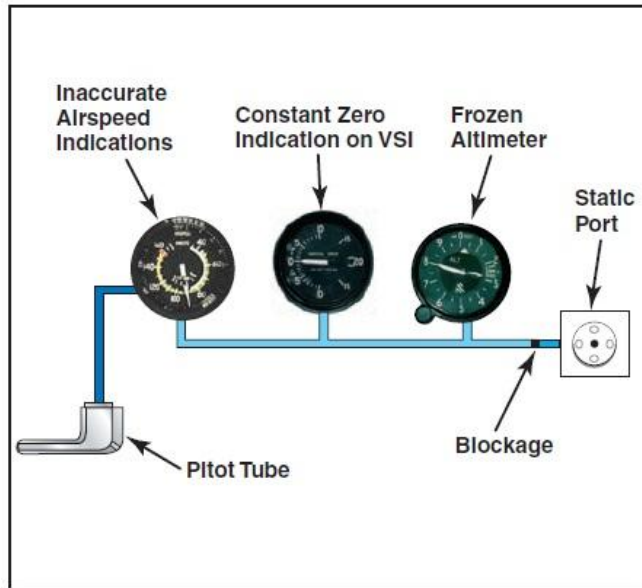


Figure **Blocked static system.**

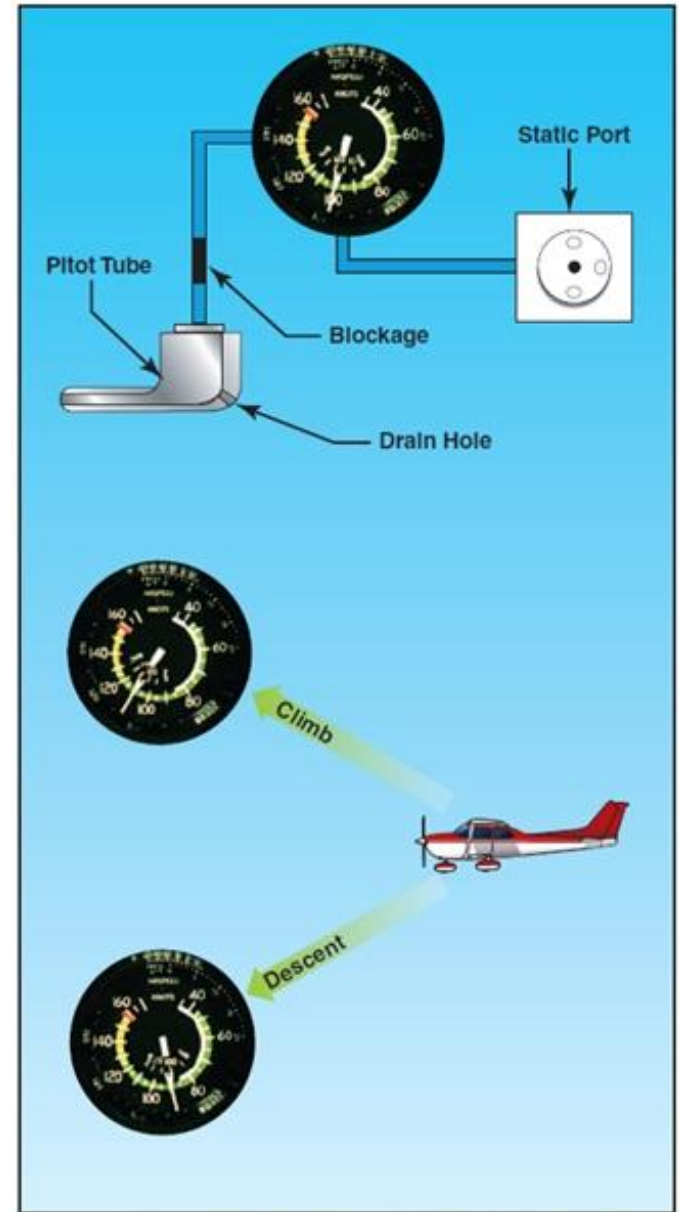
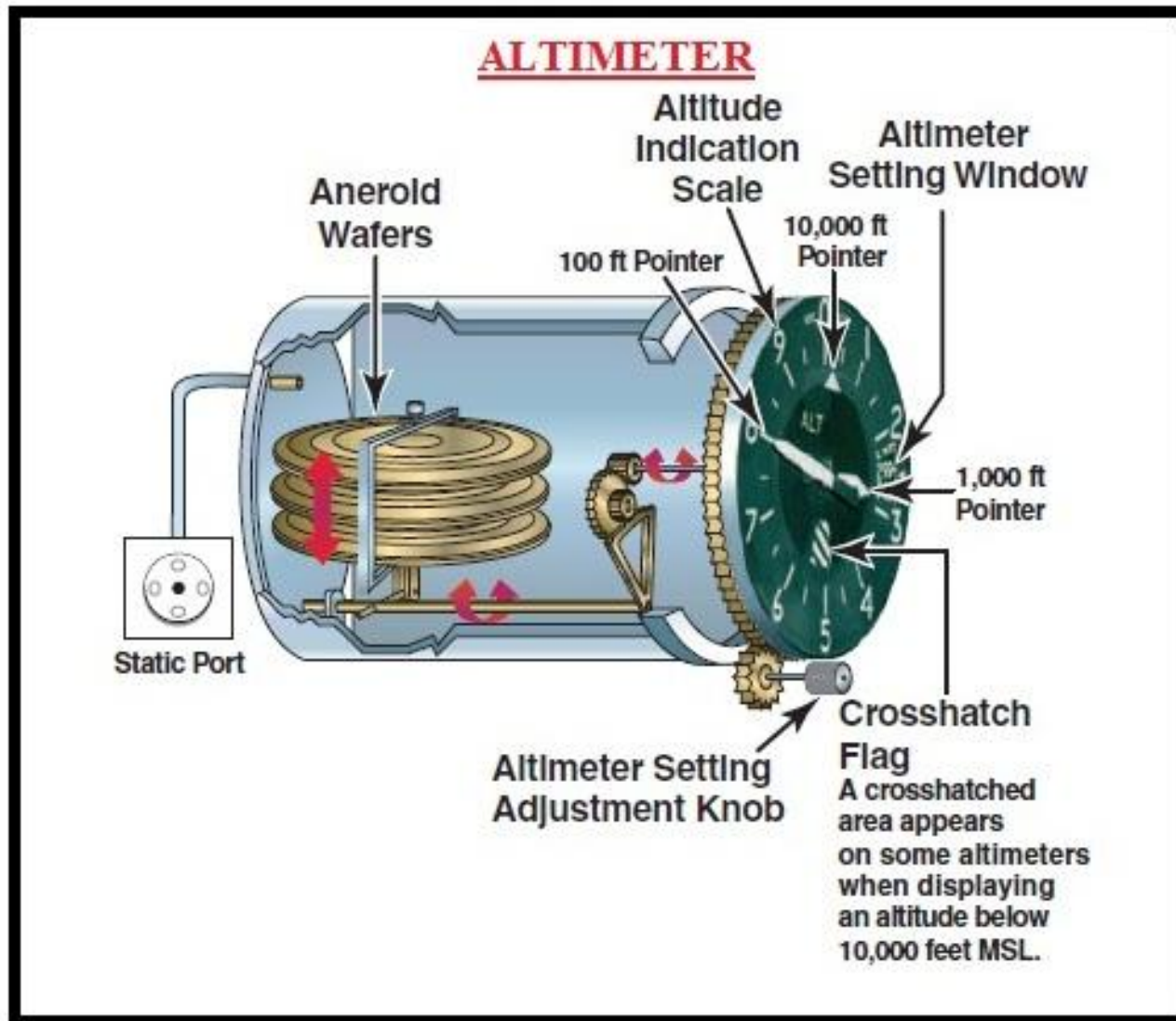
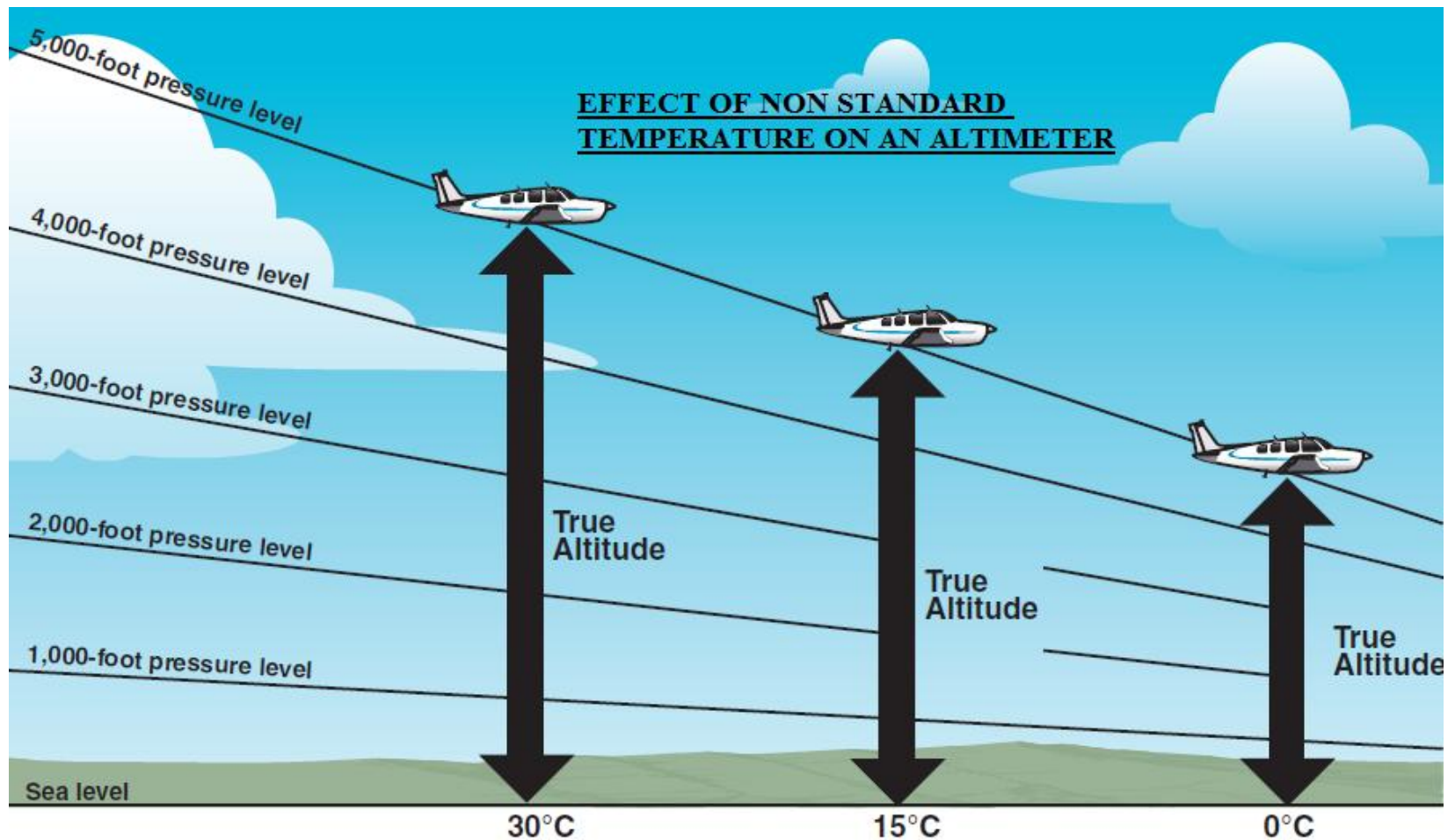


