INTRODUCTION TO AEROSPACE ENGINEERING

By
K. Sai Priyanka
Assistant professor
&
Snigdha Mandapudi
Assistant professor
Department of Aeronautical Engineering
Institute of Aeronautical Engineering

UNIT-1

HISTORY OF FLIGHT AND SPACE ENVIRONMENT

Balloons And Dirigibles

- Some 250 years later, two French brothers, Joseph Michael and Jacques Étienne Montgolfier, pioneered lighter-than-air flight with their innovative balloon designs. They conceived the idea of using the "lifting power" of hot air to achieve flight. On 25 April 1783, the Montgolfier brothers launched the first true hot-air balloon in Annonay, France. The balloon rose 305 m (1,000 ft) before the hot air cooled and it began its descent.

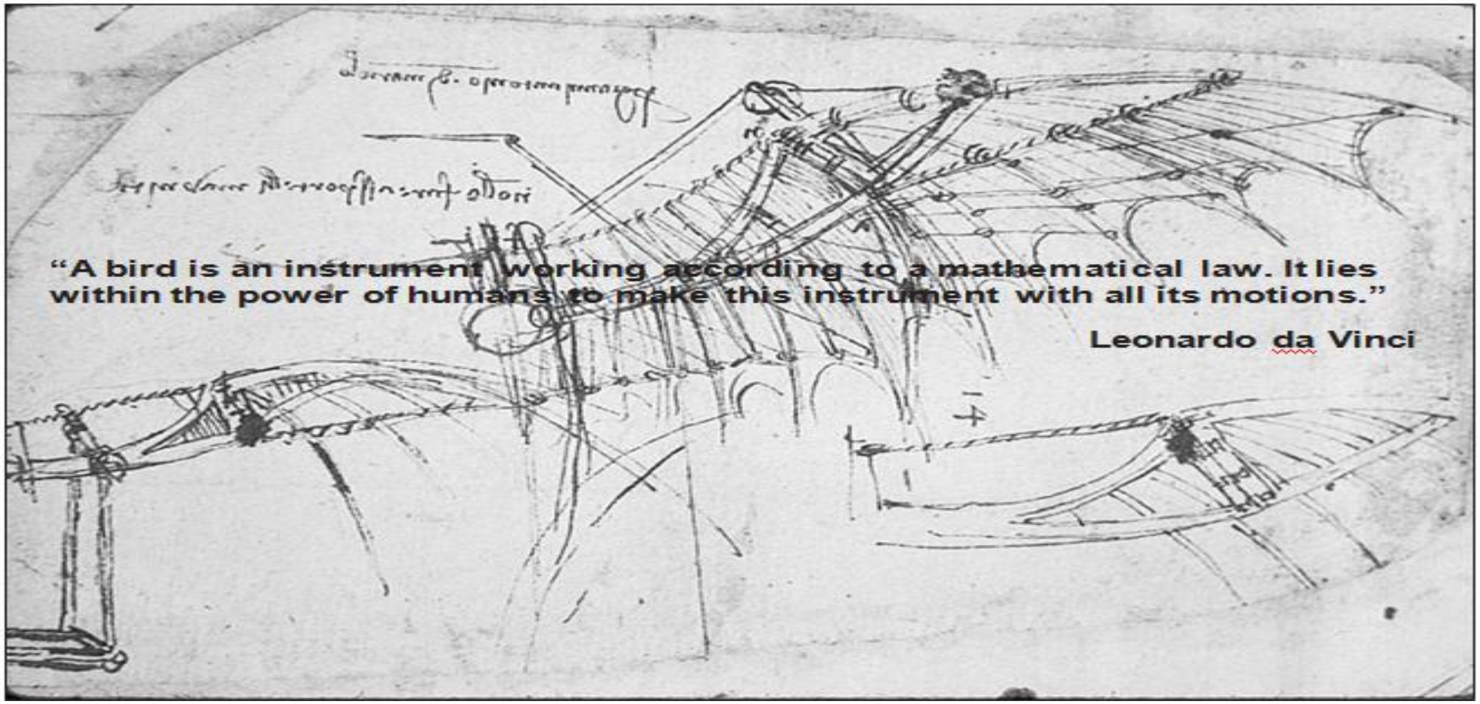


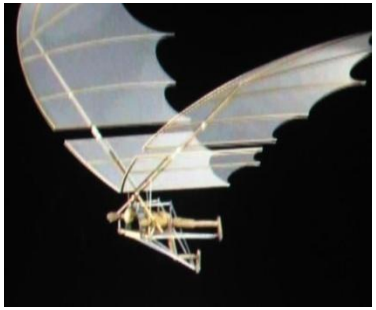
Figure :1 Leonardo da Vinci quotation and multimedia ornithopter tutorial on the accompanying CD-ROM

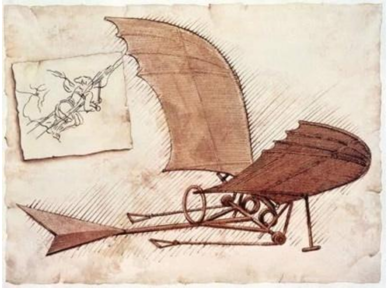
Aviation Ages 1000b.C To 1250a.D

The Greek myth of Daedalus and his son Icarus was written around 1000 B.C. The myth states that after Daedalus built the labyrinth the king of Crete threw him in it to test it. He and his son Icarus escaped by building wings of wax and flying away. However Icarus flew too high and the wax in his wings began to melt. His wings collapsed and he plunged to his death in the sea. Kites flown around the year 400 B.C. in China were ancestors of modern aviation and the airplane.

Aviation Ages1250 To 1750

I was one of the first to experiment with the science of flying. Unfortunately my writings and sketches weren't discovered until three hundred years after my death. Leonardo da Vinci spent most of his life exploring flight and left the world about 160 documents of sketches and observations about flight. He made important discoveries about the center of gravity, the center of pressure, and streamlining.



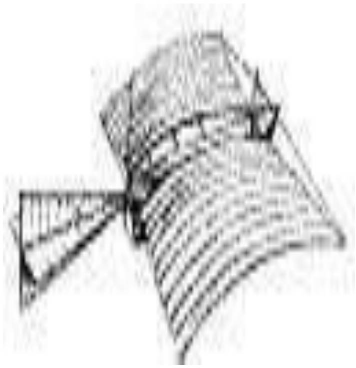


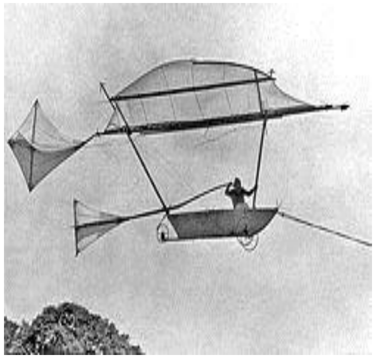
AVIATION AGES1750 TO 1850

What forces cause smoke to rise in a fireplace? This was sparked Montgolfier's curiosity. Joseph and Etienne Montgolfier designed the first successful flying craft. Their observations led them to believe that burning created a gas, which they called "Montgolfier's gas," causing a craft to rise. They constructed a balloon made of cloth and paper. The first aviators were a duck, rooster, and a sheep. Then in 1783 a crowd in Paris watched as a Montgolfier balloon carried two French men. The way the balloons worked is hot air and gases filled the balloon causing it to lift. Once it was in the air it simply went wherever the wind took it.

Aviation Ages1850 To 1900

Sir George Cayley set in motion the future study of aerodynamics in a single sentence. "The whole problem is confined within these limits, namely to make a surface support a given weight by the application of power to the resistance of air."Sir George Cayley experimented with gliders at his home in Yorkshire.





Aviation Ages 1850 To 1900

In 1896, the German engineer, Otto Lilienthal, tested several monoplane and biplane gliders. He built and flew the first glider capable of carrying a person, but died when he crashed in a sudden gust of wind before he could finish his powered plane. The structure of an airplane as we know it today was in its formative years. What are the parts of a plane and how does each function?

Heavier-than-air flight

During the height of the zeppelin era, heavier-than-air flight was still in its infancy even though the groundwork had been laid at the end of the 18th century. An Englishman, Sir George Cayley (1773–1857), devised the basic configuration of modern airplanes. He separated the means of generating lift from the means of generating propulsion. In 1799, he designed an airplane that featured fixed wings for generating lift, paddles for propulsion, and a tail unit with horizontal and vertical stabilizers.

- Among them were Orville Wright (1871–1948) and Wilbur Wright (1867– 1912). The brothers eagerly followed Lilienthal’s glider flights and corresponded frequently with him and other aviation researchers in Europe and the United States.
- The Wright brothers were the first to achieve controlled, powered, heavier- than-air flight because of their extensive research and excellent engineering approach. However, they were also fortunate that gasoline engine technology was advanced enough to permit the construction of a sufficiently lightweight power plant.

Commercial Air Transport

- As previously mentioned, airships were commercially successful in the early decades of the 20th century. While zeppelins could fly not much more than 100 km/h, they could do so for thousands of kilometers without having to land. To demonstrate the technical ability of the Third Reich, the world's largest rigid air- ship, the LZ-129 *Hindenburg,* was built in 1936.
- The *Hindenburg* had a length of 245 m, a top speed of 135 km/h, and used some 200,000 m3 of hydrogen.

Introduction Of Jet Aircraft

- At the start of World War II, in September of 1939, Germany’s aircraft industry was by far the most advanced in the world, which was reflected in the arsenal of Germany’s air force—the Luftwaffe. Its aircraft included the Messerschmitt Bf 109, Focke Wulf FW-190 Junkers Ju 88, and the frightening dive bomber Junkers Ju 87 Stuka. Overall the role of aircraft was a minor one in World War
- This was not so in World War II—aircraft played a decisive role in the conflict since achieving air superiority became important to winning land and sea battles. Early in the war the tactically oriented Luftwaffe supported a rapid advance of ground forces and with its “blitzkrieg” (lightning war) tactics quickly crushed Poland, the Netherlands, Denmark, and even France.

- Airbus’ premier model, which entered service in May 1974, was the A300B— the world’s first twin-engine wide-body jetliner. The European consortium was less conservative than the well-established U.S. manufacturers.
- The Airbus 310 introduced a two-pilot cockpit and made considerable use of composite materials for the airframe. The short-haul aircraft A320, which entered service in 1988, was the first subsonic commercial aircraft to be designed with electric primary con- trols, called “fly by wire,” and the first commercial aircraft to feature a “glass cock- pit” in which mechanical displays and gages were replaced by electronic screens.

Helicopters

- The German Focke-Wulf Fw 61 became the first practical helicopter when it flew in 1936 as the highlight of an indoor show in Berlin organized by the Nazis. How- ever, the flight brought mostly trouble.

- The rotors blew sand from the circus ring in the eyes of the spectators, and the doors of the arena had to remain open despite the cold weather due to the large need of oxygen by the engine. The audi- ence was more impressed by the famous female pilot Hanna Reitsch than by the helicopter.

- The Focke-Wulf Fw 61 had two rotors mounted on outriggers to the left and right sides of the fuselage and was quite a capable craft outdoors. It was able to reach an altitude of 2,439 m (8,000 ft).

The commercial use of space

- The first satellites were “passive” since they lacked on-board electronics and could therefore be used only as a relay station for communications, but many practical uses for more advanced satellites were evident. In 1958, the U.S.
- Air Force launched the first active communications satellite, Score, premiering the transmission of human voice from space.

Earth’s Atmosphere

Our atmosphere, or Shakespeare’s “excellent canopy of air,” that surrounds Earth protects us from the hostile environment of space and provides our life support. The atmosphere is mainly composed of molecular nitrogen and oxygen with trace elements in the following proportions:

- Nitrogen, 78 percent.
- Oxygen, 21 percent.

1. Argon, 1 percent.
2. Carbon dioxide/water vapor, 0.03 percent.

Our excellent canopy of air is impossibly fragile and small when we see it from space If breathable air were shown to scale on a basketball, it would be 1/4 mm (1/100 in) thick. Yet, compare Earth with the Moon, whose sur- face has been pitted and hammered into dust by meteors. We have been less touched by all that falling iron. Our fragile canopy absorbs and burns the mete- ors before they reach us.

Earth's atmosphere

- The atmosphere itself is divided into five parts, namely, the troposphere,stratosphere,mesosphere,thermosphere,and exosphere. The thickness of these parts is determined largely by temperature gradients.
- Each portion of the atmosphere is characterized by its temperature and plays a specific role in protecting humans from the harmful conditions in space.

- The stratosphere begins at 18 km and continues to an altitude of 50 km. Here, the temperature gradient reverses, and the air actually gets warmer. At 18 km the temperature is about 220 K and rises to about 270 K (—3°C) at 50 km.
- This higher temperature results from heating via solar radiationThe stratosphere is also the sight of the *ozone* layer. Ozone is a molecule made of three oxygen atoms.
- It forms a gossamer-thin layer that screens out ultraviolet radiation. Without ozone, that radiation would kill off our nucleic acids and make life impossible.

- The mesosphere is essential for human survival on earth as it absorbs primary cosmic radiation and deadly solar ultraviolet and X-ray radiation, and vaporizes incoming meteorites entering from interplanetary space
- Beyond the mesosphere the temperature gradient rapidly reverses in the region known as the thermosphere, extending from 85 to 300 km.
- Finally, the exosphere begins at 300 km and merges with the ionized gases of the interplanetary medium. The temperature remains constant at 1,000 K with the exception of solar cycle variations. Here, atomic oxygen is more abundant than molecular oxygen or nitrogen.

The Temperature Extremes of Space

- There are limits to the temperature range that humans and equipment can endure. The extreme thermal conditions in space require not only shielding and insulation, but heat rejection capabilities as well. On Earth, heat transfer is car- ried out in three ways:
- Conduction—heat transfer through solids, liquids, and gases.
- Convection—transfer of heat due to fluid movement.
- Radiation—transfer of heat by a hot source (e.g., electromagnetic radiation).

Microgravity

When we hear astronauts describe the feeling of "weightlessness"

While in orbit, what they are actually referring to is the effect of microgravity. Microgravity can be simulated either by placing an object in an environment where the force of gravity is naturally small.

Law of Gravitation

- Two of the most colorful personalities in the field of astronautics were Johannes Kepler and Sir Isaac Newton, who defined the laws of orbital motion and the law of gravitation, respectively.
- Specifically, Newton based his law of gravitation on his axioms of mechanics (often referred to as Newton's three laws, detailed in "Newton's Laws of Motion and Gravitation") and Kepler's law of equal areas of an orbit being covered in equal time intervals to state that Every particle in the universe attracts every other particle with the force that is directly proportional to the product of their masses and inversely proportional to the distance between their centers.

Low Earth Orbit

- Scientists and engineers often refer to the environment within an orbiting spacecraft as microgravity, because of the similar effects experienced if the spacecraft were a thousand Earth radii away.
- In practice, however, there are still a multitude of accelerations affecting the spacecraft and everything in it— motions due to orbital thrusters, vibrations, aerodynamic drag, and astronaut motions.

Benefits of Microgravity

- Working in a microgravity environment allows researchers to investigate essential questions of fundamental physics, life science, materials science, space science, earth observation, medicine, gravitational biology, and engineering technology. Microgravity allows scientists to observe phenomena usually overshadowed by the effect of gravity on the surface of Earth.
- There are four areas that are targeted for future exploration and microgravity investigations:

- The Earth Science Enterprise is to expand scientific knowledge of the Earth system, using NASA's unique vantage points of space, aircraft, and in situ platforms, creating an international capability to forecast and assess the health of the Earth system; disseminate information about the Earth system; and enable the productive use of Mission to Planet Earth science and technology in the public and private sectors.

1. A major purpose of ISS is to provide a laboratory for long-duration micro- gravity experiments in the life and physical sciences. ISS offers major capabil- ity in the following areas:
2. Biomedical research and countermeasures development.
3. Gravitational biology and ecology (under variable gravity).
4. Materials science.
5. Biotechnology.
6. Fluids and combustion.
7. Human-machine interfaces and advanced life support.
8. Low-temperature physics.
9. Earth observation and space science.

Environmental impact on spacecraft

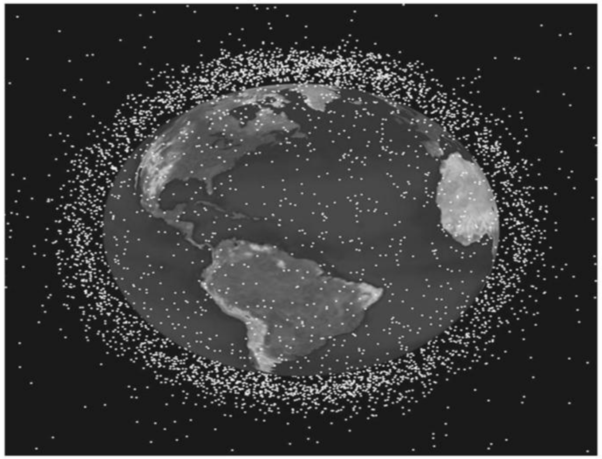
- Energetic radiation can severely degrade the optical, mechanical, and electrical properties of a spacecraft. Specifically, satellite degradation results from ionization of atoms encountered, the breakup of chemical liaison, and displacement of atoms from crystal lattice sites.
- The important parameters that aerospace engineers design for include cumulative dose of radiation, transient effects that depend on the instantaneous flux of radiation, and electrostatic arcing due to the accumulation of electric charges encountered.

Space debris

- The aesthetic feature of this space debris picture raises our concern and consciousness of the problem, and the dangers posed by these human-made debris to operational spacecraft (pilotless or piloted) are a growing concern.
- A dramatic illustration of this fact is the recent impact of the mini satellite Cerise with an Ariane 4 third stage. Ground controllers lost contact with Cerise, a s What does the near-Earth space environment look like to an external observer with regard to artificial objects in orbit? illustrates a partial answer.
- mall British- built satellite, only to discover weeks later that the satellite was struck by a fragment from an Ariane rocket which had exploded several years previous.

.

The aesthetic feature of this space debris picture raises our concern and consciousness of the problem, and the dangers posed by these human-made debris to operational spacecraft (pilotless or piloted) are a growing concern. A dramatic illustration of this fact is the recent impact of the mini satellite Cerise with an Ariane 4 third stage. Ground controllers lost contact with Cerise, a small British- built satellite, only to discover weeks later that the satellite was struck by a fragment from an Ariane rocket which had exploded several years previous.