Figure Blocked pitot system with clear static system.

ALTIMETER



Effect of Temperature on an Altimeter



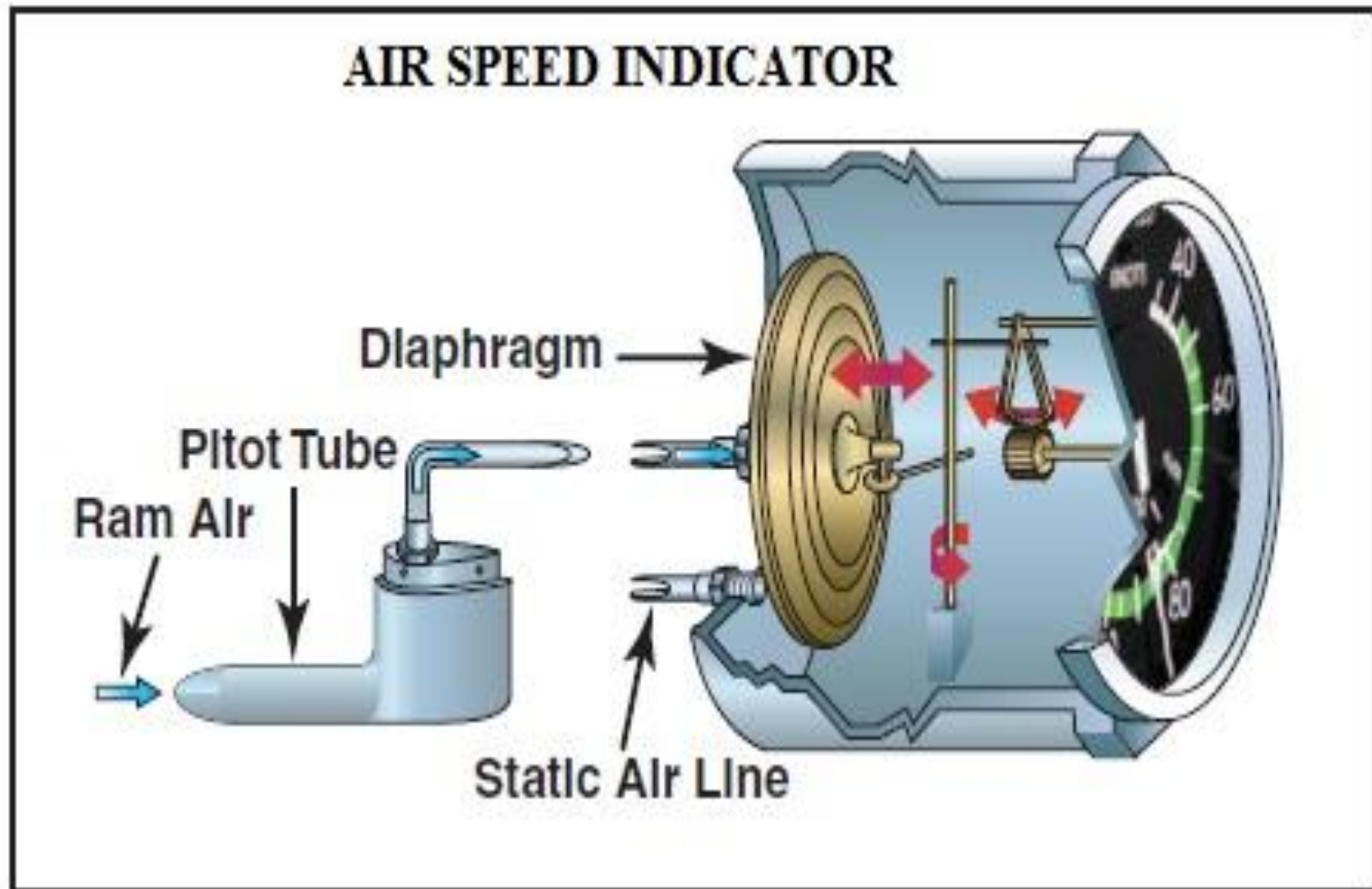
Types of Altitude

- **Indicated Altitude** : Altitude read directly from the altimeter (uncorrected)
- **True Altitude** : The vertical distance of the airplane above sea level—the actual altitude. It is often expressed as feet above mean sea level (MSL). Airport, terrain, and obstacle elevations on aeronautical charts are true altitudes.
- **Absolute Altitude** : The vertical distance of an airplane above the terrain, or above ground level (AGL).

Types of Altitude

- **Pressure Altitude** : The altitude indicated when the altimeter setting window (barometric scale) is adjusted to 29.92 in. Hg (Corrected to 15°C). Pressure altitude is used to compute density altitude, true altitude, true airspeed, and other performance data.
- **Density Altitude** : Pressure altitude corrected for variations from standard temperature. When conditions are standard, pressure altitude and density altitude are the same. If the temperature is above standard, the density altitude is higher than pressure altitude. If the temperature is below standard, the density altitude is lower than pressure altitude. This is an important altitude because it is directly related to the airplane's performance.

AIRSPEED INDICATOR (ASI)



Types of Airspeeds

- **Indicated Airspeed (IAS)** : The direct instrument reading obtained from the airspeed indicator, **uncorrected** for variations in atmospheric density, installation error, or instrument error
- **Calibrated Airspeed (CAS)** : Indicated airspeed **corrected** for installation error and instrument error.
- **True Airspeed (TAS)** : Calibrated **airspeed** corrected for altitude and nonstandard temperature.
- **Groundspeed (GS)** : The actual speed of the airplane over the ground. It is **true airspeed** **adjusted** for **wind**. Groundspeed **decreases with a headwind**, and increases with a tailwind.