Planetary environments

- The environments of the planets within our solar system vary greatly. In addition, the gravitational forces on the planets depend on their mass; therefore, the 1 G environment in which we humans have evolved is unique within our solar system.

  Planetary Atmospheres

- All the larger planets have atmospheres. The atmospheres of planets are held in place only by the force of gravity and do not have distinct boundaries in space. Therefore, a spacecraft operating in the vicinity of a planet with an atmosphere must be designed to tolerate the effects of that atmosphere, particularly if humans are aboard the vehicle.

- In the case of Earth, research has shown that the presence of uncombined oxygen in noticeably large quantities is a direct result of the presence of life and suggests that the current atmosphere has evolved significantly over time (the past 4 billion years). Conversely, studies of the outer planets (Jupiter to Pluto) suggest that the atmospheres present today are nearly identical to those present when the planets formed.

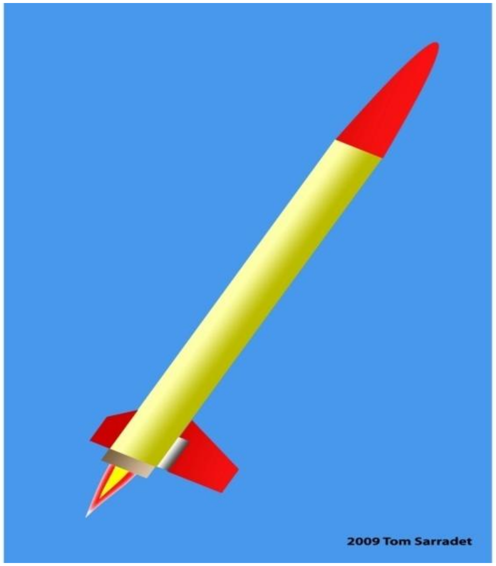
UNIT-II

A Basic Introduction to Aerodynamics and Propulsion

Factors that Affect Aerodynamics

The Object:
Shape & Size

The Motion:
Velocity &
Inclination to
Flow



The Air:
Mass, Viscosity,
Compressibility

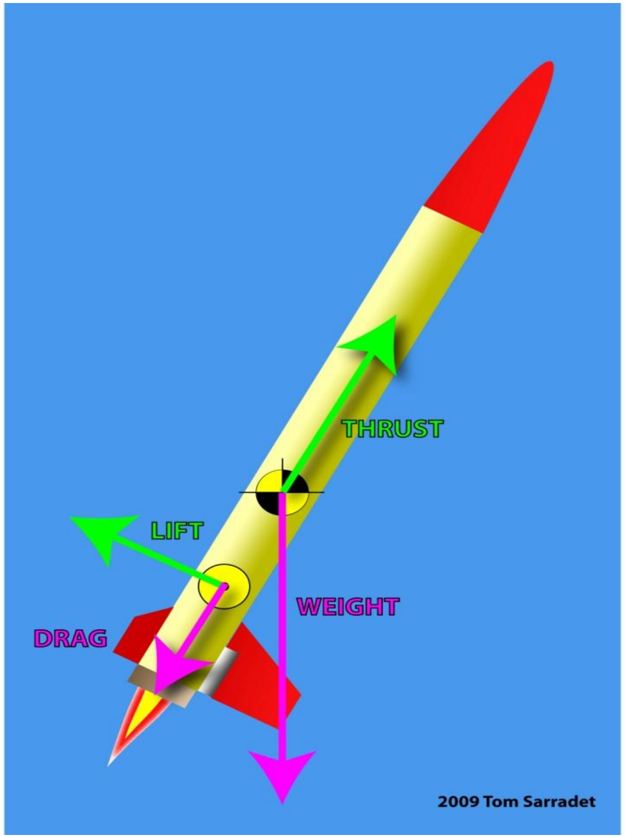
Four Forces of Flight

1. Lift is a force used to stabilize and control the direction of flight.
2. Drag is the aerodynamic force parallel to the relative wind.
3. Weight is the force generated by gravity on the rocket.
4. Thrust is the force which moves the rocket forward.

Aerodynamic Forces

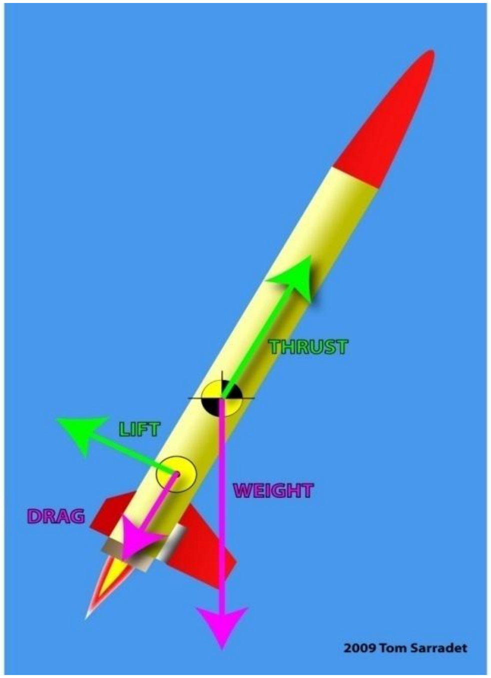
Aerodynamic forces are generated and act on a rocket as it flies through the air.

The lift and drag act through the center of pressure which is the average location of the aerodynamic forces on an object.



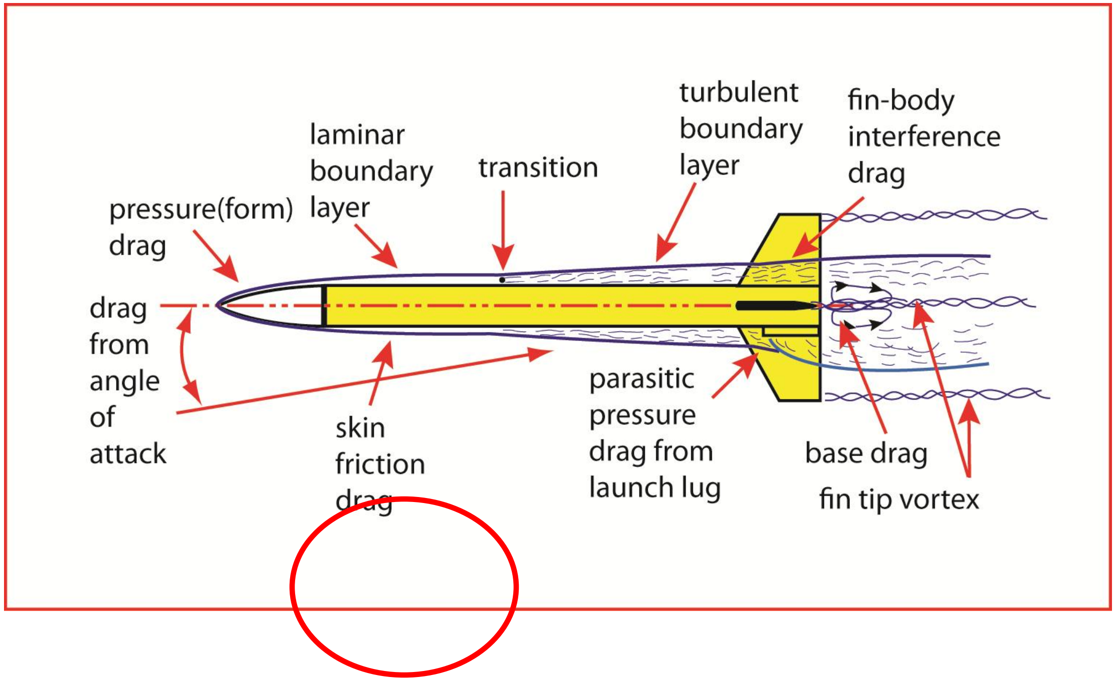
Aerodynamic Forces

- Lift occurs when a flow of gas (the air) is turned by a solid object (the rocket).
- The flow is turned in one direction, and the lift is generated in the opposite direction.
- For a model rocket, the nose, airframe, and fins can become a source of lift if the rocket's flight path is at an angle.



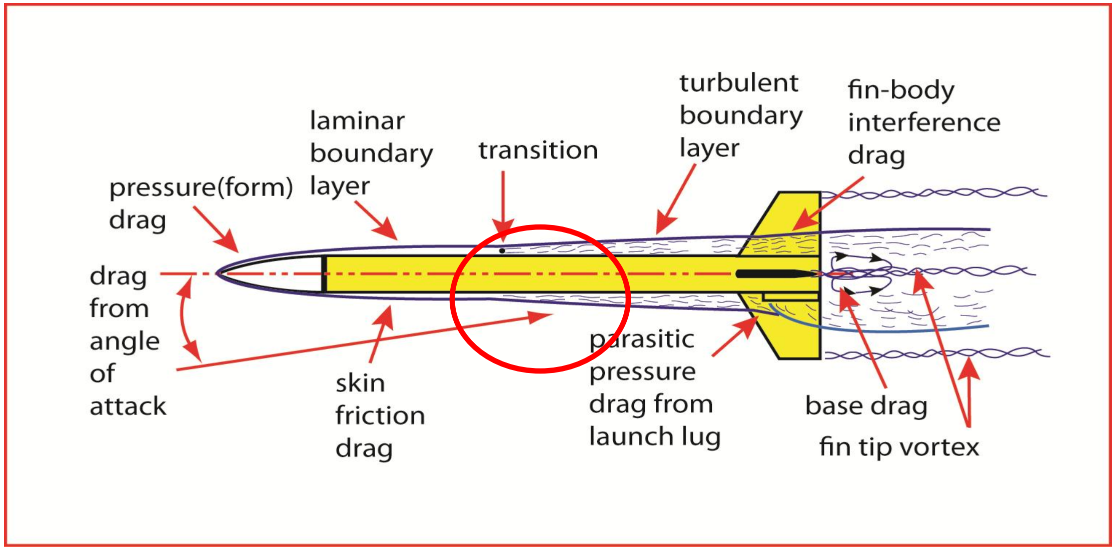
Aerodynamic Forces

- Drag is aerodynamic friction, and one of the sources of drag is the skin friction between the molecules of the air and the solid surface of the moving rocket.



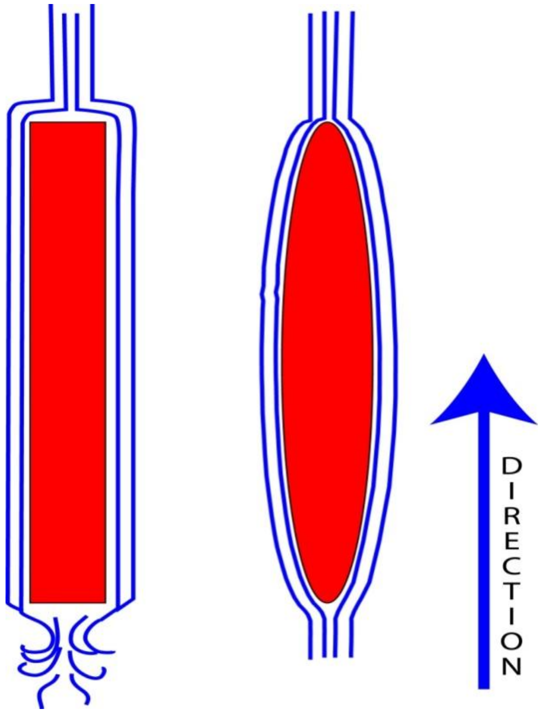
Aerodynamic Forces

- The point in which a laminar boundary layer becomes turbulent is called the transition.



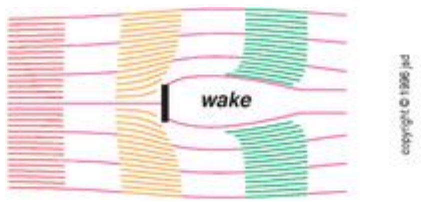
Airfoil Fins

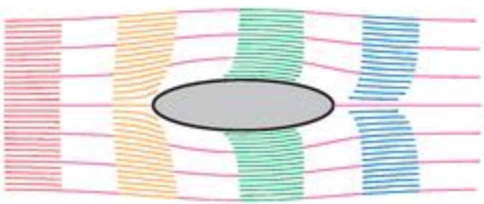
- A model rocket's fin that is square on the edges creates a lot of drag and turbulence.
- If the fin's leading and trailing edges are sanded in a round shape, called an airfoil, it reduces the drag.

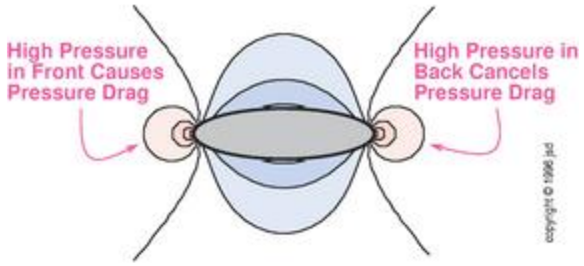


Airfoil Fins

- Airfoil shape fins creates high pressure behind the fin and pushes it forward, cancelling out most of the pressure drag caused by the fins. This is called pressure recovery.





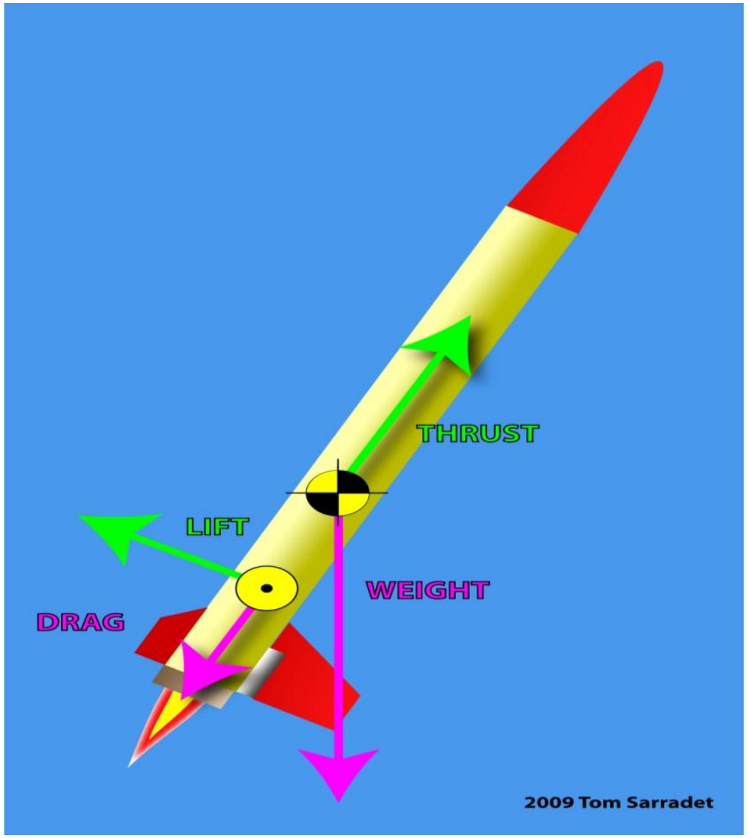


Weight

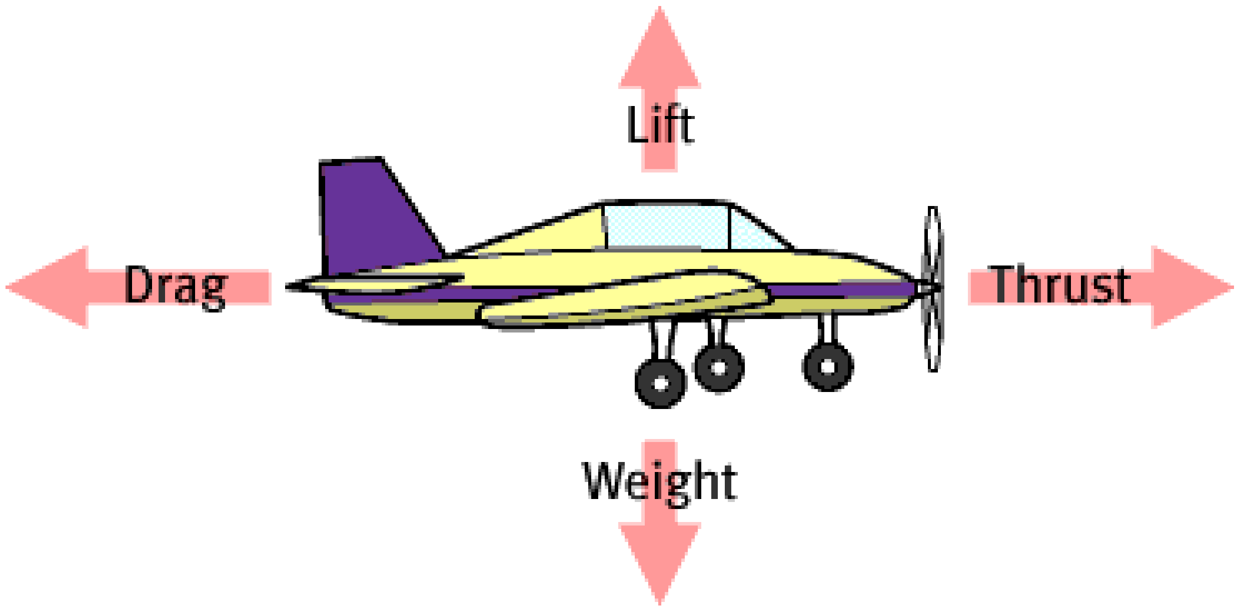
- Weight is the force generated by the gravitational attraction on the rocket.
- The gravitational force is a field force; the source of the force does not have to be in physical contact with the object.
- Gravity affects the rocket whether it is stationary or moving (up or down).

Thrust

- Thrust is the force applied to the rocket to move it through the air, and through space.
- Thrust is generated by the propulsion system of the rocket through the application of Newton's Third Law of Motion.
- The direction of the thrust is normally along the longitudinal axis of the rocket through the rocket’s center of gravity.

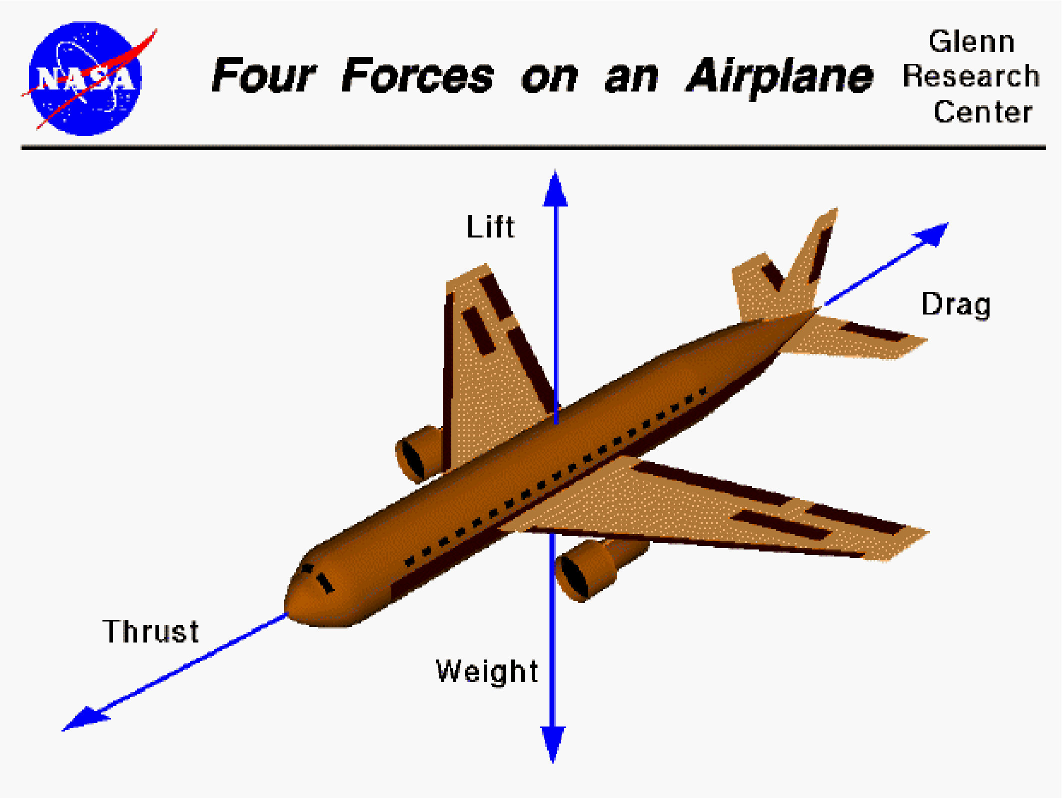


The Four Forces of Flight



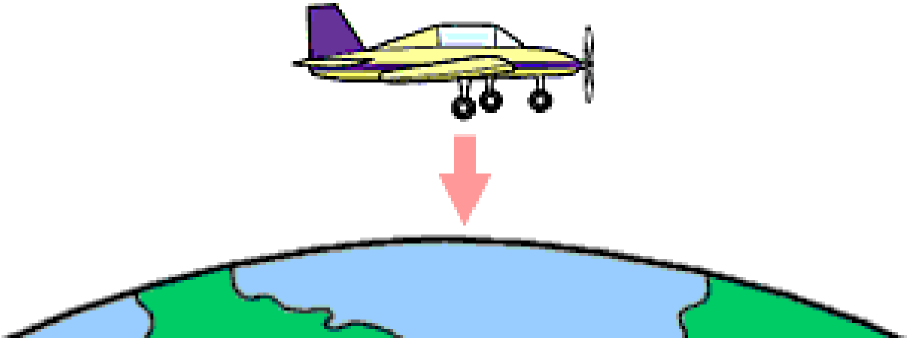
The four forces act on the airplane in flight and also work against each other.

The Four Forces of Flight

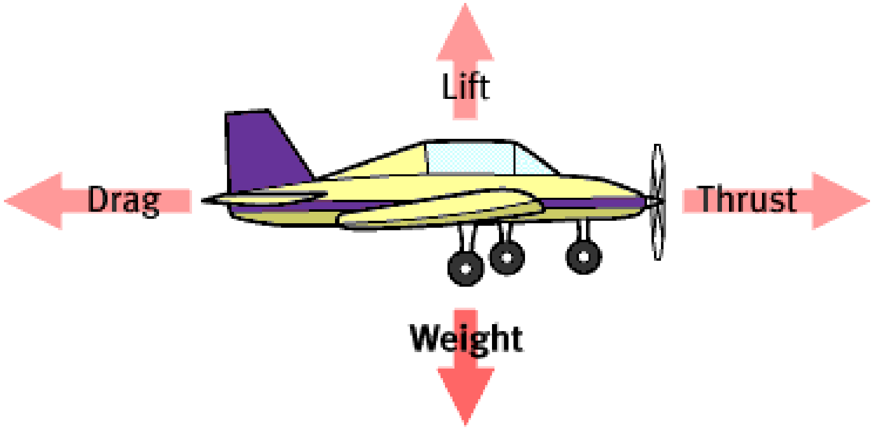


The four forces act on the airplane in flight and also work against each other.

The earth’s gravity pulls down on objects and gives them weight.



Weight counteracts lift.

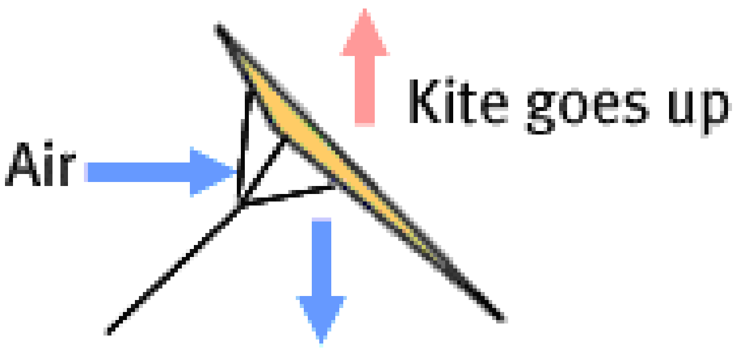


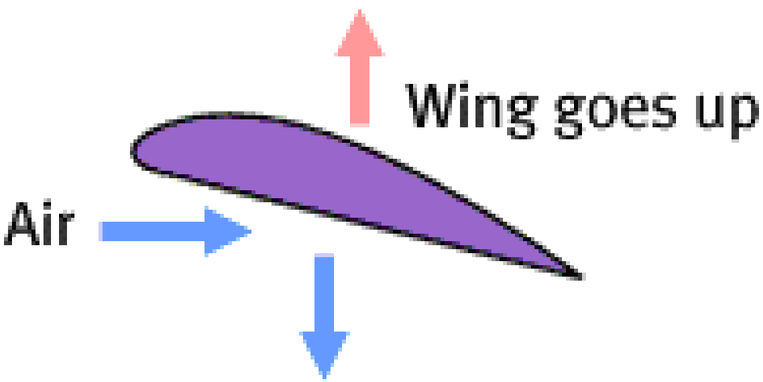
What's it take to create lift?

How do we explain lift?

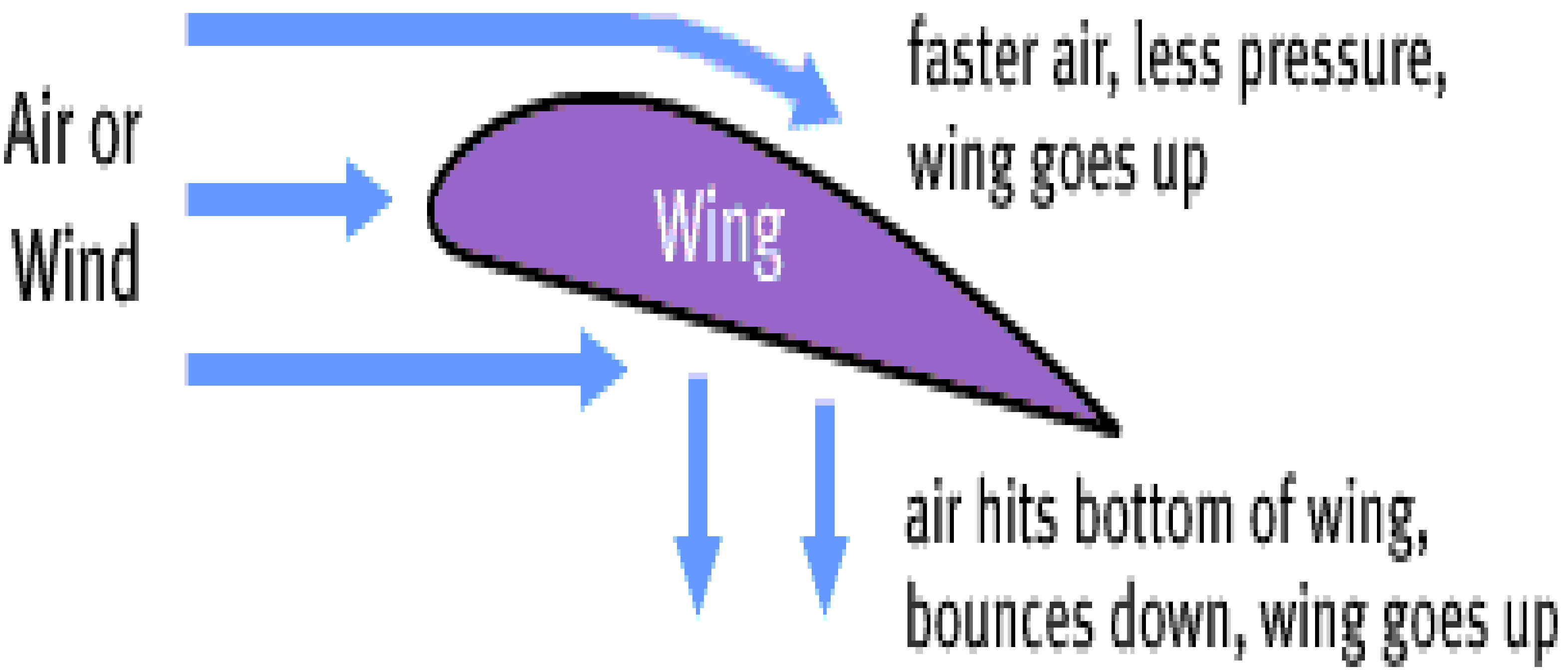
Newton's Laws of Motion and Bernoulli's Principal are used to explain lift.

Newton's Third Law states that for every action there is an equal and opposite reaction.

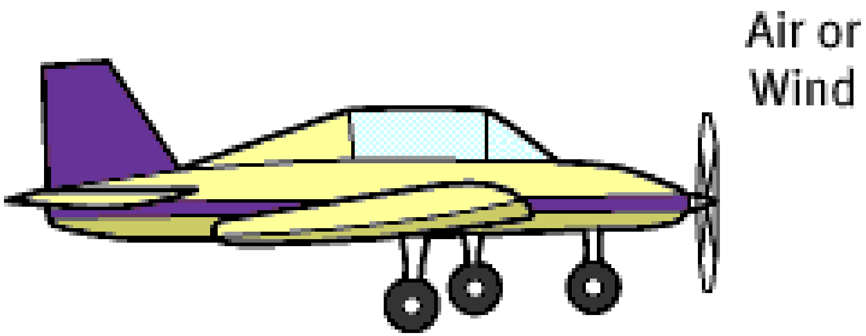




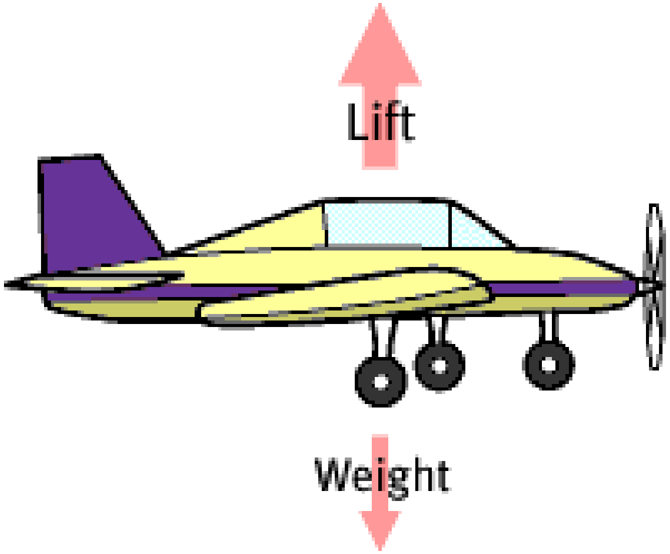
A wing creates lift due to a combination of Bernoulli’s Principal & Newton’s Third Law



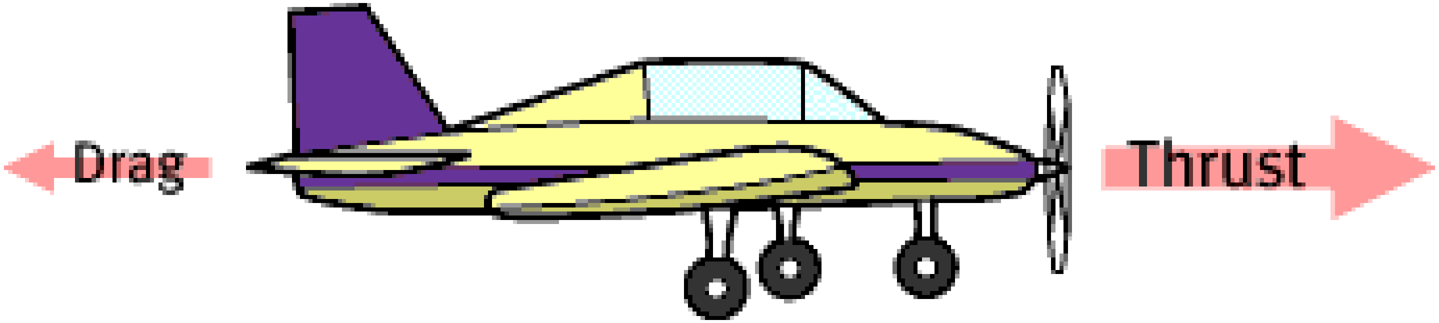
Drag is the force of resistance an aircraft ‘feels’ as it moves through the air.



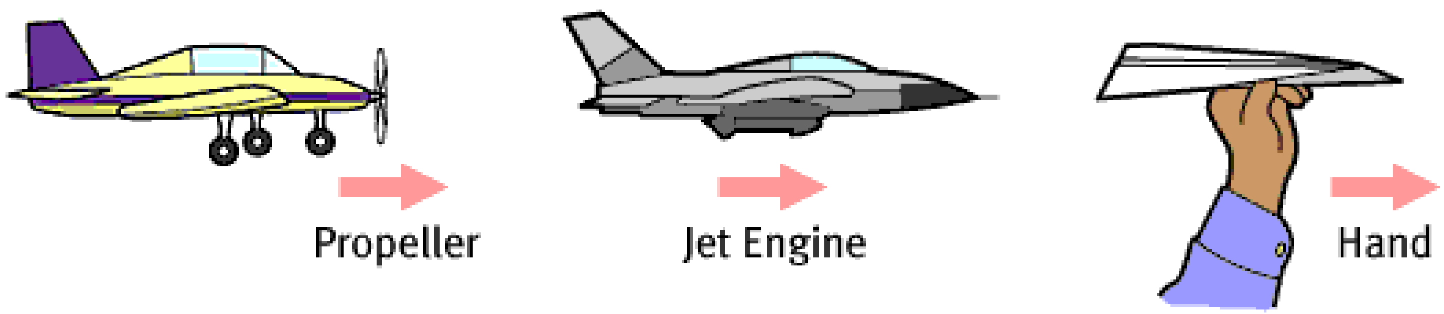
For an airplane to take off, lift must be greater than weight.



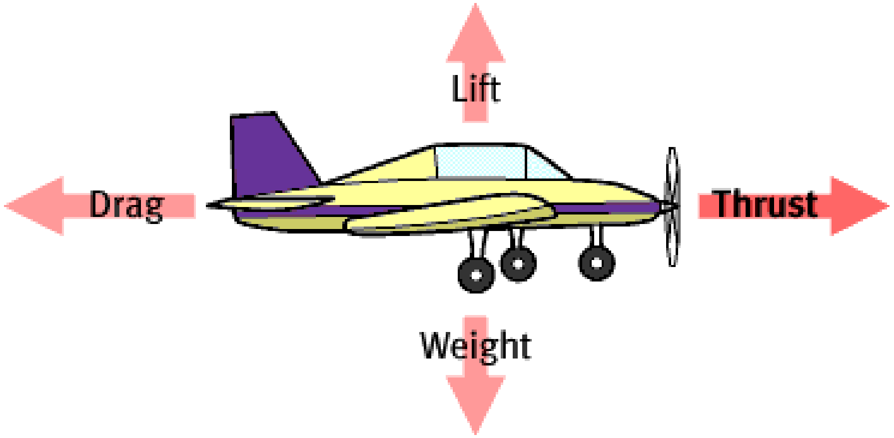
For an airplane to speed up while flying, thrust must be greater than drag.



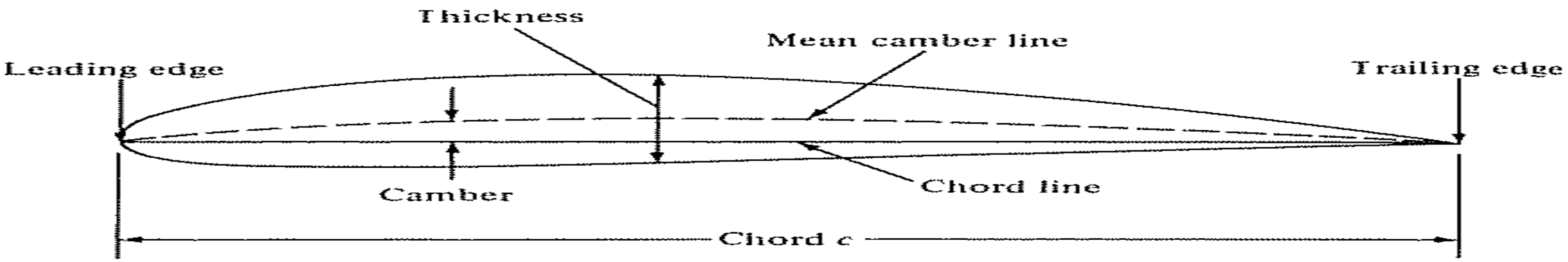
Engines (either jet or propeller) typically provide the thrust for aircraft. When you fly a paper airplane, you generate the thrust.