ASI – Colour Codes

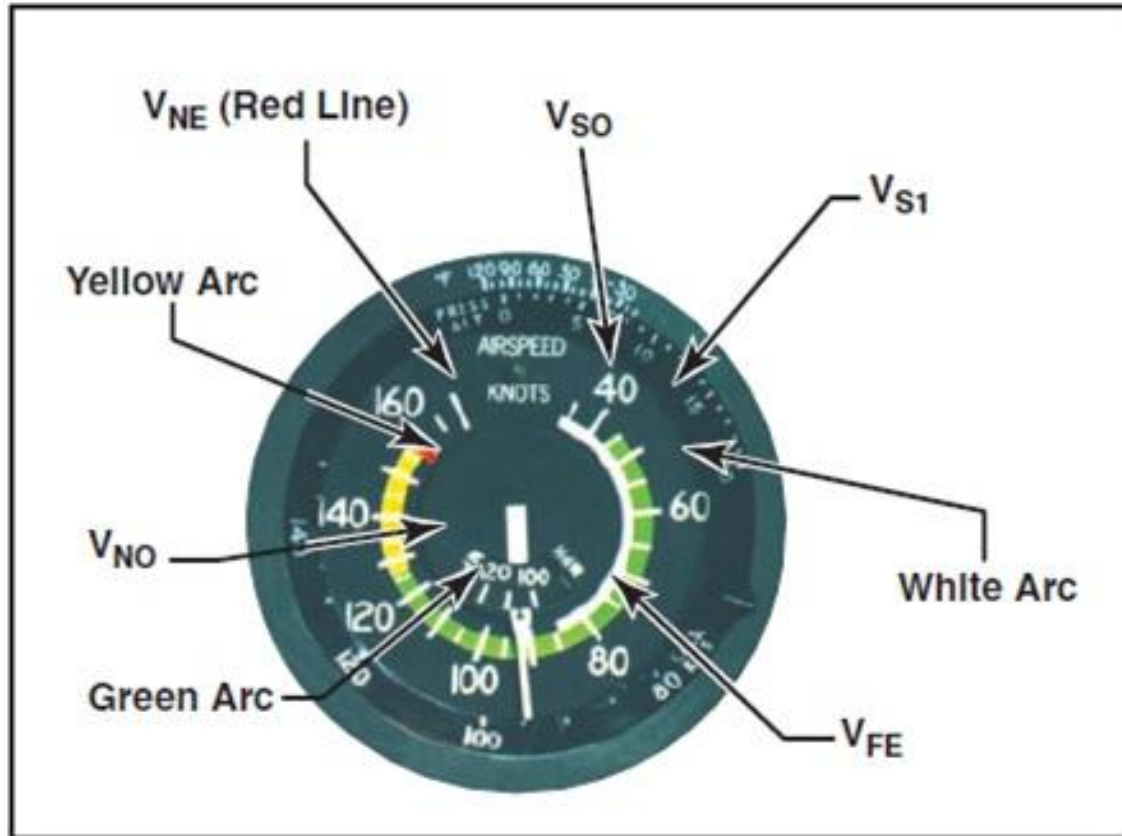


Figure . In addition to delineating various speed ranges, the boundaries of the color-coded arcs also identify airspeed limitations.

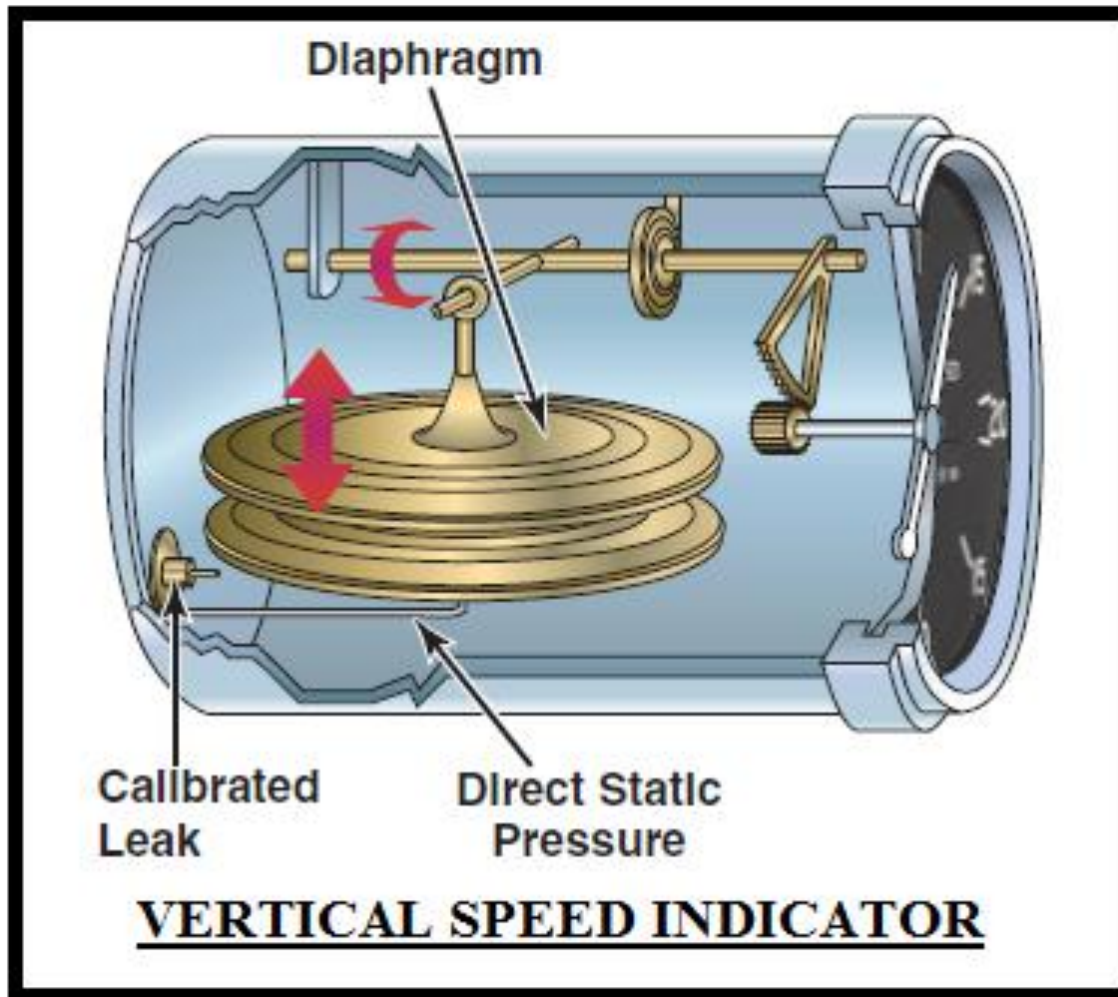
ASI – Colour Codes

- **White arc**—This arc is commonly referred to as the **flap operating range** since its lower limit represents the **full flap stall speed** and its upper limit provides the **maximum flap speed**. Approaches and landings are usually flown at speeds within the white arc.
- **Lower limit of white arc (V_{S0})**— The stalling speed or the minimum steady flight speed in the landing configuration. In small airplanes, this is the power-off stall speed at the maximum landing weight in the landing configuration (gear and flaps down).
- **Upper limit of the white arc (V_{FE})**—The maximum speed with the flaps extended.
- **Green arc**—This is the normal operating range of the airplane. Most flying occurs within this range.

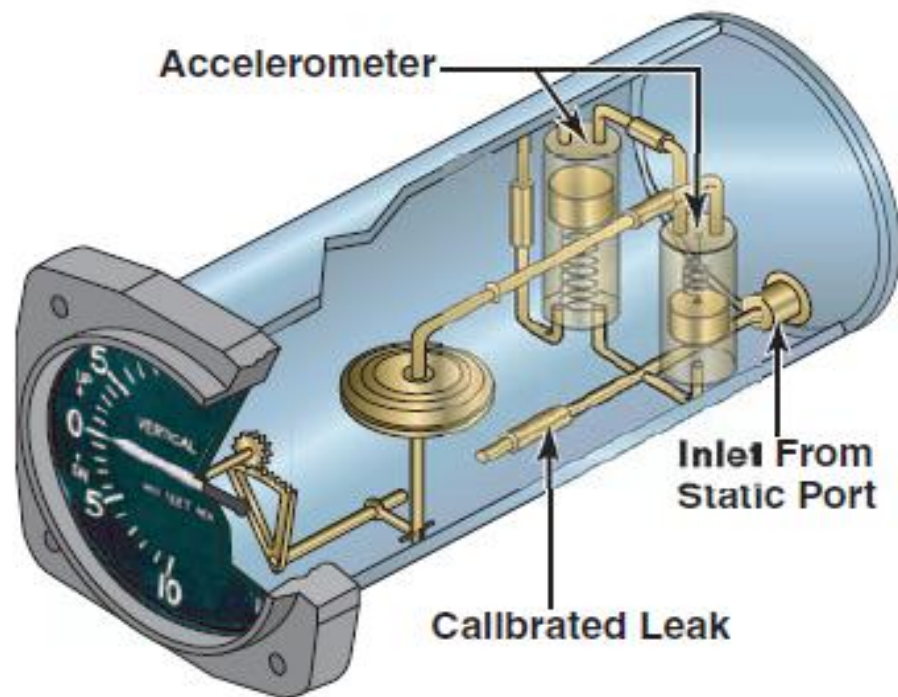
ASI – Colour Codes

- Lower limit of green arc (VS1)—The stalling speed or the minimum steady flight speed obtained in a specified configuration. For most airplanes, this is the power-off stall speed at the maximum takeoff weight in the clean configuration (gear up, if retractable, and flaps up).
- Upper limit of green arc (VNO)—The maximum structural cruising speed. Do not exceed this speed except in smooth air.
- Yellow arc—Caution range. Fly within this range only in smooth air, and then, only with caution
-
- Red line (VNE)—Never-exceed speed. Operating above this speed is prohibited since it may result in damage or structural failure.