A propeller is a spinning wing that generates lift forward.



Airfoil nomenclature



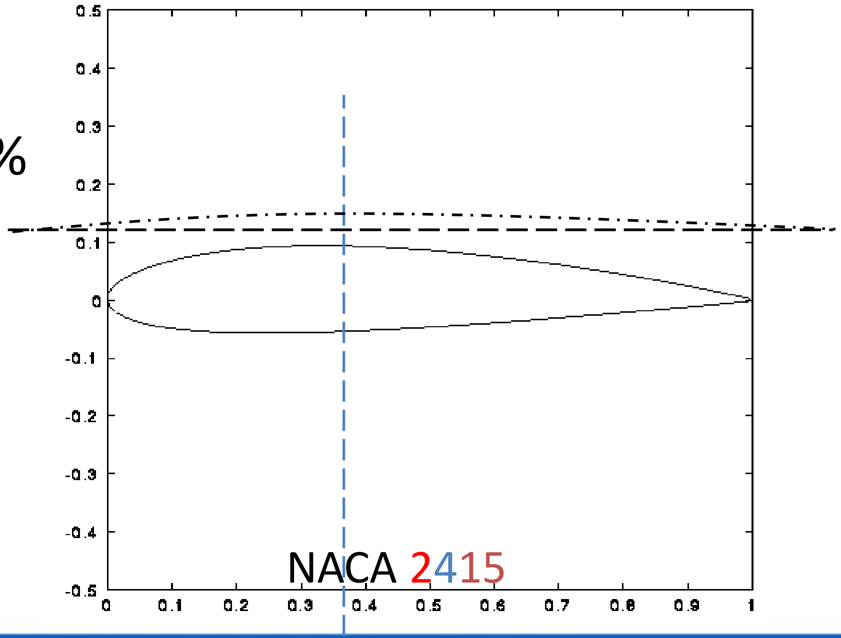
1. Mean Chamber Line: Set of points halfway between upper and lower surfaces.Measured perpendicular to mean chamber line itself
2. Leading Edge: Most forward point of mean chamber line
3. Trailing Edge: Most reward point of mean chamber line
4. Chord Line: Straight line connecting the leading and trailing edges
5. Chord, c: Distance along the chord line from leading to trailing edge
6. Chamber: Maximum distance between mean chamber line and chord line.Measured perpendicular to chord line.

NACA FOUR-DIGIT SERIES

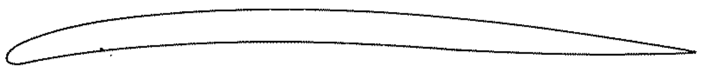
- First set of airfoils designed using this approach was NACA Four-Digit Series
- First digit specifies maximum camber in percentage of chord
- Second digit indicates position of maximum camber in tenths of chord
- Last two digits provide maximum thickness of airfoil in percentage of chord

Example: NACA <u>2415</u>

- Airfoil has maximum thickness of 15% of chord (0.15c)
- Camber of 2% (0.02c) located 40% back from airfoil leading edge (0.4c)



Airfoil thickness: WWI Airplanes

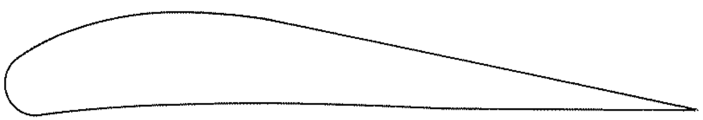


RAF 14. British

Thin wing, lower maximum C_L

Bracing wires required – high drag

German Fokker Dr-1



Göttingen 298. German

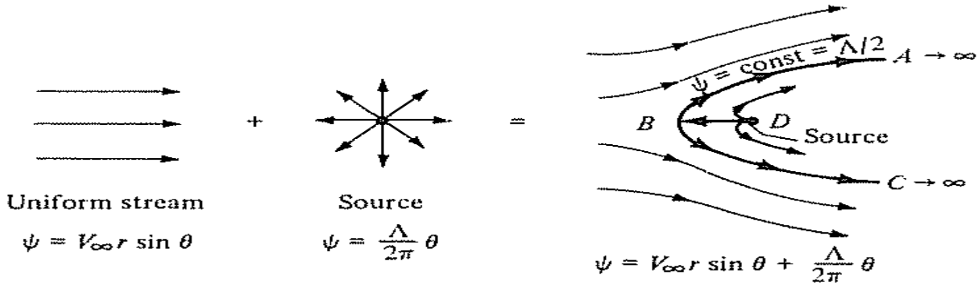
Higher maximum C_L

Internal wing structure

Higher rates of climb

Improved maneuverability

Streamline flow patterns



- Uniform flow + source produces a shape that looks something like the leading edge of an airfoil

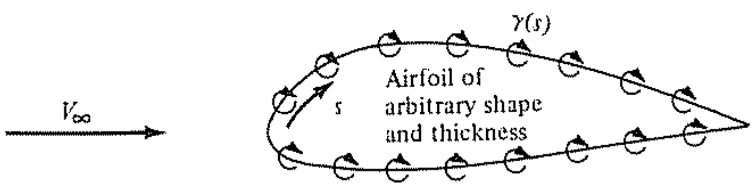
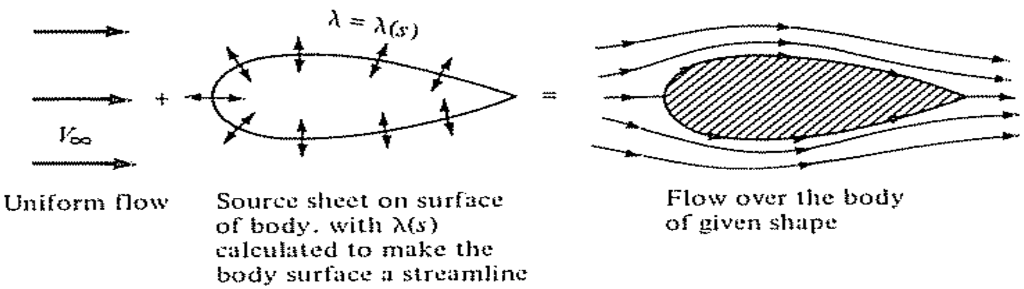


Figure 4.10 Simulation of an arbitrary airfoil by distributing a vortex sheet over the airfoil surface

Concept of vortex sheet

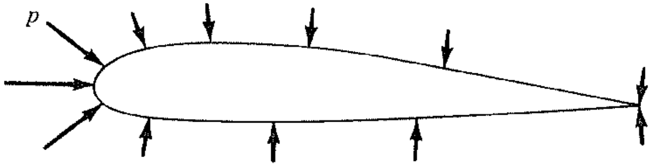
Uniform flow + vortex sheet can create an airfoil shape of interest



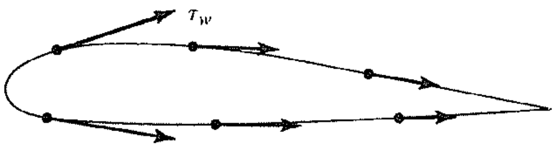
- Mathematical model mimics that shape of airfoil in flow field

What creates aerodynamic forces?

- Aerodynamic forces exerted by airflo sources



- Pressure, p, distribution on surface
  - Acts normal to surface

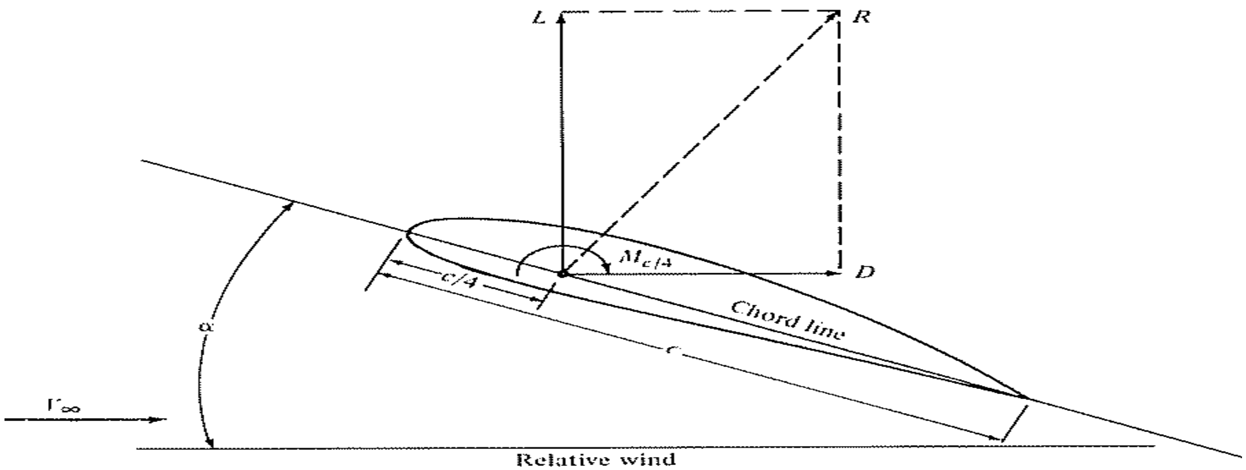


Shear stress, t_w, (friction) on surface
  - Acts tangentially to surface
  - Pressure and shear are in units of force per unit area (N/m^2)
- Net unbalance creates an aerodynamic force
- "No matter how complex the flow field, and no matter how complex the shape of the body, the only way nature has of communicating an aerodynamic force to a solid object or surface is through the pressure and shear stress distributions that exist on the surface.

Resolving the aerodynamic force

- **Relative Wind:** Direction of V_∞
  - We used subscript ∞ to indicate far upstream conditions
- **Angle of Attack, a:** Angle between relative wind (V_∞) and chord line

- Total aerodynamic force, **R**, can be resolved into two force components
- **Lift, L:** Component of aerodynamic force perpendicular to relative wind
- **Drag, D:** Component of aerodynamic force parallel to relative wind



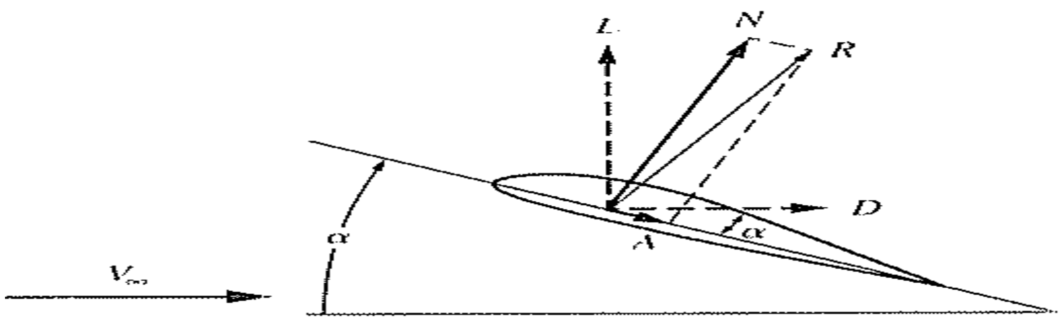
RESOLVING THE AERODYNAMIC FORCE

- Aerodynamic force, R, may also be resolved into components perpendicular and parallel to chord line
  - Normal Force, N: Perpendicular to chord line
  - Axial Force, A: Parallel to chord line
- L and D are easily related to N and A

$$L = N\cos\alpha - A\sin\alpha$$

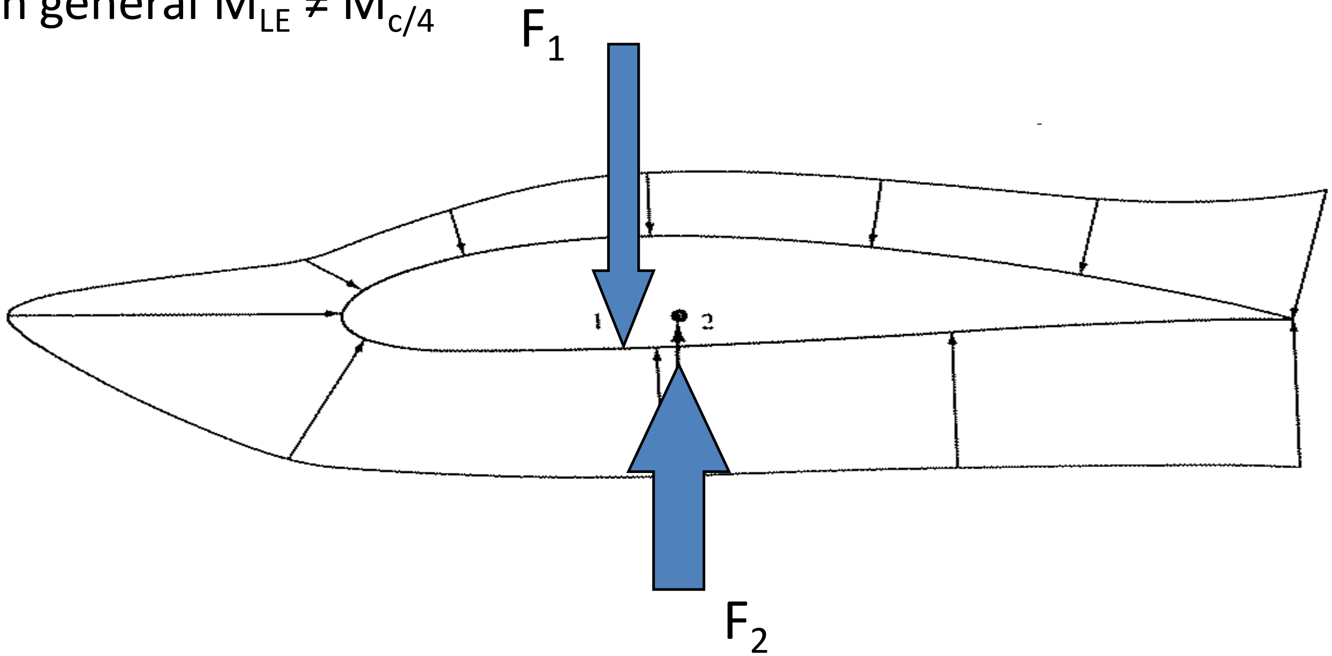
$$D = N\sin\alpha + A\cos\alpha$$

- For airfoils and wings, L and D most common
- For rockets, missiles, bullets, etc. N and A more useful



Aerodynamic moment

- Total aerodynamic force on airfoil is summation of F_1 and F_2
- Lift is obtained when $F_2 > F_1$
- Misalignment of F_1 and F_2 creates Moments, M, which tend to rotate airfoil/wing
- Value of induced moment depends on point about which moments are taken
  - Moments about leading edge, MLE or quarter-chord point, c/4, $M_{c/4}$
  - In general $M_{LE} \neq M_{c/4}$



Variation of l, d, and m with a

- Lift, Drag and M on a airfoil or wing will change as a changes
- Variations of these quantities are some of most important information that an airplane designer needs to know
- Aerodynamic Center
  - Point about which moments essentially do not vary with a
  - M_{ac}=constant (independent of a)
  - For low speed airfoils aerodynamic center is near quarter-chord point

How does an airfoil generate lift?

- Lift due to imbalance of pressure distribution over top and bottom surfaces of airfoil (or wing)
  - If pressure on top is lower than pressure on bottom surface, lift is generated
  - Why is pressure lower on top surface?

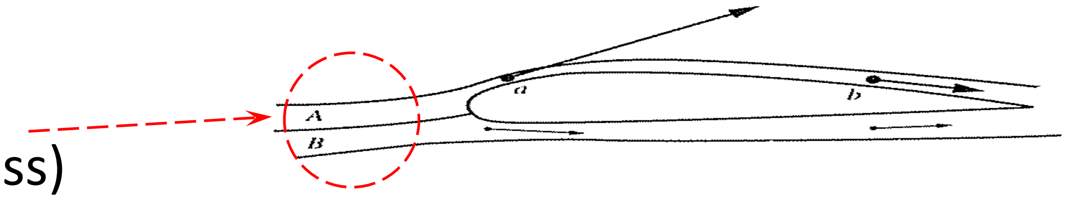
- We can understand answer from basic physics:
  - Continuity (Mass Conservation)
  - Newton’s 2nd law (Euler or Bernoulli Equation)

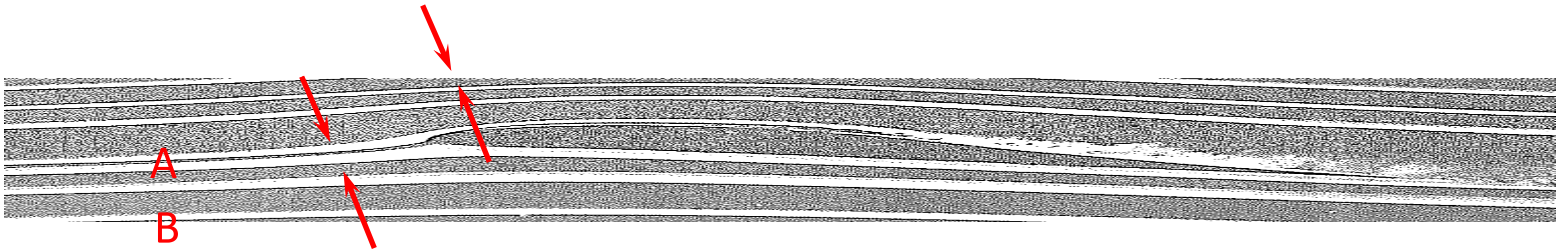
Lift = PA

How does an airfoil generate lift?

1. Flow velocity over top of airfoil is faster than over bottom surface
   - Streamtube A senses upper portion of airfoil as an obstruction
   - Streamtube A is squashed to smaller cross-sectional area
   - Mass continuity rAV=constant: IF A↓ THEN V↑

Streamtube A is squashed most in nose region (ahead of maximum thickness)





How does an airfoil generate lift?

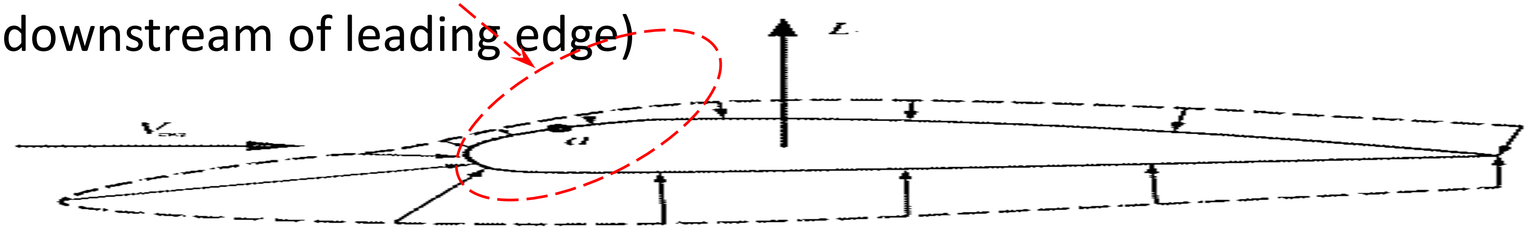
2. As V ↑ p↓
   - Incompressible: Bernoulli's Equation
   - Compressible: Euler's Equation
   - Called **Bernoulli Effect**

$$p + \frac{1}{2}\rho V^2 = \text{constant}$$

$$dp = -\rho V dV$$

3. With lower pressure over upper surface and higher pressure over bottom surface, airfoil feels a net force in upward direction → Lift

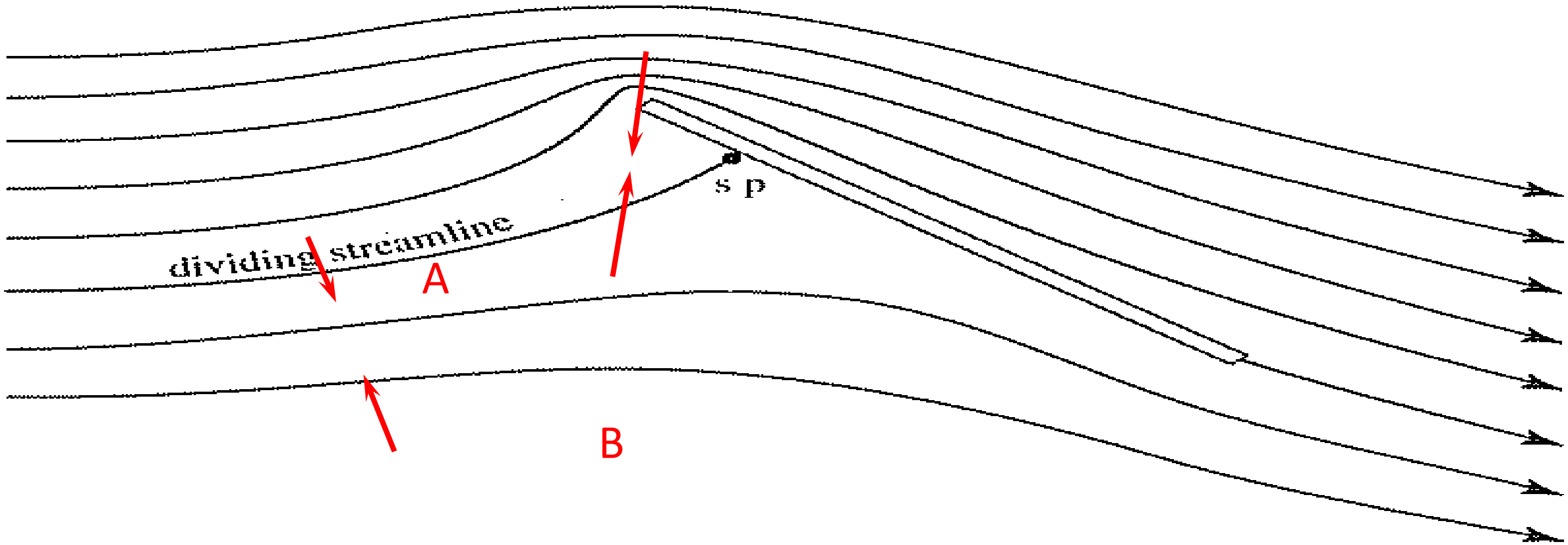
Most of lift is produced
in first 20-30% of wing
(just downstream of leading edge)



Can you express these ideas in your own words?

Even a flat plate will generate lift

- Curved surface of an airfoil is not necessary to produce lift



Lift, Drag, and Moment Coefficients

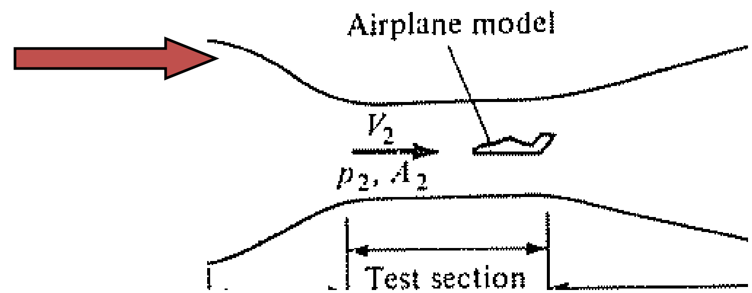
- Behavior of L, D, and M depend on a, but also on velocity and altitude
  - V_∞, r $_\infty$, Wing Area (S), Wing Shape, m $_\infty$, compressibility.Characterize behavior of L, D, M with coefficients (c_l, c_d, c_m)

Matching Mach an Reynolds (called similarity parameters)

$$L = \frac{1}{2}\rho V_\infty^2 S c_l$$

M_∞, Re

$$c_l \equiv \frac{L}{\frac{1}{2}\rho V_\infty^2 S} = \frac{L}{q_\infty S}$$



M_∞, Re

$$c_l = f(\alpha, M_\infty, \mathrm{Re})$$

c_l, c_d, c_m **identical**

- Behavior of L, D, and M depend on a, but also on velocity and altitude
  - V_∞, r $_\infty$, Wing Area (S), Wing Shape, m $_\infty$, compressibility.Characterize behavior of L, D, M with coefficients (c_l, c_d, c_m)

$$\boxed{L = \frac{1}{2}\rho V_\infty^2 S c_l}$$

$$c_l \equiv \frac{L}{\frac{1}{2}\rho V_\infty^2 S} = \frac{L}{q_\infty S}$$

$$c_l = f_1(\alpha, M_\infty, \text{Re})$$

$$\boxed{D = \frac{1}{2}\rho V_\infty^2 S c_d}$$

$$c_d \equiv \frac{D}{\frac{1}{2}\rho V_\infty^2 S} = \frac{D}{q_\infty S}$$

$$c_d = f_2(\alpha, M_\infty, \text{Re})$$

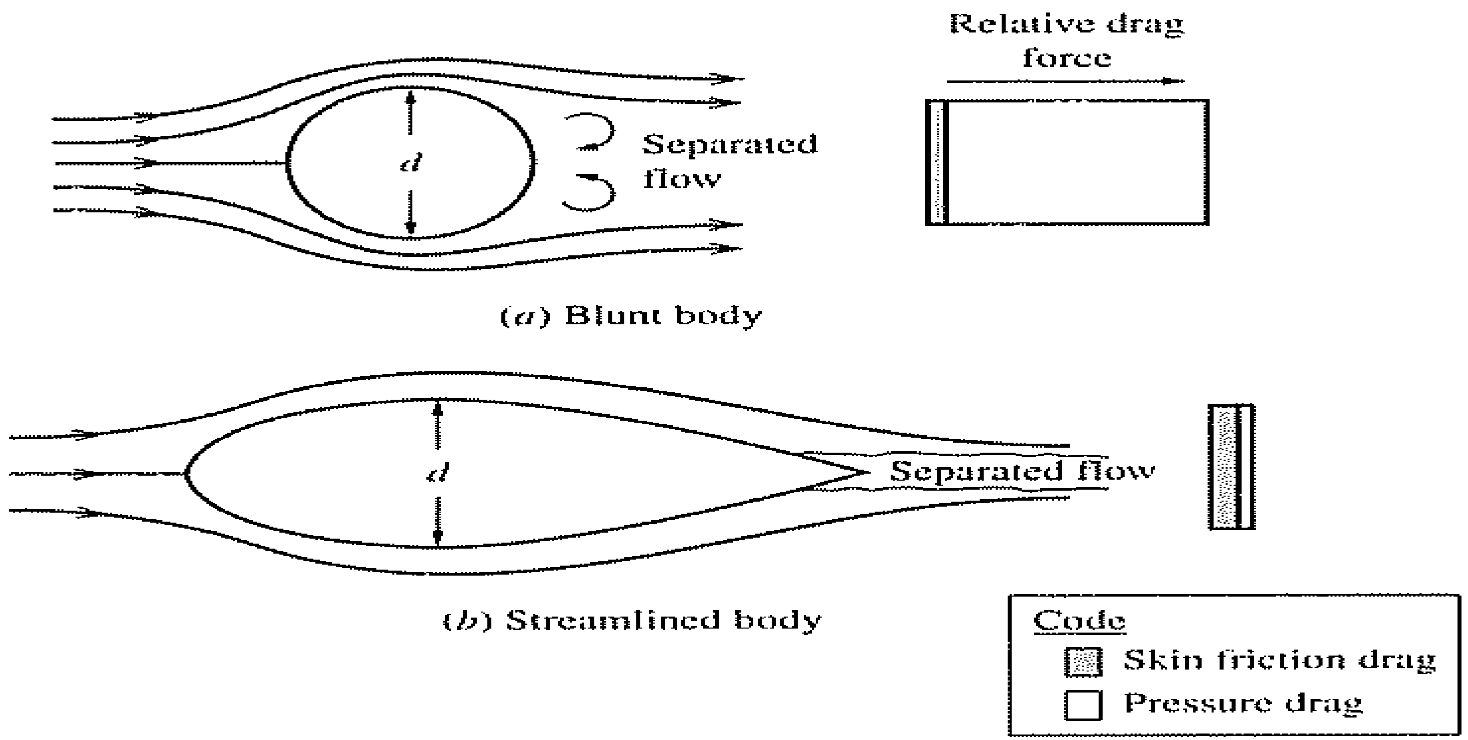
$$\boxed{M = \frac{1}{2}\rho V_\infty^2 S c c_m}$$

$$c_m \equiv \frac{M}{\frac{1}{2}\rho V_\infty^2 S c} = \frac{L}{q_\infty S c}$$

$$c_m = f_3(\alpha, M_\infty, \text{Re})$$

Note on Notation:
We use lower case, c_l, c_d, and c_m for infinite wings (airfoils)
We use upper case, C_L, C_D, and C_M for finite wings

Comparison of drag forces



UNIT-III

FLIGHT VEHIVLE PERFORMANCE AND STABILITY

Performance parameters

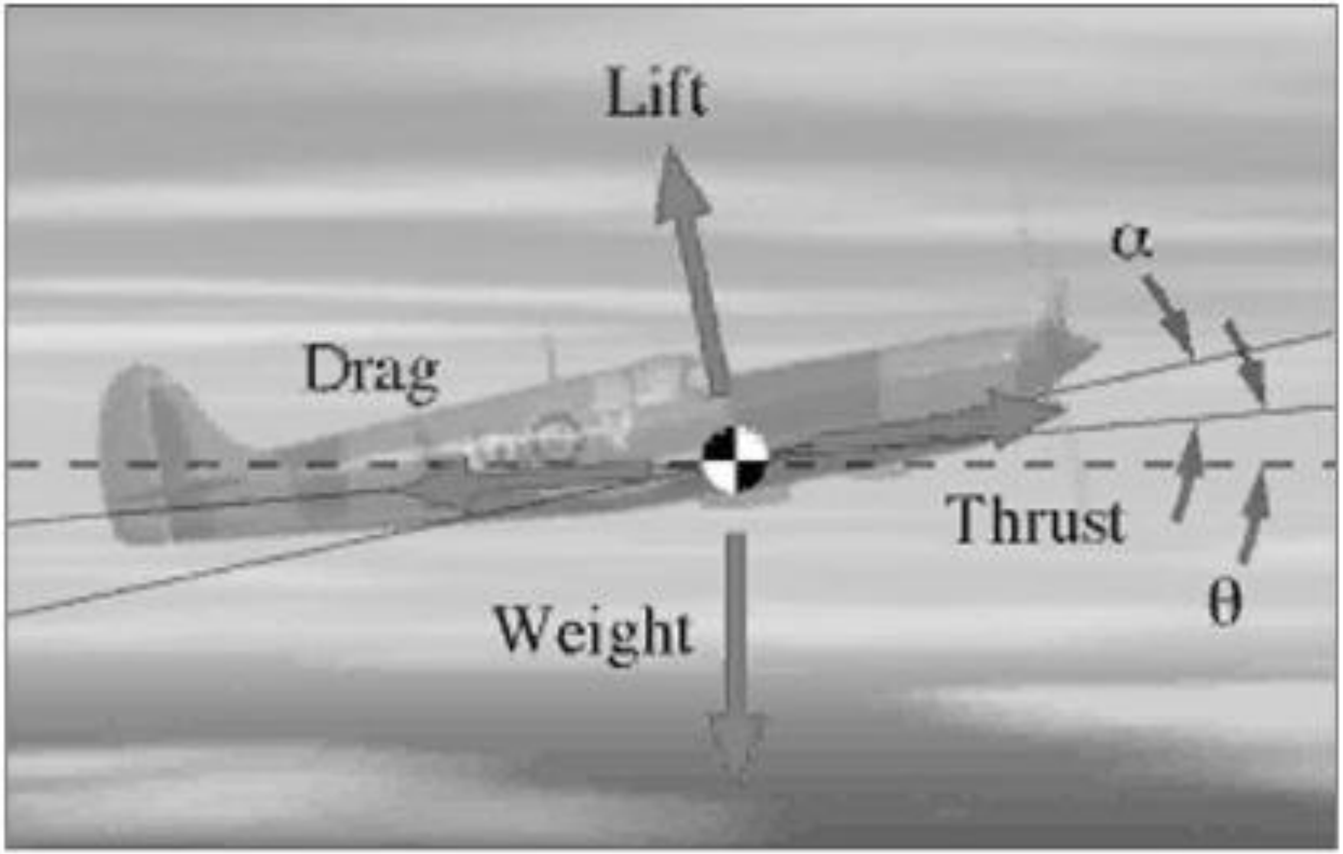
- The most common performance parameters, applicable to all types of airplanes, include speed, range, and endurance.

- Speed: What is the minimum and maximum speed of the aircraft?
- Range : How far can the aircraft fly with a tank of fuel?
- Endurance: How long can the aircraft stay in the air with a tank of fuel?

Equations of Motion

- To derive the equations of motion, let us consider an aircraft in flight inclined at an angle with the horizon. The aircraft is considered a rigid body on which four forces are acting at the center of mass. These forces are:

- Lift (L) acting perpendicular to the flight path
- Drag (D) acting parallel to the forward velocity vector
- Weight (W) acting vertically downward
- Thrust (T) generally inclined at an angle ‘a’

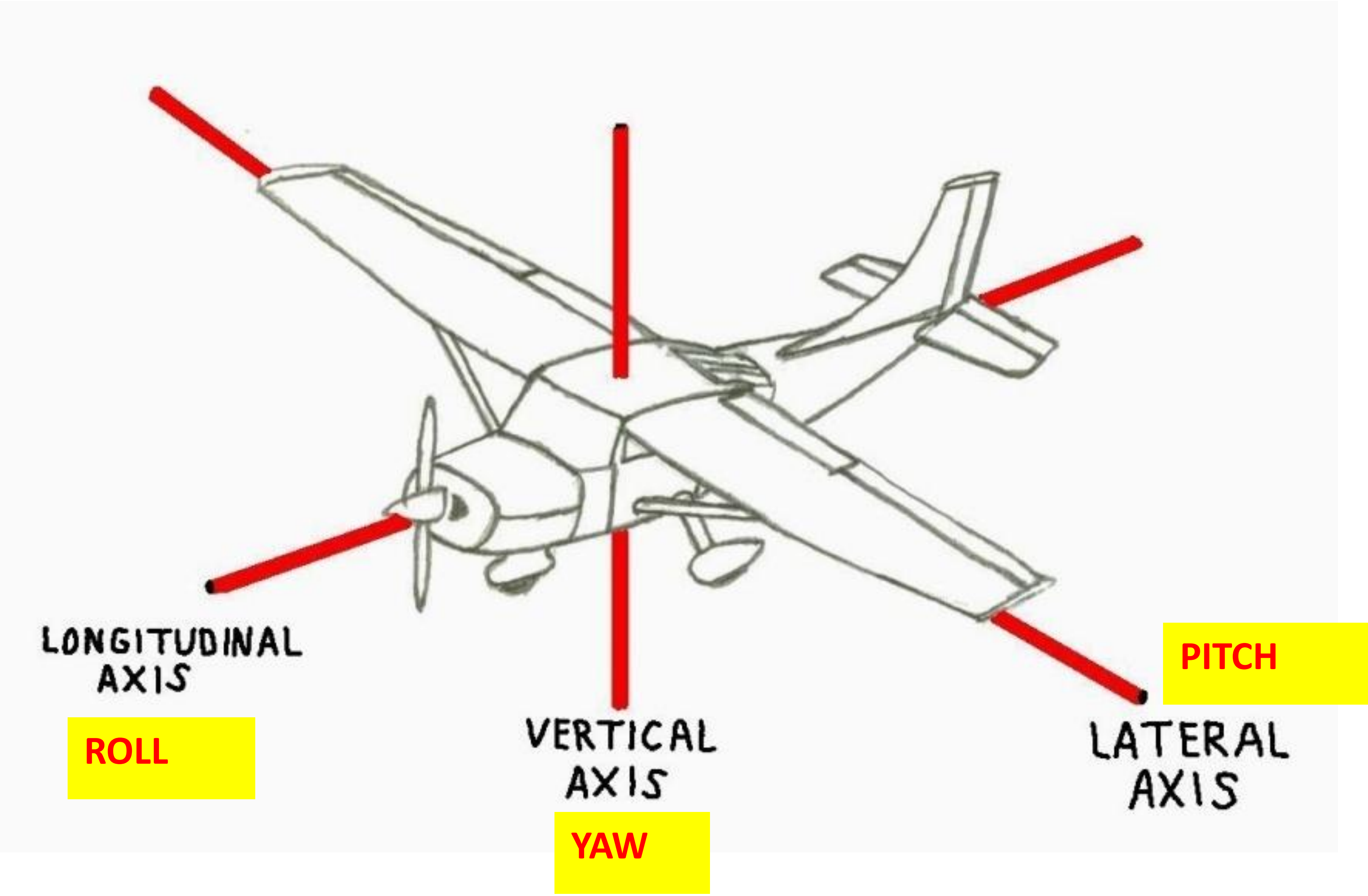

Lift
α
Drag
Thrust
θ
Weight

Aircraft Motion and Control

Objective: Know basic aircraft motion and how it is controlled.