VERTICAL SPEED INDICATOR (VSI)



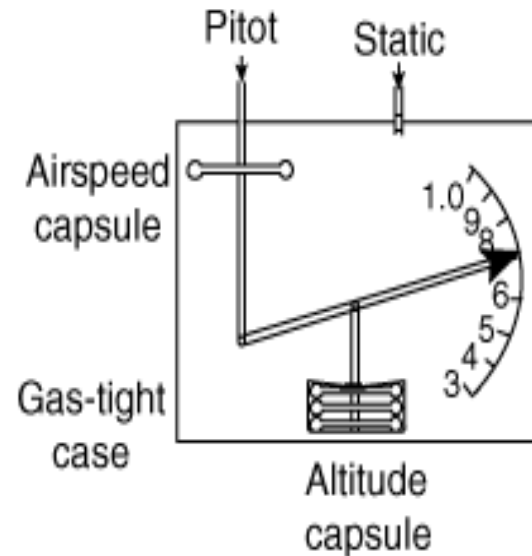
IVSI



An instantaneous vertical speed indicator incorporates accelerometers to help the instrument immediately indicate changes in vertical speed.

Machmeter

- The older **mechanical Machmeters** use an **altitude aneroid** and an **airspeed capsule** which together convert **pitot-static pressure** into **Mach number**. Modern **electronic Machmeters** use information from an **air data computer system**.

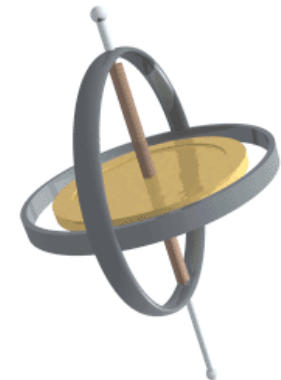


Gyroscopic Instruments

- **Gyroscope** : Device consisting of a **wheel** having much of its **mass concentrated around the rim**, mounted on a **spinning axis**.

Characteristics :

- **Rigidity in Space** : Directional reference
- **Precession** : Tendency of the gyro to react to an applied force 90° in the direction of rotation from the point the force is applied.



Principle

- **Rigidity in Space**
- Principle that a gyroscope **remains in a fixed position** in the **plane in which it is spinning**
- By mounting this wheel, or gyroscope, on a set of Gimbal rings, the gyro is able to rotate freely in any direction.
 - If the **gimbal rings are tilted, twisted, or otherwise moved**, the **gyro remains in the plane** in which it was originally.
 - Think of the gyro as being aligned with the horizon, and the **airplane rotates around it**.
- **Stability increases** if the rotor has **great mass and speed**
 - Approximately **15,000 rpm** for the **attitude indicator** and **10,000 rpm** for the **heading indicator**

Principle

- **Gyroscopic Precession**

Whenever a force attempts to tilt the plane of rotation, the force is applied 90 degrees ahead of, and in the direction of rotation

- Inversely proportional to the speed of the rotor and proportional to the deflective force

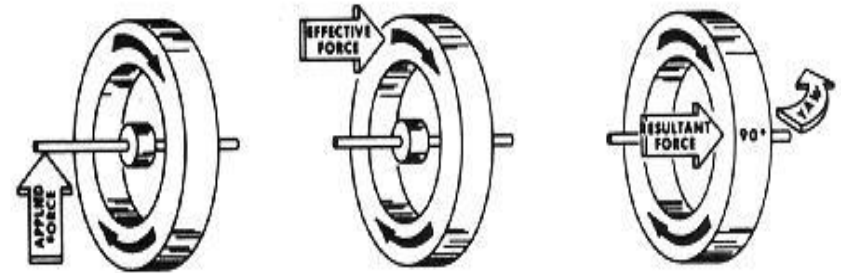


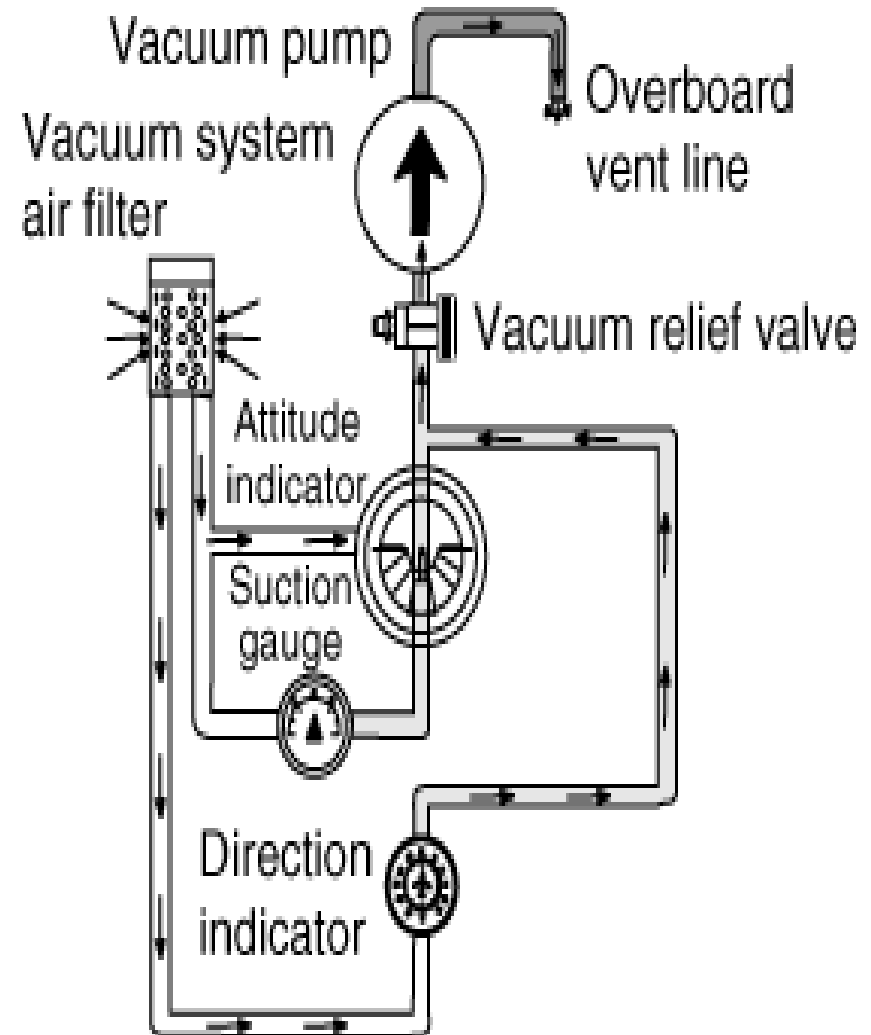
Figure 17-44 Gyroscopic Precession

Power Sources

- **Vacuum System:**

Runs the **Attitude Indicator** and **Heading Indicator**

- Engine Driven Pump creates suction through system
- Air sucked through system is **diverted over "buckets"** in gyroscope walls to turn gyros
- **Semi-frictionless** design



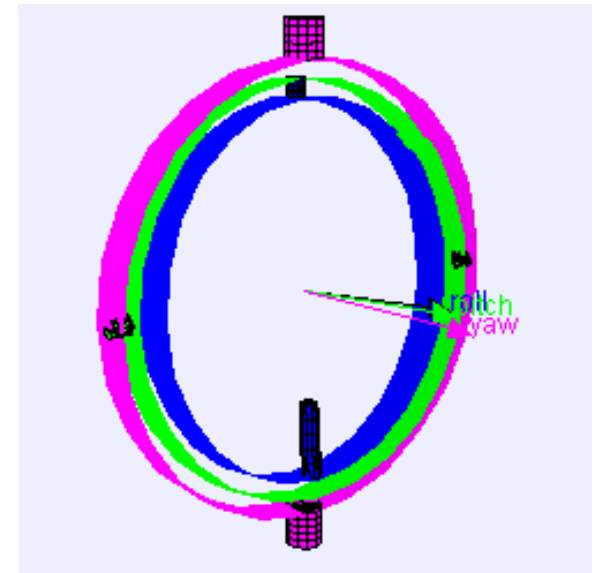
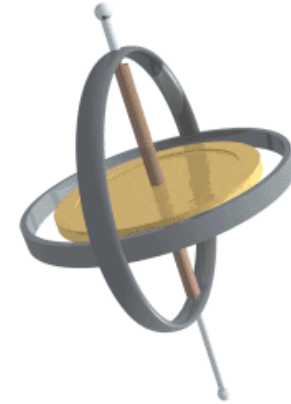
Power Sources

- **Electrical System:**

The **turn coordinator** uses an electrical gyro so that in the event of a **vacuum system failure**, the pilot still has one working gyroscopic instrument

Gyroscopic Instruments

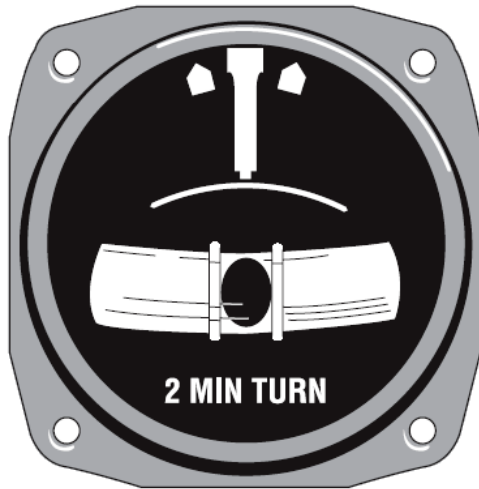
- Turn and Bank Indicator
(or) Turn Coordinator
- Attitude Indicator
(or) Artificial Horizon
- Heading Indicator



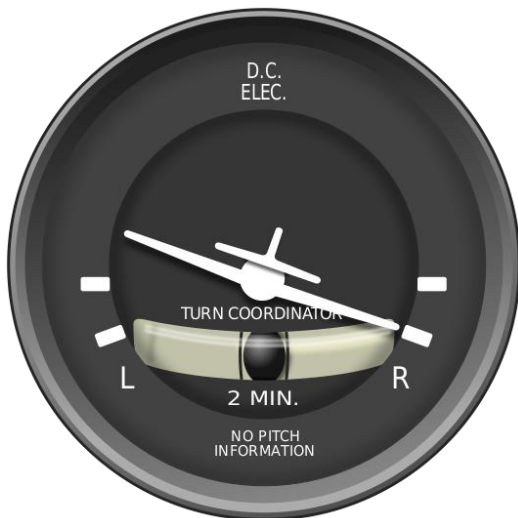
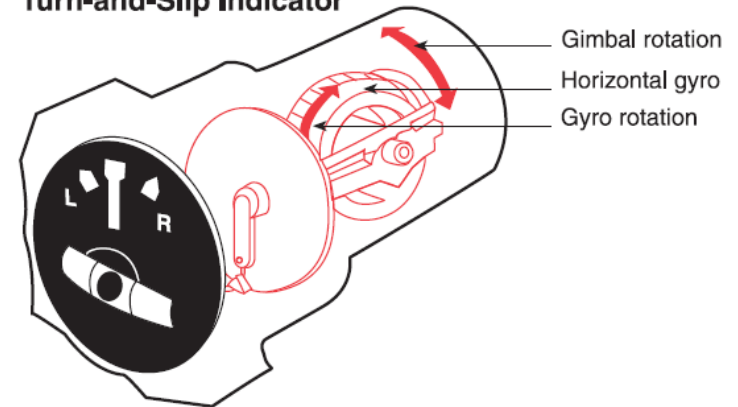
Turn and Bank Indicator

- Uses an **electric gyroscope** to give pilot information about **rate of turn and rate of roll**
 - Tells us direction and how quickly we are rolling initially
 - Then tells us rate of turn, or how many degrees per second
- Markings at "**Standard Rate Turn**", which the airplane will turn **360 degrees in 2 minutes**
- Gyroscope **mounted diagonally**, balanced by **a spring**, and works by **precession** to sense bank angle
- **Inclinometer (ball)**
 - Separate instrument used to **measure quality of turn**
 - Ball on the inside of turn indicates **a slipping turn**
 - Ball on the outside of turn indicates **a skidding turn**

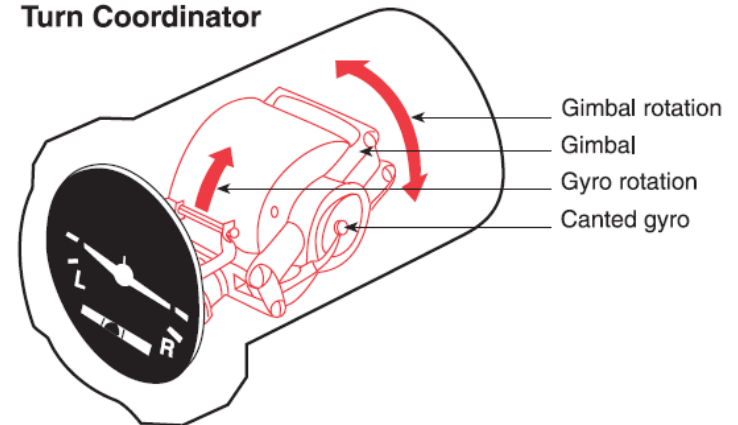
Turn and Bank Indicator



Turn-and-Slip Indicator



Turn Coordinator



Inclinometer



Coordinated Turn



Skid



Slip

Inclinometer (ball)

Separate instrument used to **measure quality of turn**

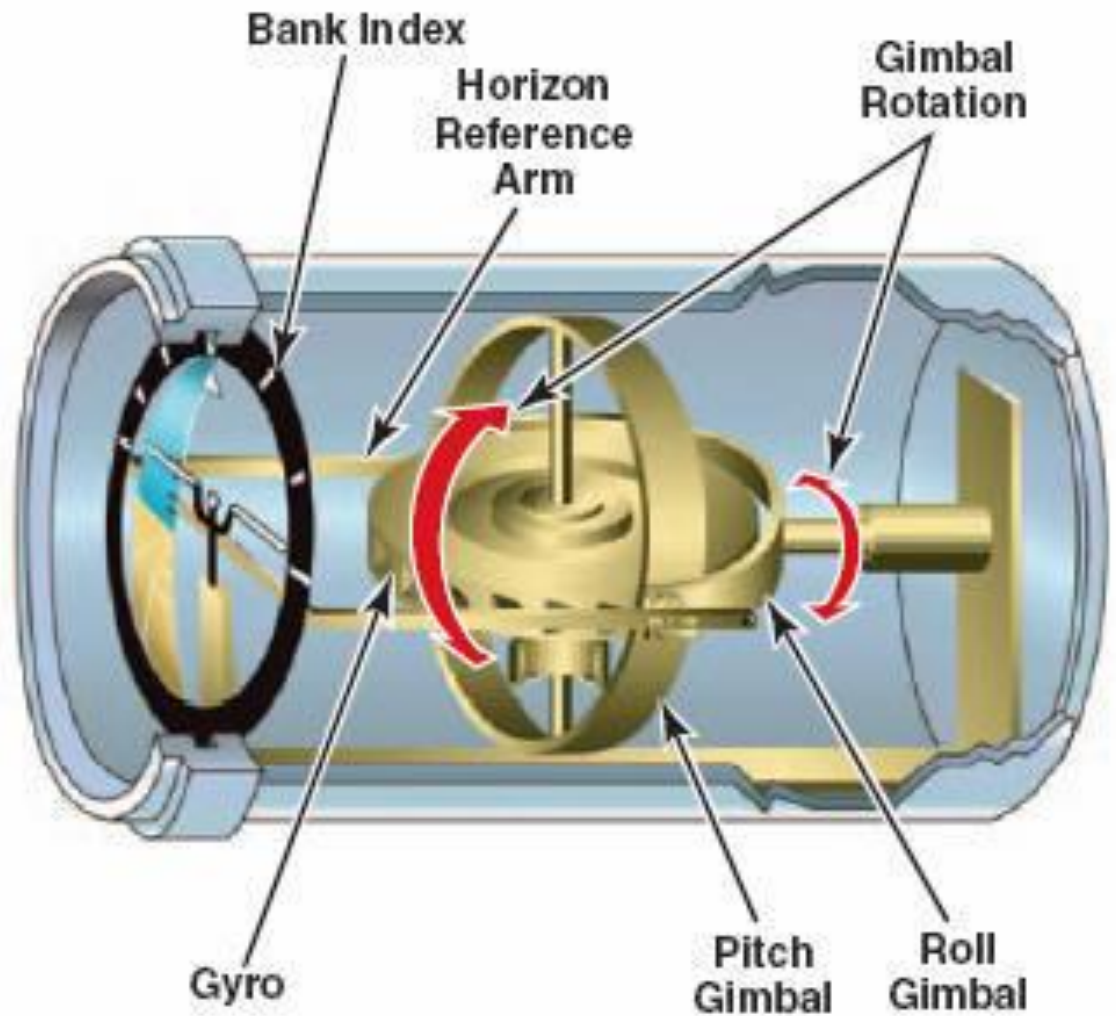
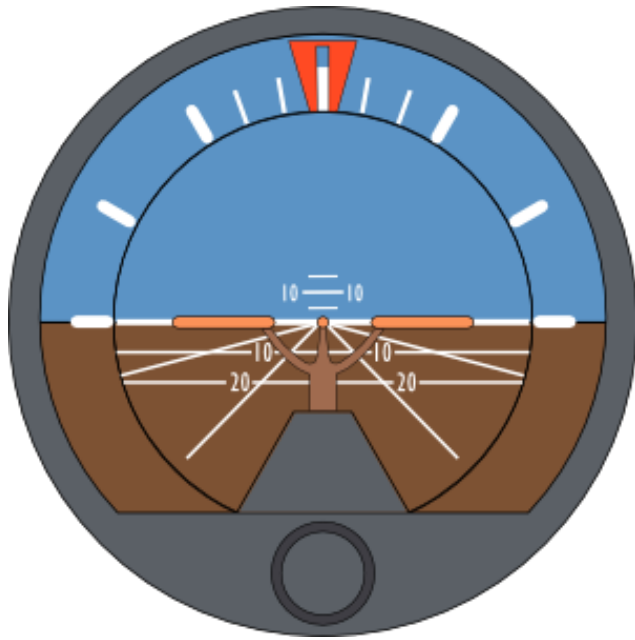
Ball on the inside of turn indicates **a slipping turn**