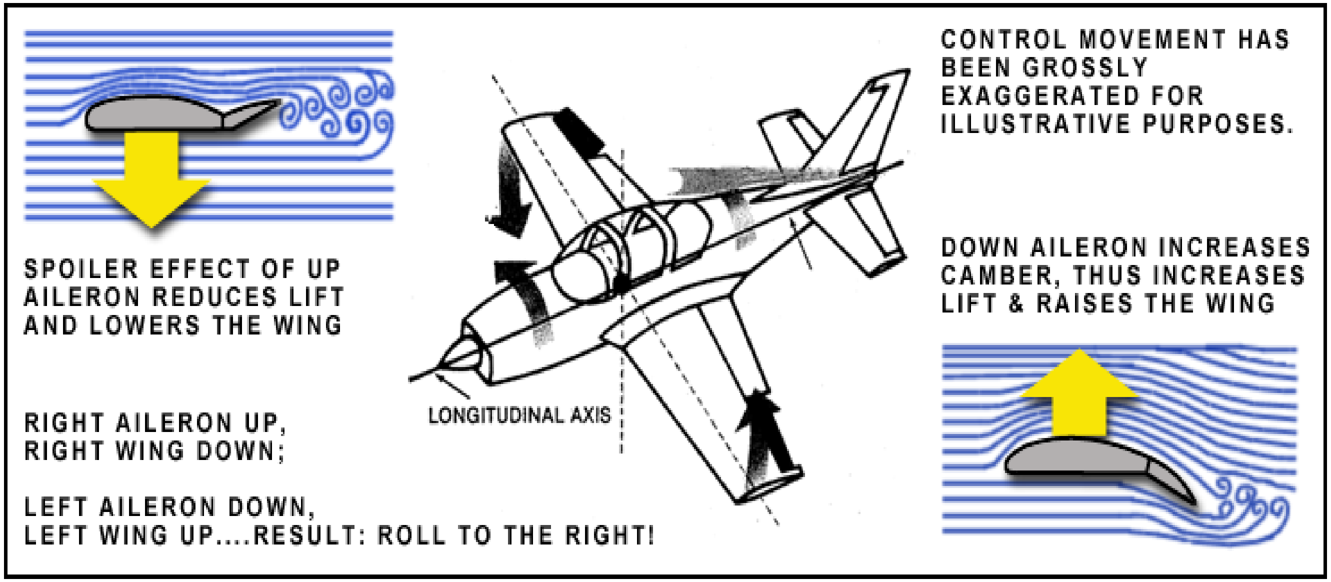
1. Identify the axes of rotation.
2. Identify the effects of ailerons and elevators on flight.
3. Identify the effects of flaps on flight.
4. Identify the effects of the rudder on flight
5. Identify the effects of spoilers on flight.

The Axes of Rotation



Longitudinal Axis

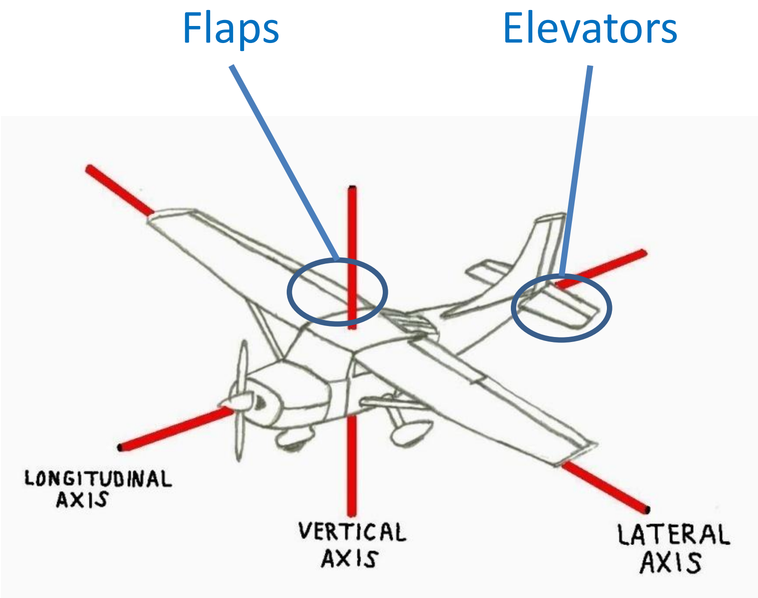
- Running from the tip of the nose to the tip of the tail. This axis can be thought of as a skewer which turns either right or left and causes everything attached to it to turn.



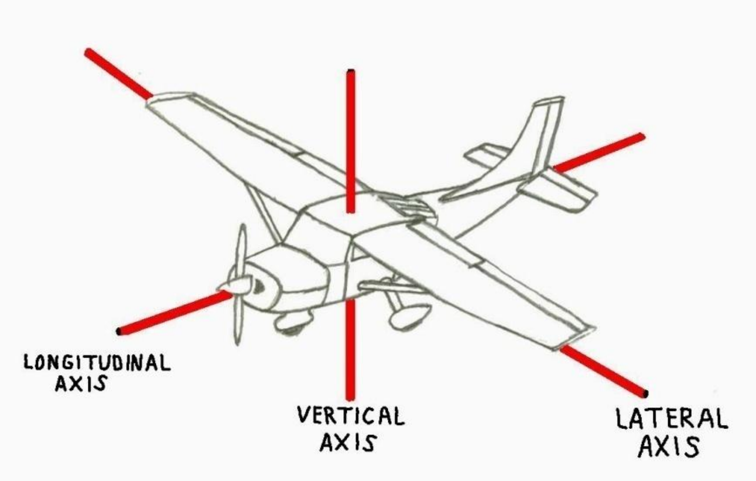
Longitudinal Axis

- The cause of movement or roll about this axis (roll axis) is the action of the ailerons.

- Lateral Axis
    - An imaginary rod, running from one wing tip through the other wing tip, forms an airplane's lateral axis.
    - Another name for the lateral axis is the pitch axis.
    - The flaps and elevators can be deflected up or down as the pilot moves the control column backward or forward.

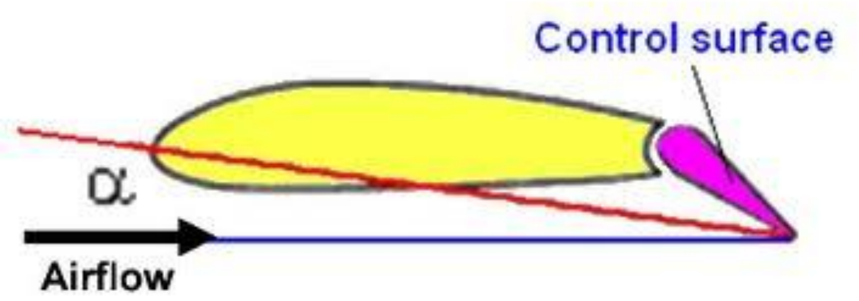


- Vertical Axis
    - An imaginary rod or axis which passes through the meeting point of the longitudinal and lateral axes. It is also referred to as the “yaw” axis.
    - The airplane turns about this axis in a side-to-side direction.
    - The airplane’s rudder is responsible for the movement about this axis.

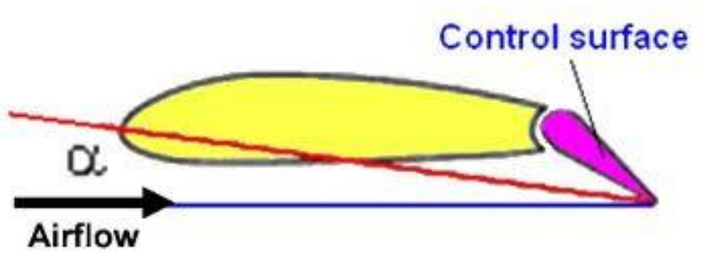


Flaps

- The flaps are attached to the trailing edge of the wing. In cruising flight, the flaps simply continue the streamline shape of the wing's airfoil.
- When flaps are lowered either partially or fully, lift and drag are increased.

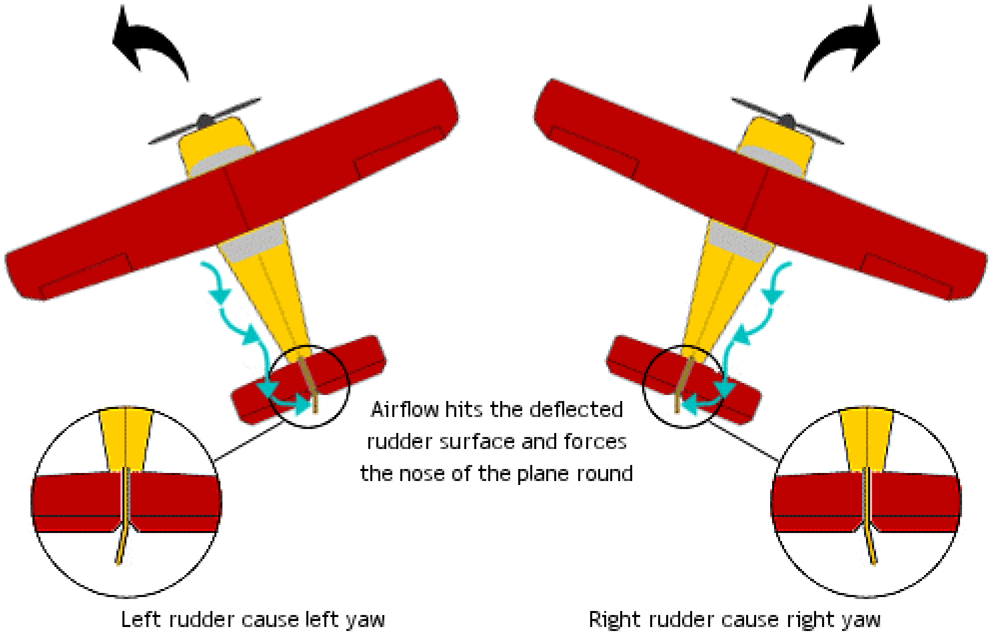


- Flaps increase the camber of the wing airfoil for the portion of the wing that it is attached.
  - This causes the air to speed up over the wing section where the most lift is created.
  - On the underside of the wing, dynamic lift is increased.
  - Using flaps when taking off helps the airplane get off the ground in a shorter distance.



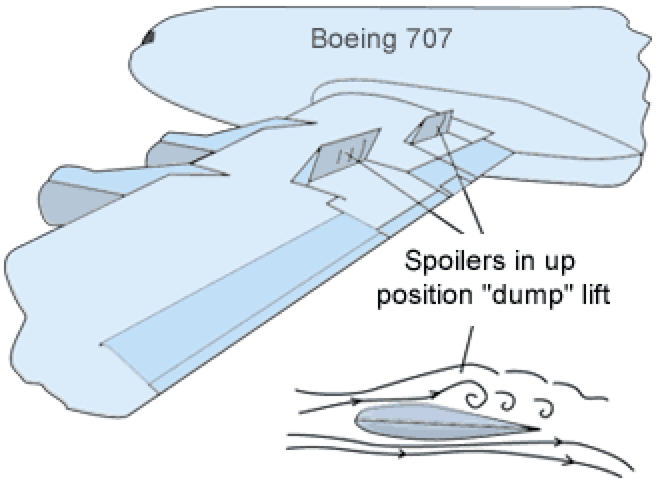
Rudder

- Located on the Vertical Stabilizer (tail)
- Controls the aircraft's yaw
- Right Rudder = Right Yaw
- Left Rudder = Left Yaw



Spoilers

- Spoilers work to destroy lift.
- Spoilers are found on various aircraft from the jet airliner to the sailplane.
- On the jet airliners, spoilers are hinged so that their aft portion is tilted upward into the smooth airflow.



Aircraft motion and control

Objective: Know basic aircraft motion and how it is controlled.

1. Identify the axes of rotation.
2. Identify the effects of ailerons and elevators on flight.
3. Identify the effects of flaps on flight.
4. Identify the effects of the rudder on flight
5. Identify the effects of spoilers on flight.

Aerodynamics-stability

- “The balance of an airplane in flight depends, therefore on the relative position of the center of gravity (CG) and the center of pressure (CP) of the airfoil” (PHAK 2-7).

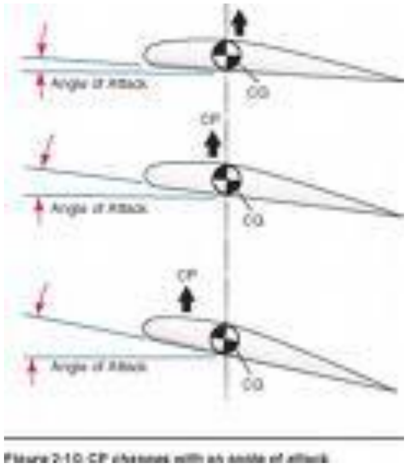
- What is center of pressure (CP)
  - Answer: CP is the point where the resultant force crosses the chord line. Because AOA changes, pressure forces (positive and negative) are constantly changing. The resultant force is the total positive and negative forces for each angle of attack

- Therefore, if AOA increases, CP moves forward. If AOA decreases, CP moves aft.

■As the CG and CP get closer, the aircraft becomes less stable. The farther apart they are, the more stable the aircraft is.

The CG is usually forward of the CP. Rotations around the different axis (lateral, longitudinal, and vertical), occur around the CG.

■Because CP is located aft of the CG, the aircraft wants to tumble forward, as it rotates around the CG. Hence, the horizontal stabilizer, counteracting the flipping rotation by creating downward lift.



- Stability=the tendency to correct back to the original state
- Maneuverability=the ability to change attitude and withstand stresses
- Controllability=the aircraft's response to pilot imputs

- Types of Stability: Static & Dynamic

- Static- the aircraft's initial response
- Dynamic-the response over a period of time

- Static Stability (initial tendency)
  - Positive Static=immediately return to the original state
  - Neutral Static=remain in the new position
  - Negative Static=continue away from the original state

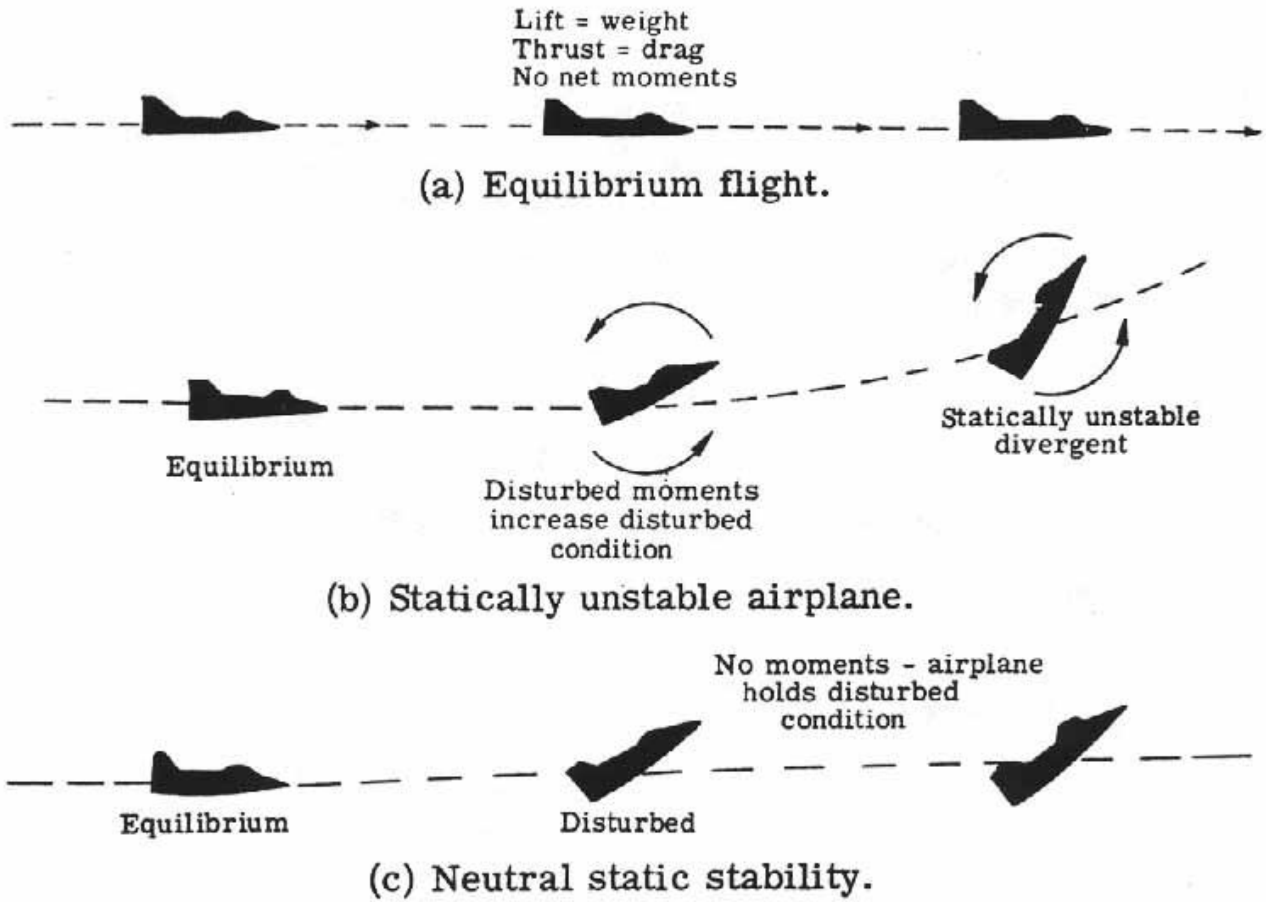
Dynamic Stability (over time)