Ball on the outside of turn indicates **a skidding turn**

Attitude Indicator (or) Artificial Horizon

- Provides an **artificial horizon** to the pilot to display information about **both pitch and bank**
- Gyroscope has **two gimbals** that the aircraft can **rotate about for pitch and bank**
- 10,20,30,60,90 degree markings for bank
- **Pitch angle** is indicated by a **series of lines**, each representing **5° or 10°** of pitch
- Pilot **can set** where the miniature airplane meets the **horizon before takeoff**

Attitude Indicator



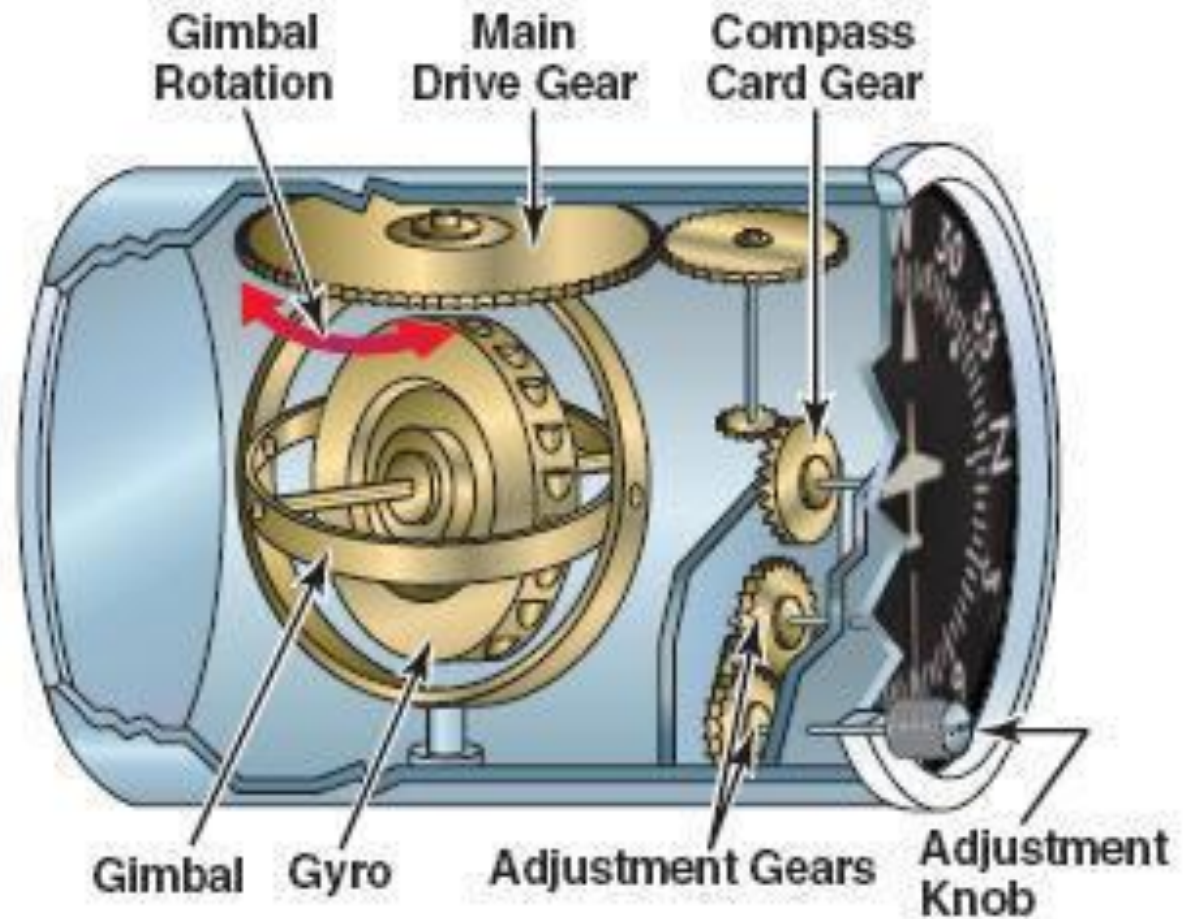
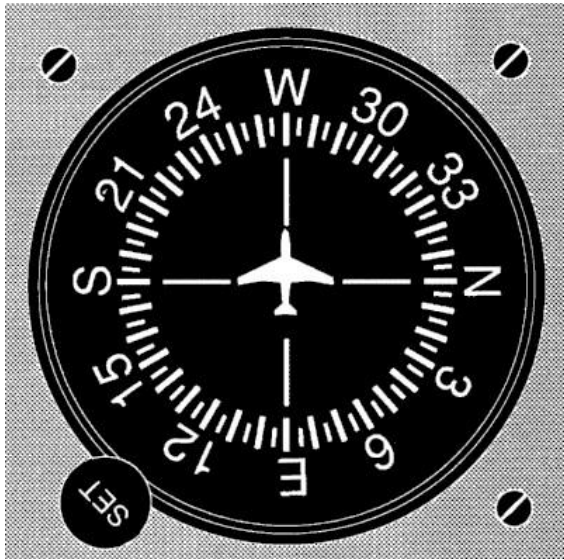
Heading Indicator

- There are a number of errors when using the magnetic compass. The **gyroscopic heading indicator** makes it **easy to turn to headings**.
- Unfortunately, the heading indicator **does not seek magnetic north by itself**
- **Vertically mounted gyroscope with one gimbal gives us heading information**
 - We set where the gyroscope considers **north with the knob** and it **tells us heading** as we rotate around it.

]Errors

- **Drift**
 - Because the earth rotates and because of small accumulated errors caused by friction and imperfect balancing of the gyro, the Heading Indicator **will drift over time**
 - Must **be set every 15 min**

Heading Indicator



NAVIGATION INSTRUMENTS

Accelerometer

- It is used on new airplanes during test flights to measure the acceleration loads on the aircraft structure.
- Serves as the basis for stress analysis as it gives an accurate indication of stresses imposed on airplane during flight.
- It measures accelerations exerted on airplane in gravity units.
- It indicates change only along the aircraft vertical axis
- It is graduated in gravity units from $-5g$ to $+12g$.
- Vertical acceleration can be illustrated by carrying a heavy parcel in elevator

Accelerometer

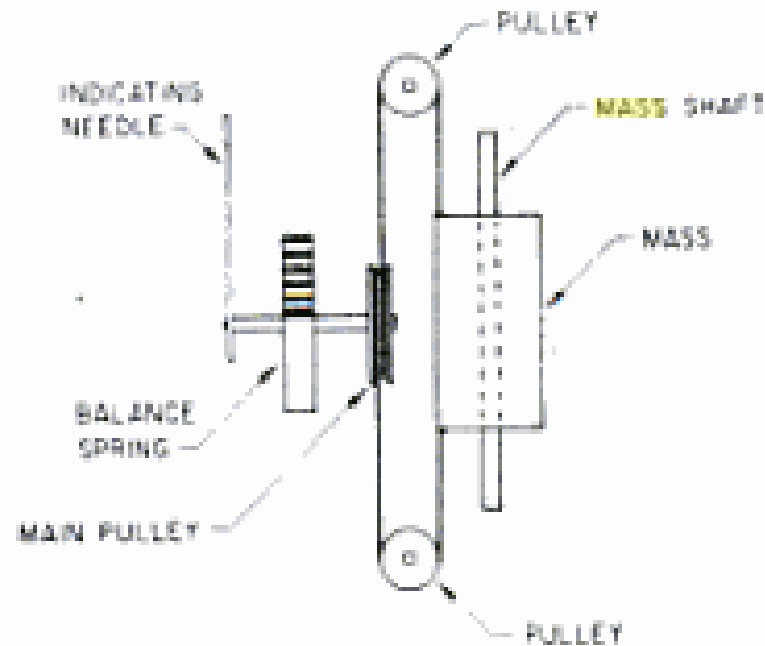


FIGURE 17-26 Diagram illustrating the principle of an accelerometer.