-Positive Dynamic=returns to original state

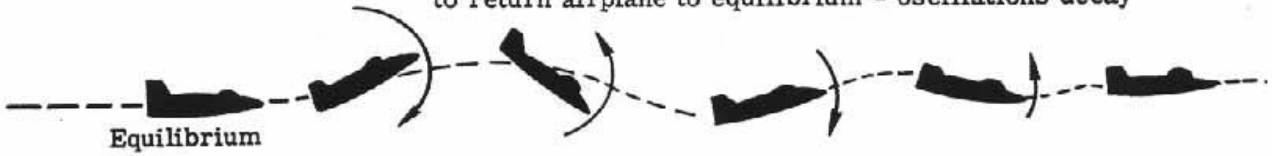
-Neutral Dynamic-Once displaced, the plane neither increases or decreases in amplitude, stays the same

-Negative Dynamic=continues going away, becomes more divergent if displaced

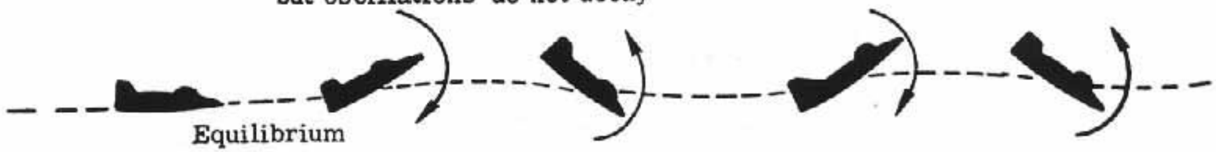
- Static Stability:



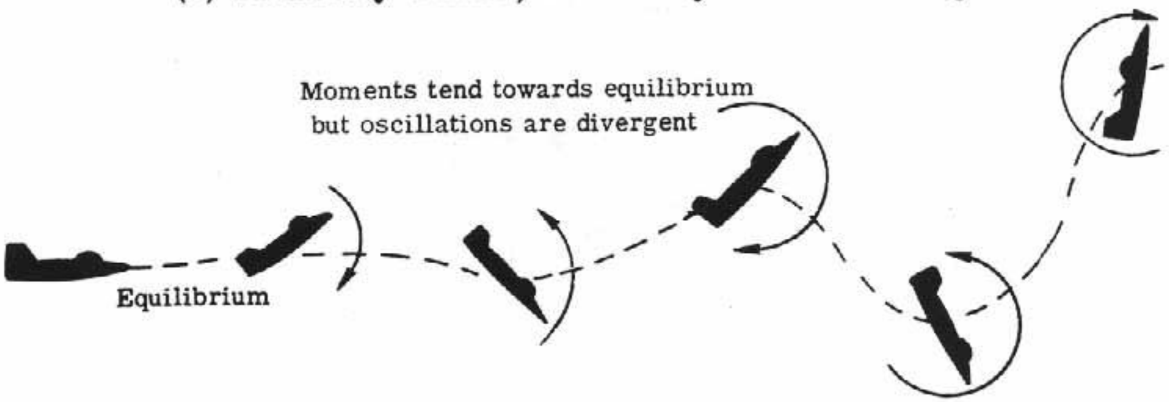
- Dynamic Stability:



(a) Statically and dynamically stable.



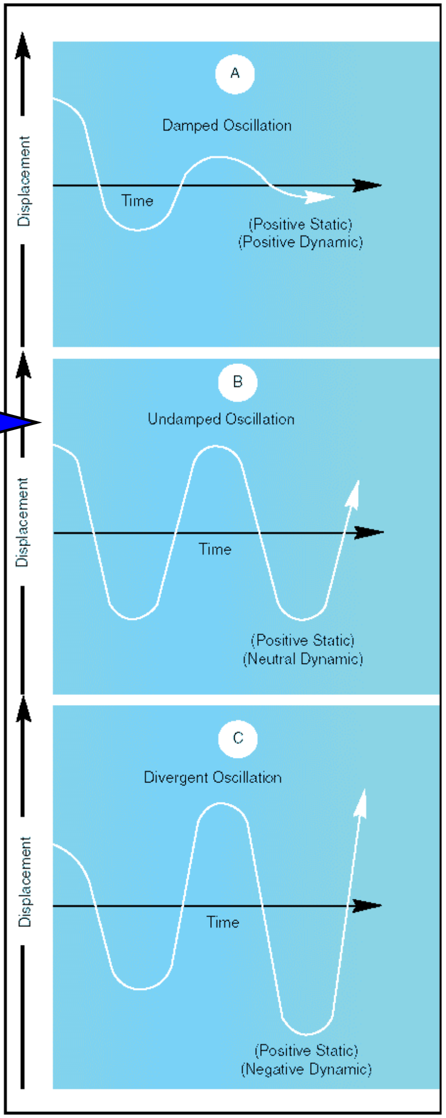
(b) Statically stable; neutral dynamic stability.



(c) Statically stable; dynamically unstable.

Phugoid Oscillations- Result from the worse type of stability (Positive static, neutral dynamic). They are long oscillations, and very slow. Phugoid oscillations occur with a close CG and CP (inherently unstable).

Phugoid



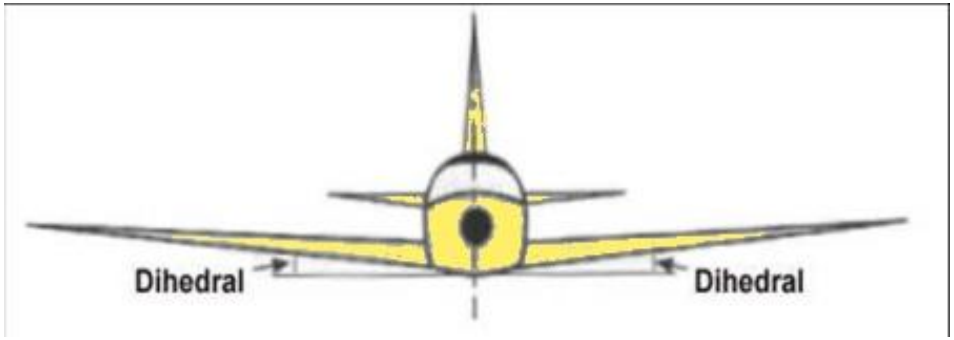
- Dihedral- This is the angle that exists between the wings and the fuselage. Dihedral affects longitudinal stability
- Yaw stability-developed from the vertical stabilizer

Longitudinal stability-roll

Vertical stability-yaw

Lateral stability-pitch

Through the CG



Steady flight

- For the performance parameters we are interested in, we make another simplifying assumption that the aircraft is in steady, level flight.
- This means that the aircraft is in un-accelerated flight; therefore, the flight path angle is zero. Hence, the generalized equationsof motion reduce to

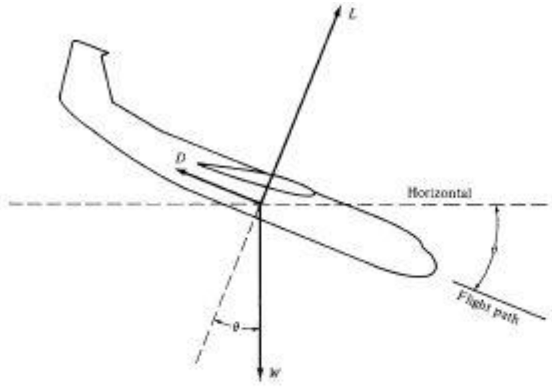
$$D=T$$

$$L=W$$

- The thrust produced by the engine(s) exactly balances the drag, and the lift balances the weight. The performance of an airplane in steady, level flight is called the static performance

Gliding or unpowered flight

In this case the thrust is equal to zero; the flight path is steady, but it is not level.



it is easy to balance the forces. We write

$$L = mg\cos\theta$$
$$D = mg\sin\theta$$

To calculate the glide angle, we divide Equation with each other which can be rewritten as

$$\frac{mg\sin\theta}{mg\cos\theta} = \frac{D}{L}$$

$$\tan\theta = \frac{1}{L/D}$$

To achieve the maximum range, the glide angle has to be a minimum, which occurs when the lift-to-drag ratio is a maximum

$$\tan\theta_{\min} = \frac{1}{L/D_{\max}}$$

Gliding flight is an excellent illustration of how the lift-to-drag ratio represents an overall aerodynamic efficiency criterion for an aircraft.

Review

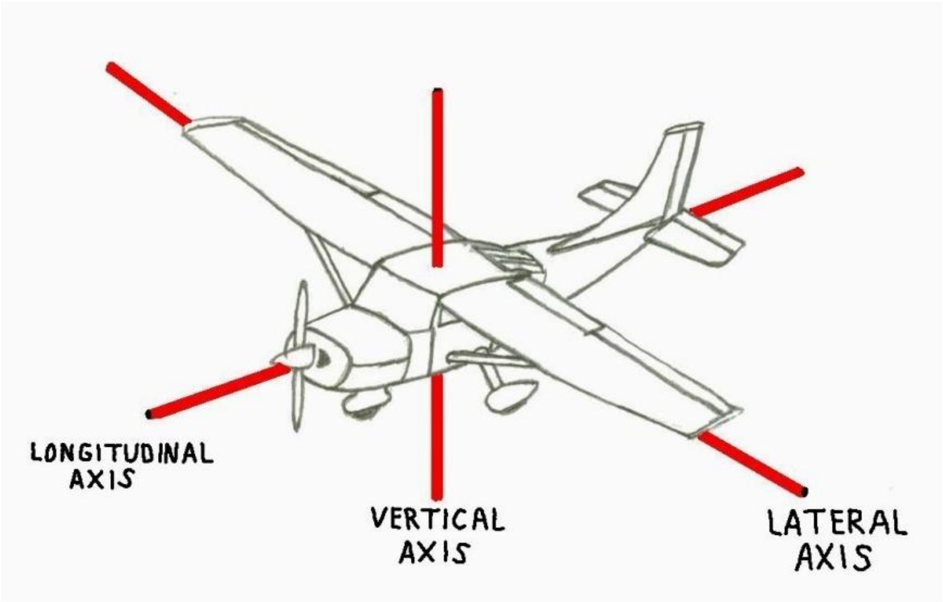
- Which is **not** a primary axis associated with basic aircraft motion?

A. Longitudinal Axis

B. Lateral Axis

C. Vertical Axis

D. Diagonal Axis



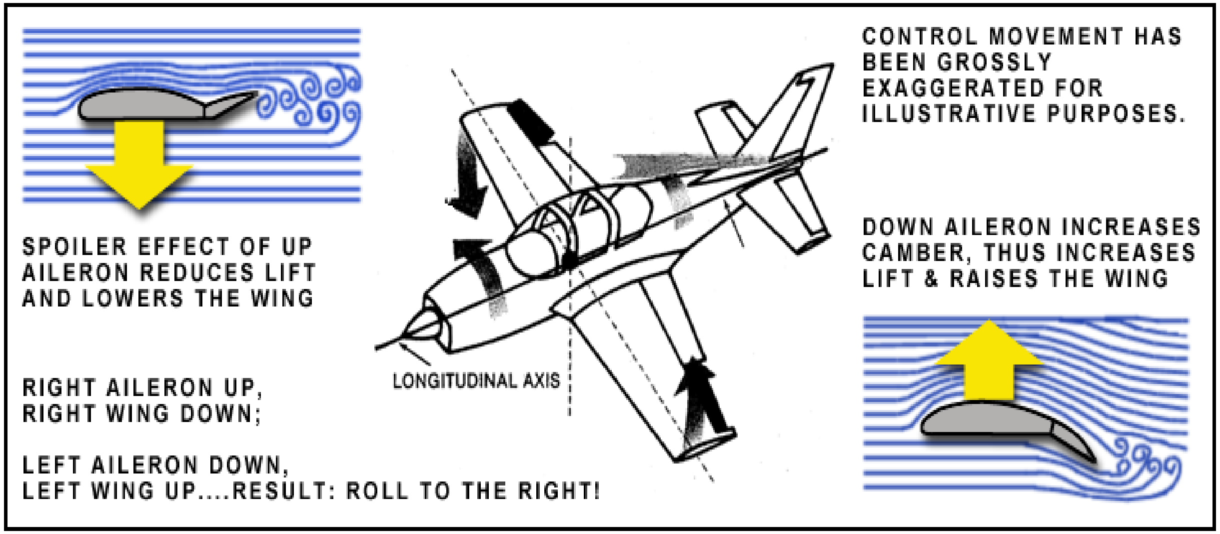
- Affecting movement along the Longitudinal Axis, which basic aircraft control surface results in the aircraft rolling?

A. Ailerons

B. Flaps

C. Elevators

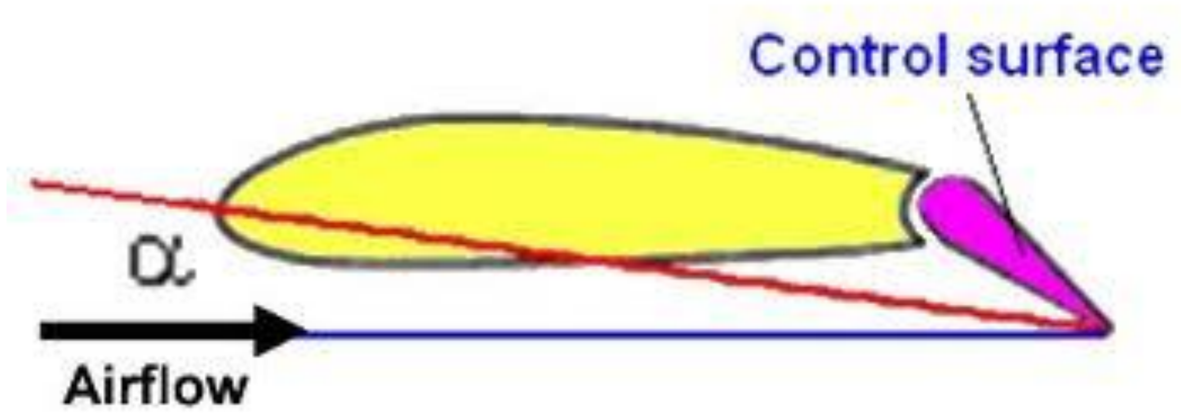
D. Rudder



- True or False? Extending flaps, increases both lift as well as drag?

A. True

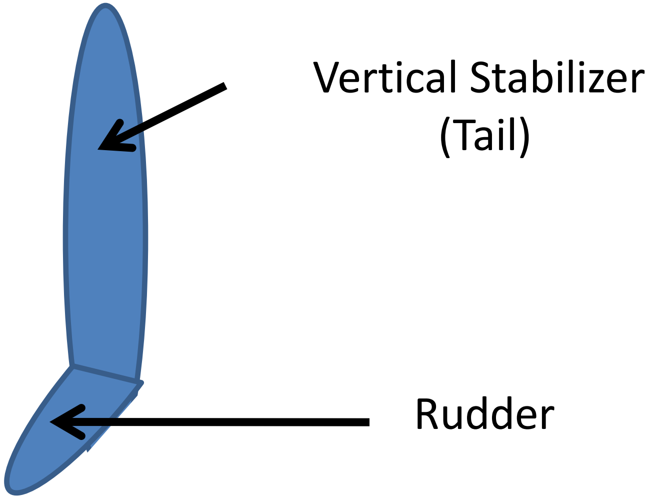
B. False



- If an aircraft rudder was positioned as in the picture below, which direction would the aircraft begin to yaw?

A. Left

B. Right



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

Monocoque

- The monocoque design relies largely on the strength of the skin, or covering, to carry various loads. The monocoque design may be divided into three classes—monocoque, semimonocoque, and reinforced shell.
- The true monocoque construction uses formers, frame assemblies, and bulkheads to give shape to the fuselage. However, the skin carries the primary stresses. Since no bracing members are present, the skin must be strong enough to keep the fuselage rigid.
- The biggest problem in monocoque construction is maintaining enough strength while keeping the weight within limits. .

Semi - monocoque

- Semimonocoque design overcomes the strength-to-weight problem of monocoque construction.
- In addition to having formers, frame assemblies, and bulkheads, the semimonocoque construction has the skin reinforced by longitudinal members

Reinforced

- The reinforced shell has the skin reinforced by a complete framework of structural members. Different portions of the same fuselage may belong to any one of the three classes. Most are considered to be of semimonocoque-type construction.
- The semimonocoque fuselage is constructed primarily of aluminum alloy, although steel and titanium are found in high-temperature areas. Primary bending loads are taken by the longerons, which usually extend across several points of support. The longerons are supplemented by other longitudinal members known as stringers. Stringers are more numerous and lightweight than longerons. red to be of semimonocoque-type construction.

wings

- Wings develop the major portion of the lift of a heavier-than-air aircraft. Wing structures carry some of the heavier loads found in the aircraft structure. The particular design of a wing depends on many factors, such as the size, weight, speed, rate of climb, and use of the aircraft.
- The wing must be constructed so that it holds its aerodynamics shape under the extreme stresses of combat maneuvers or wing loading. Wing construction is similar in most modern aircraft. In its simplest form, the wing is a framework made up of spars and ribs and covered with metal.

Fuselage

- The fuselage is the main structure, or body, of the aircraft. It provides space for personnel, cargo, controls, and most of the accessories. The power plant, wings, stabilizers, and landing gear are attached to it. There are two general types of fuselage construction—welded steel truss and monocoque designs. The welded steel truss was used in smaller Navy aircraft, and it is still being used in some helicopters.

Metallic Materials

1. Alloys
2. Aluminum
3. Titanium
4. Steel Alloys

Nonmetallic Materials

1. Transparent Plastic
2. Reinforced Plastic

Uses of aluminium

1. Aluminum Aluminum alloys are widely used in modern aircraft construction.
2. Aluminum alloys are valuable because they have a high strength-to-weight ratio.
3. Aluminum alloys are corrosion resistant and comparatively easy to fabricate.
4. The outstanding characteristic of aluminum is its lightweight.