Horizontal Situation Indicator (HSI)

- It combines the information supplied by heading indicator with radio navigation information(VOR/ILS)
- It reduces eye motion of pilot
- Electrically or Pneumatically driven gyro for heading indicator
- Information from navigation radio is displayed through a deviation bar and selected course pointer
- When gyro is operating properly, the flag (NAV, HDG, GS) is retracted out of sight

HSI



ENGINE INSTRUMENTS

Electrical Tachometer System

- They are **used on large aircraft** – **distance** from engine to instrument panel makes **Mechanical tachometer impractical**
- **3 phase AC alternator** to generate **signal**
- The signal **drives a synchronous motor** inside the instrument – the motor synchronizes its speed with alternator
- The **motor turns the drag cup**
- **Drag cup positions the needle** on the face of the instrument

Electrical Tachometer System

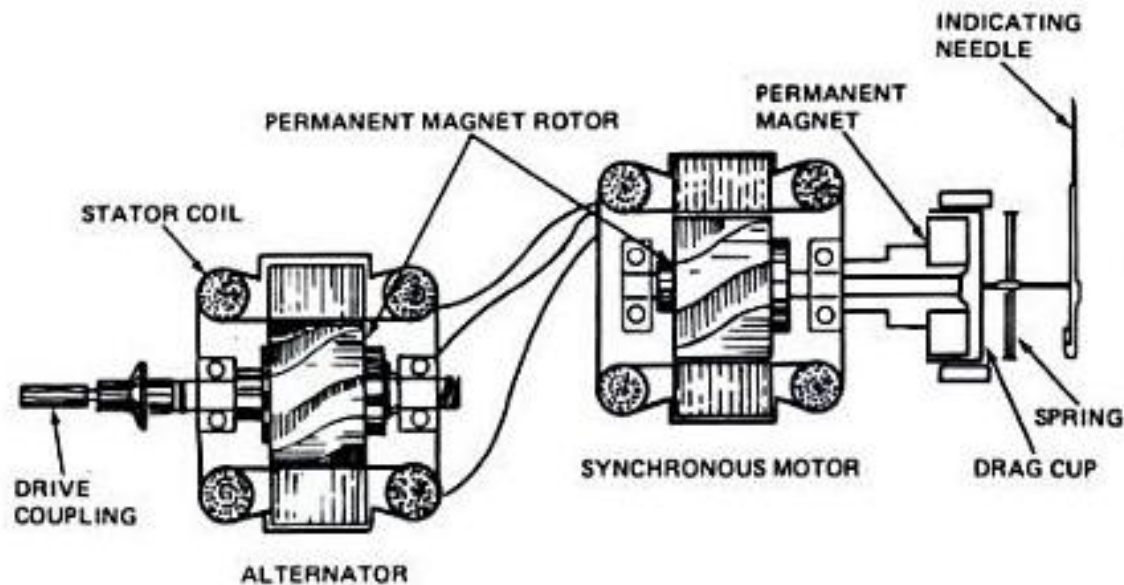


FIGURE 17-61 Electric tachometer system. (AC.)

Exhaust Gas Temperature Indicator (EGT)

- It is a **primary instrument** for monitoring **turbine engine operation**
- They are used to **monitor the performance of the engines** and make flight and maintenance adjustments.
- The system operate by **placing thermocouples in the stream of exhaust gases** exiting the engine.
- The **thermocouple generate the current**, which **drives the indicator**.
- The amount of **current is very low** and is **amplified or adjusted** in order to drive the indicator display.

Exhaust Gas Temperature Indicator (EGT)

- If **Multiple probes** are used, a **selector switch** on the instrument is used to allow **selection of the cylinder being monitored**.
- In turbine engine, system uses **several probes in parallel**.
- The **average reading** of the temperature and the indication **does not change** substantially if **one probe** should fail.

Exhaust Gas Temperature Indicator (EGT)

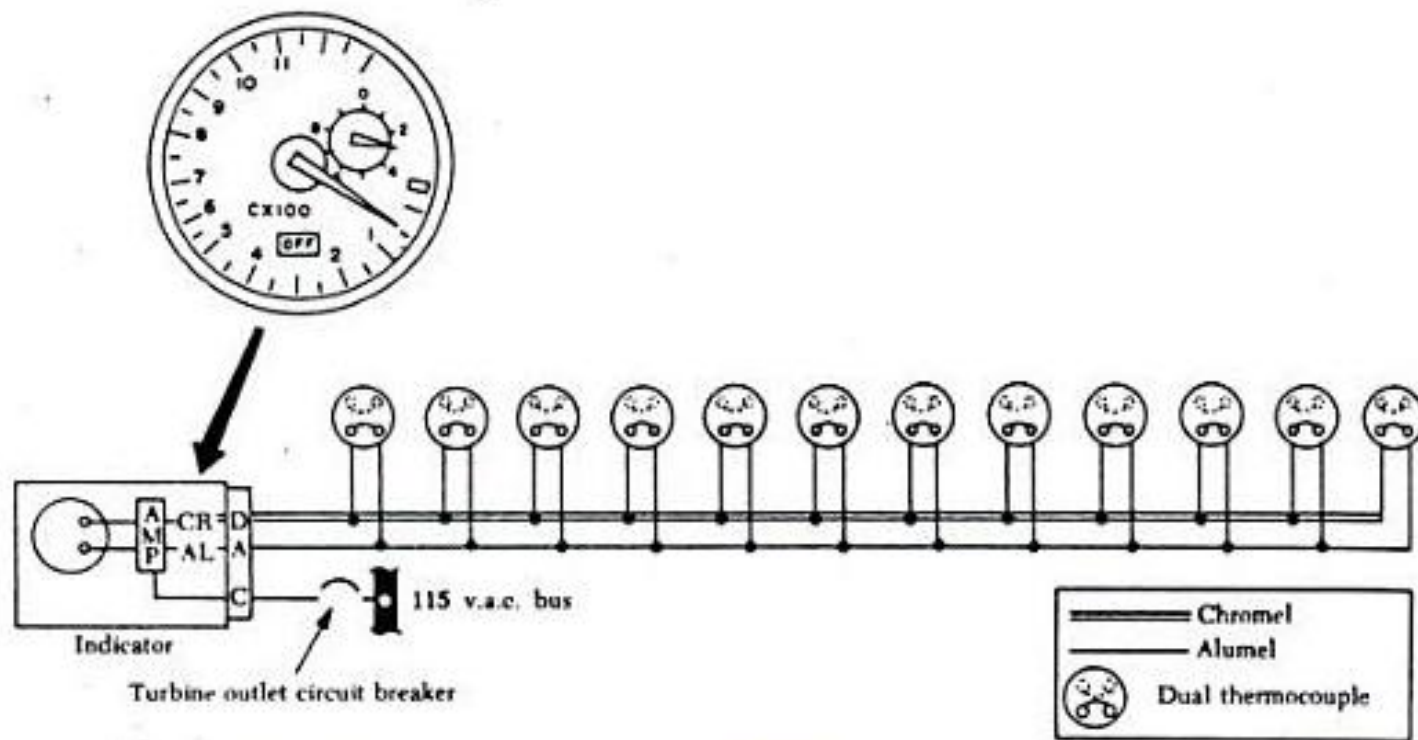


FIGURE 17-62 Simplified schematic drawing of a turbine-engine exhaust gas system.

Oil Pressure Indicator

- It can be mechanically operated or electrically powered.
- A Mechanically operated gauge uses an oil-pressure line from the engine to the instrument to operate a bourdon tube and gear segment to position the indicator needle.
- Restrictor in oil line prevent rapid oil loss if line breaks.
- Light oil is used in line between gauge and engine for quick response.

Oil Pressure Indicator

- Electric oil pressure sensors use pressure sensor on the engine, it varies its resistance as pressure changes.
- The pressure signal generated is processed and indicated in the cockpit display.

PRESSURE GAUGES

Bourdon – Tube Pressure Gauge

- The bourdon tube is made of spring tempered brass, bronze or beryllium copper.
- They have strong spring effect that cause the bourdon tube to return to its original position when pressure is released.
- When pressure enters the bourdon tube, the tube tends to straighten out
- This move the mechanical linkage connected to the sector gear
- The movement of sector gear causes spur gear to rotate and in turn moves the indicating needle along the scale.

Bourdon – Tube Pressure Gauge



FIGURE 17-2 A bourdon tube.

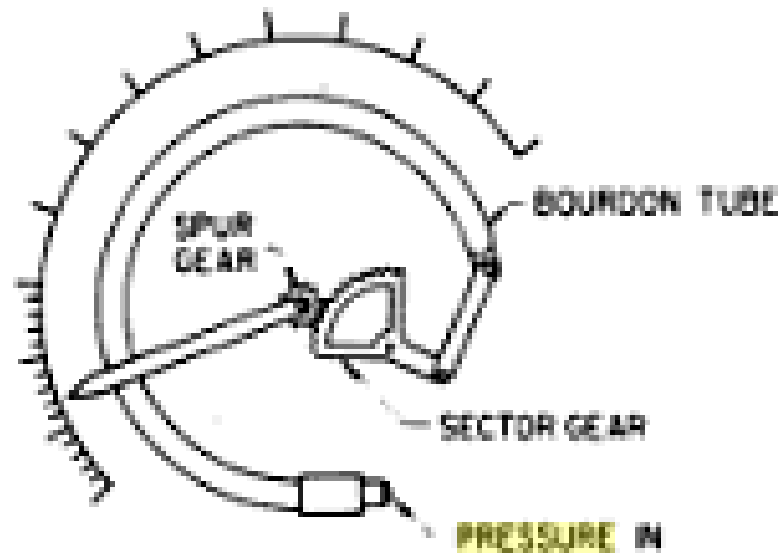


FIGURE 17-3 Bourdon-tube instrument mechanism.

Hydraulic Pressure Gauge

- A pressure gauge to measure the differential pressure in the hydraulic system indicates how this system is functioning.
- Hydraulic pressure gauges are designed to indicate either the pressure of the complete system or the pressure of an individual unit in the system.
- The case of this gauge contains a Bourdon tube and a gear-and-pinion mechanism by which the Bourdon tube's motion is amplified and transferred to the pointer.
- The position of the pointer on the calibrated dial indicates the hydraulic pressure in p.s.i.

Hydraulic Pressure Gauge

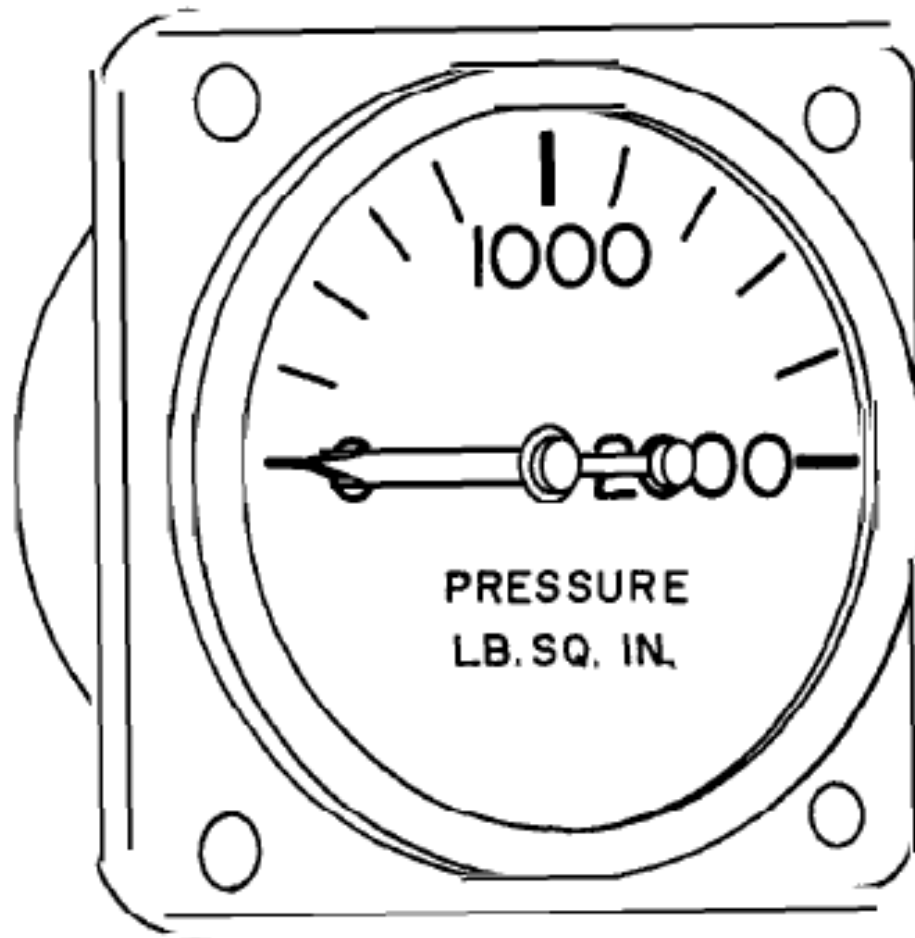


FIGURE 12-4. Hydraulic pressure gage

Diaphragm Type Pressure Gauge

- It is a differential- pressure measuring device
- They use a diaphragm for measuring pressure
- The pressure or suction to be measured is admitted to the pressure-sensitive diaphragm through an opening in the back of the instrument case
- An opposing pressure, such as that of the atmosphere, is admitted through a vent in the case

Diaphragm Type Pressure Gauge

- The walls of the diaphragm are very thin, an increase of pressure will cause it to expand, and a decrease in pressure will cause it to contract.
- Any movement of the diaphragm is transferred to the pointer by means of the rocker shaft, sector, and pinion, which are connected to the front side of the diaphragm.

Diaphragm Type Pressure Gauge

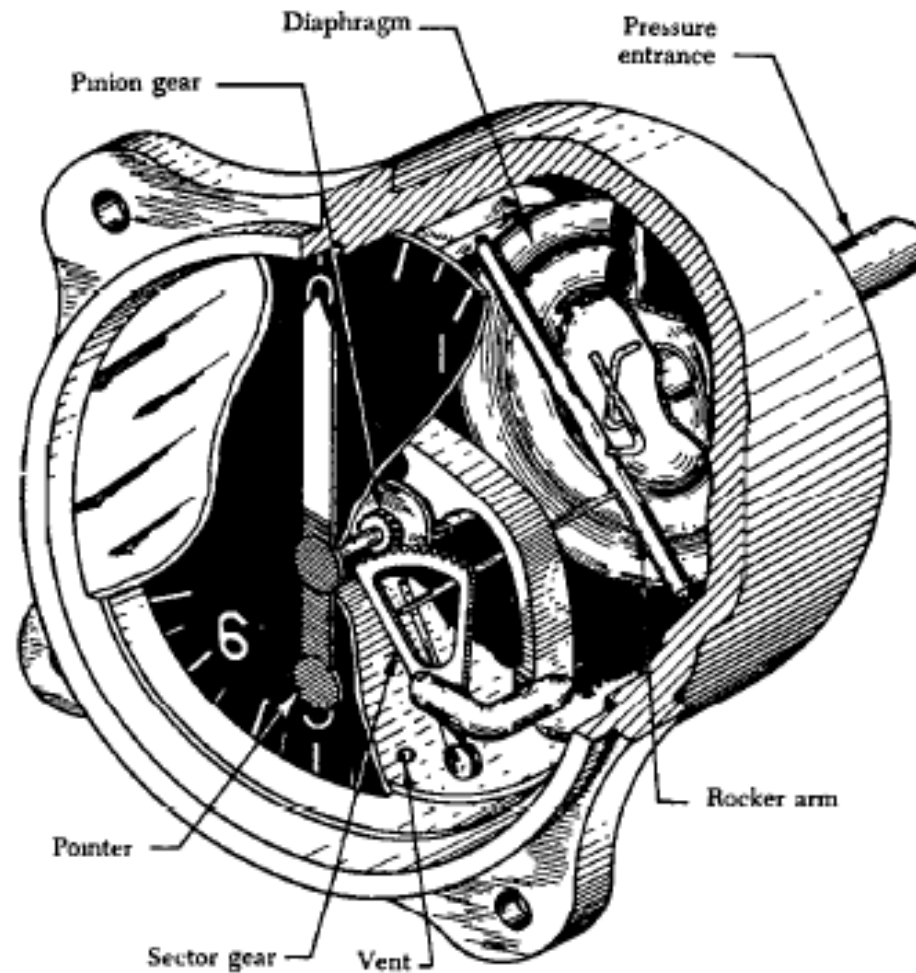


FIGURE 12-6. Diaphragm-type pressure gage.