Alloys

- An alloy is composed of two or more metals. The metal present in the alloy in the largest amount is called the base metal. All other metals added to the base metal are called alloying elements.
- Adding the alloying elements may result in a change in the properties of the base metal. For example, pure aluminum is relatively soft and weak.
- However, adding small amounts or copper, manganese, and magnesium will increase aluminum's strength many times. Heat treatment can increase or decrease an alloy's strength and hardness.
- Alloys are important to the aircraft industry. They provide materials with properties that pure metals do not possess.

Titanium

- Titanium is a lightweight, strong, corrosion resistant metal.
- Recent developments make titanium ideal for applications where aluminum alloys are too weak and stainless steel is too heavy.
- Additionally, titanium is unaffected by long exposure to seawater and marine atmosphere.

Composite and carbon fiber materials

1. High-performance aircraft require an extra high strength-to-weight ratio material.
2. Fabrication of composite materials satisfies this special requirement. Composite materials are constructed by using several layers of bonding materials (graphite epoxy or boron epoxy).
3. These materials are mechanically fastened to conventional substructures.
4. Another type of composite construction consists of thin graphite epoxy skins bonded to an aluminum honeycomb core.
5. Carbon fiber is extremely strong, thin fiber made by heating synthetic fibers, such as rayon, until charred, and then layering in cross sections.

Six Types Of Jet Engines

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

Turbo Jet

- The common components of the engine have been described, so now we con- centrate on the entire engine system operation. The different types of engines will be discussed, specifically, the turbojet, turbofan, turboprop, afterburning turbojets, ramjets, and ultra high bypass engines. The turbojet is the basic engine of the jet age.
- Large amounts of air surrounding the engine are continuously brought into the engine through the inlet which then enter the compressor. The many rows of compressor squeeze the air to many times the free stream pressure.
- The compressor requires air and an energy supply to operate. At the exit of the compressor, the compressed air is forced into the burner. In the burner a small amount of fuel is sprayed into the compressed air, is ignited, and is burned continuously.

Turbofan

1. Most modern airliners use turbofan engines because of their high thrust and good fuel efficiency. A turbofan engine is a variation of the basic gas turbine engine, where the core engine is surrounded by a fan in the front and an additional fan turbine at the rear.
2. The fan and fan turbine are composed of many blades, as are the core compressor and core turbine, and are connected to an additional shaft.
3. As with the core compressor and turbine, some of the fan blades turn with the shaft and other blades remain stationary. The fan shaft typically passes through the core shaft for mechanical reasons.

Turboprop

1. Many small commuter aircraft use turboprop engines that have a gas turbine core to turn a propeller. As mentioned previously, propeller engines develop thrust by moving a large mass of air through a small change in velocity. There are two main parts to a turboprop propulsion system: the core engine and the propeller.
2. The core is very similar to a basic turbojet except that instead of expanding all the hot exhaust gases through the nozzle to produce thrust, most of the exhaust energy is used to turn the turbine. There may be an additional turbine stage present, which is connected to a driveshaft.
3. The shaft drives the propeller through gear connections and produces most of the thrust.

Working Of After Burning Turbojets

1. Most modern fighter aircraft employ an afterburner on either a low bypass turbo- fan or a turbojet. In order for planes to fly at supersonic speeds, they have to overcome a sharp rise in drag near the speed of sound.
2. A simple way to get the necessary thrust is to add an afterburner to a core turbojet, often called an augmentor. In a basic turbojet, some of the energy of the exhaust from the burner is used to turn the turbine.
3. The afterburner is essentially a long tailpipe into which additional fuel is sprayed directly into the hot exhaust and burned to provide extra thrust.

Ramjets

1. A ramjet is a very different engine design from a gas turbine engine since it has no moving parts. It achieves compression of intake air by the actual forward speed of the aircraft.
2. Air entering the intake of a supersonic aircraft is slowed by aerodynamic diffusion created by the inlet and a diffuser to velocities comparable to those in a turbojet afterburner.
3. The expansion of hot gases after fuel injection and combustion accelerates the exhaust air to a velocity higher than that at the inlet, thus creating positive forward thrust.

Ultra High By Pass Engines

1. To improve fuel consumption, some ultra high bypass engines are on the drawing board. The physical layouts of components vary, but one example is the un ducted fan (UDF) engine that eliminates the need for a gearbox to drive a large fan.
2. The jet engine exhaust drives two counter rotating turbines that are directly coupled to the fan blades. The large-span fan blades are designed with variable pitch (blade angle of attack) to accommodate various aircraft speed and power requirements.
3. The advantage of a UDF engine is that 20 to 30 percent reductions in fuel consumption can be achieved over subsonic turbofans.

UNIT-V

SATELLITE SYSTEMS ENGINEERING
HUMAN SPACE EXPLORATION

Satellite Missions

- Satellites provide humans with the ability to send electronic and mechanical equipment beyond the confines of Earth’s atmosphere. In Earth orbit, satellites provide humans with one key benefit—altitude.
- Satellite missions serve many purposes, but can generally be divided into four main categories:

1. Scientific
2. Military and national security
3. Civil
4. Commercial

Scientific Missions

1. Scientific missions are initiated with the intent to discover. They are typically government-funded missions assembled and operated by consortia from universities, industry, and national space administrations.
2. The primary role of these missions is to provide answers to questions; for example, the Lunar Prospector mission's primary function was to determine if there was ice on the lunar polar caps.

Military and National Security

1. Military and national security missions are conducted with the intent to protect, monitor, and learn about world situations pertinent to the security of a nation.
2. These missions involve early-warning satellites, communications satellites, and reconnaissance satellites that are used to learn about what is occurring in other countries, such as weapons and stock piling and troop movements.

Civil Satellites

1. Civil satellites have the primary function of supporting the well-being of humans, either directly or indirectly.
2. These satellites are usually government funded, and they provide information that is critical for helping society.
3. National weather satellites fall into this category, where government-funded satellites monitor the Earth’s weather and provide up-to-date information to weather bureaus around the country.
4. This service allows meteorologists to monitor and disseminate weather information that can be vital for emergencies, such as approaching hurricanes, or equally vital for farmers who need to be warned of flooding or frosts that may damage crops.

Commercial Satellites

1. Commercial In recent years commercial satellites have become the major source of satellite activity, with telecommunications satellites dominating the market.
2. Commercial satellites are ordered by companies who wish to offer a service for a fee. In the case of a telecommunications satellite, a service provider orders a satellite that is capable of routing a given amount of information at a predetermined rate

An Operational Satellite

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

1. Satellite.
2. Ground station.
3. Command and control center.
4. Data storage center.
5. Data analysis and distribution center.

1. The ground station is used to receive data from the satellite and to transmit data to the satellite.
2. The downlink provides data on the “health” of the satellite, or how well its subsystems are operating, and the mission data that are collected from the onboard payload.
3. The command and control center is the center for satellite operations. The down linked operational information is reviewed and analyzed in this center.
4. And consequently decisions are made about any necessary changes to the satellite’s operational parameters.

Elements Of a Satellite

1. There are three main elements of any satellite: the payload, the bus, and the launch vehicle adapter assembly.
2. The Payload : The payload is defined as the equipment that performs the satellite mission function. For example, a telecommunication satellite's payload would be defined as the equipment that receives, processes, and transmits communication data.
3. The Bus The satellite bus is defined as the systems and structure within the satellite, which provide functions to allow the payload to perform its intended mission. This includes providing power, thermal protection, stability, and orbital control so the payload performs within its design limits.
4. The launch vehicle adapter assembly The launch vehicle adapter assembly acts as the interface between the satellite bus and the launch vehicle that boosts the satellite into orbit.

Satellite Bus Subsystems

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

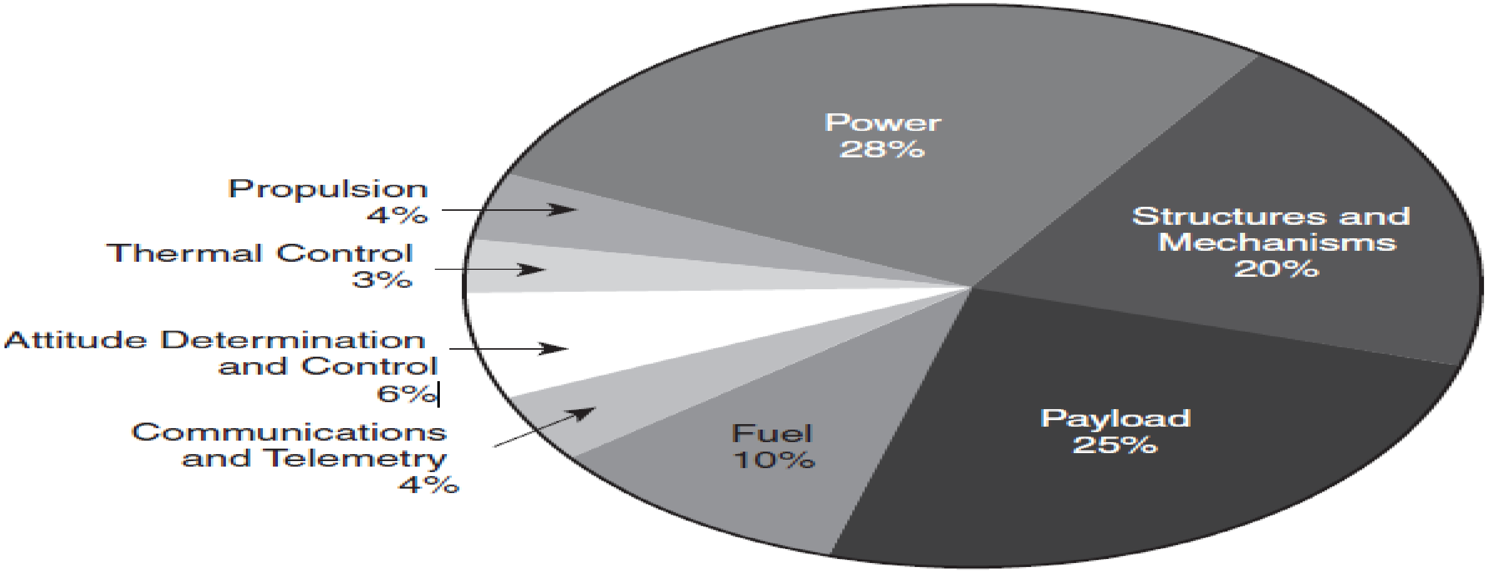
A satellite bus is typically composed of the following subsystems that all interact to ensure the mission payload operates successfully:

1. Structures and mechanisms.
2. Power.
3. Communications and Telemet

4. Thermal control.

5. Attitude determination and control.

6. Propulsion and station keeping



Structures,Mechanisms,Materials

Satellite structures act to support all the spacecraft subsystem components and provide a means for attaching the satellite to the launch vehicle. The design of the structures must meet the strength and stiffness requirements necessary to survive the launch environment and on-orbit operational environment. The launch environment is characterized by

1. High linear accelerations due to the vehicle acceleration (3 to 12 G's sustained).
2. Shocks from stage separations and stage firings (2,000 G's).
3. Acoustically induced vibration from engine sound pressure waves reflecting off the launch pad structure (140 dB at 0 to 20,000 Hz).

- High-energy structural vibrations from any of the above sources that excite. The natural frequency of structural members in the launch vehicle and are transmitted to the satellite being launched.
- Highly flexible structures that do not dampen vibrations are not conducive to high pointing accuracy for satellite payloads. On-orbit loads are created by

1. Internal motion of momentum wheels and gyroscopes.
2. Attitude control adjustments.
3. Mechanism deployment (i.e., solar arrays).
4. Thermal stresses

Power Systems

- A satellite's power system performs three main functions. It must provide/produce energy; store energy; and regulate, distribute, and control power flow. Early spacecraft carried battery packs that would provide low voltage for a matter of hours or days, after which the satellite would be inoperable. It was quickly realized that for any long-term use of satellites, on-orbit energy production would be needed. The result was two design philosophies: solar photovoltaic cells and nuclear isotopes.

Communication and Telemetry

- The operation of a satellite requires knowing a satellite’s location in space (tracking),the health of the onboard subsystems and payload (telemetry), and an ability to tell the satellite what to do (control). All these procedures require some form of communication between the satellite and a ground station

Propulsion And Station Keeping

Once in orbit, the propulsion system provides a satellite with several operational roles, including

1. Initial spin-up.
2. Station keeping (North–South, East–West).
3. Attitude control.
4. Satellite orbit change.
5. Angular-momentum management.
6. Satellite end-of-life (EOL) disposal

Space Mission Case Studies

Four Satellite Case Studies:

"Introduction to Satellites," listed four types of satellitemissions, namely, scientific, military, civil, and commercial. The selected case studies discuss scientific, public, and commercial satellite mission applications. These satellite missions truly cover space, as the missions extend from low earth orbit(which roughly extends from 200 km altitude to the first Van Allen belt around 1,400 km) to geostationary Earth orbit (GEO) at 36,000 km, and an interplanetary satellite probe.

1. **The Topex /Poseidon mission, a satellite dedicated to monitoring the global** ocean circulation and improving global climate predictions (scientific,public).
2. **The Land sat 7 remote-sensing satellite and instruments provide low-cost,** multipurpose, land remote-sensing data for Earth with a focus on technology and images applicable for the next century (commercial, public).
3. **The Thuraya system, a space-based telecommunication system that consists** of two satellites in GEO offering mobile telephone services (commercial).
4. **The Magellan interplanetary spacecraft designed to reveal Venus's surface**(volcanic lava flows, quake faults, and other features) through the planet's thick atmosphere (scientific, public).

SUMMARY OF MISSION OBJECTIVES

Now that we have briefly discussed satellite missions, reflection on the process of designing a space mission is useful. Developing a satellite space system consists of

1. Creating system requirements based on the mission objectives.
2. Translating the system requirements to subsystem specifications.
3. Translating subsystem specifications to a subsystem design that can be fabricated and tested.
4. Integrating the subsystems into a complete system that can be tested.
5. Integrating the system and the launch vehicle.
6. Launching and operating the space segment of the mission.
7. Eventually phasing out and ending the mission

Goals Of Human Space Flight Missions

1. Human exploration of space captivates us as no other endeavor. Human spaceflight
2. Missions have four main goals:
3. To increase knowledge of nature's processes, using the space environment.
4. To explore and settle the solar system.
5. To achieve affordable, routine space travel.
6. To enrich life on Earth through people living and working in space.
7. The history of research, technology, and spaceflight missions focused on

HISTORICAL BACKGROUND

In the United States, five major programs preceded the current Space Shuttle and International Space Station activities: Mercury, Gemini, Apollo, Skylab, and the Shuttle-Mir (denoted as phase I of ISS). The goals and objectives of these programs are briefly reviewed. Then the milestone EVAs of history are recounted. The Soviets/Russians accomplished many firsts in human spaceflight underseven main programs, namely, Sputnik, Vostok, Voskhod, Soyuz (Soyuz and Kosmos launches), Lunar (Zond and Kosmos launches), Salyut, and Mir

Mercury

1. Project Mercury was the United States’ first human space program, initiated in
2. 1958 and completed in 1963. The Mercury program goal was to demonstrate that
3. humans could survive in space. The objectives of the program, which culminated
4. in six human spaceflights between 1961 and 1963, were
5. To orbit a human-occupied spacecraft around Earth.
6. To investigate a human’s ability to function in space.
7. To recover both the crew and spacecraft safely

Gemini

1. Project Gemini, the second U.S. human space program, was announced in January1962.
2. The name comes from the two-person crew, Gemini,for the third constellation of the Zodiac and its twin stars, Castor and Pollux. Gemini involved 12flights, including two flight tests of the equipment without crew.
3. Between March1965 and November 1966, the United States flew 10 Gemini two-person spacecraft.

Apollo

I believe this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to Earth. No single space project in this period will be more impressive to [hu]mankind, or more important in the long-range exploration of space; and none will be so difficult or expensive to accomplish. (John F. Kennedy, Special Joint Session of Congress, May 25, 1961)

Skylab

Skylab provided the United States' first experimental space station. Designed for long duration mission, Skylab program objectives were twofold: to prove that humans could live and work in space for extended periods and to expand our knowledge of solar astronomy well beyond Earth-based observations. Successful in all respects despite early mechanical difficulties, three three -person crews occupied the Skylab workshop for a total of 171 days, 13 h. It was the site of nearly 300 scientific and technical experiments: medical experiments on humans' adaptability to microgravity, solar observations, and detailed Earth resources experiments. The empty Skylab spacecraft returned to Earth on July 11, 1979,scattering debris over the Indian Ocean and a bit of western Australia [109].

APOLLO-SOYUZ

A remarkable joint mission was undertaken by the Americans and Russians in1975, namely, the Apollo-Soyuz Test Project (ASTP). The mission started with the Russian Soyuz launch on July 15, 1975, followed by the U.S. Apollo launch on the same day. The mission lasted 9 days, and docking in space of the two craft occurred on July 17 with the Soyuz and Apollo spacecraft docked for 2 days while the crews exchanged visits and conducted joint operations

The Space Shuttle

The Space Shuttle is a significant part of human space exploration. Standing as one of NASA's foremost projects, the Shuttle has accomplished many tasks that have enhanced the quality of life on Earth. The Space Shuttle is the world's first reusable spacecraft and the first U.S. vehicle having a standard sea-level atmospheric pressure and composition. Mercury, Gemini, and Apollo all operated at 33.4 kPa (5 lb/in2 or 0.33 atm) pressure and 100 percent oxygen composition.

International Space Station

The International Space Station will offer a world-class research laboratory in low Earth orbit. Once assembled, the ISS will afford scientists, engineers, and entrepreneurs an unprecedented platform on which to perform complex,long duration,and repeatable experiments in the unique environment of space. The ISS's invaluable assets include prolonged exposure to microgravity and the presenceof human experimenters in the research process. Yet the ISS is much more than just a world-class laboratory in a novel environment; it is an international human experiment—an exciting "city in space"—a place where we will learn how to live and work "off planet" in an international way [113].

The primary purposes for the ISS are to serve as

1. An advanced test bed for technology and human exploration.
2. A world-class research facility.
3. A commercial platform for space research and development

Extra Vehicular Activity

Human space exploration is epitomized by space walks, or extravehicular activity. In March of 1965, cosmonaut Alexei Leonov became the first human to walk in space. Attached to a 5 m long umbilical that supplied him with air and communications, Leonov floated free of the Voskhod spacecraft for more than 10min. In June of the same year, Edward White became the first U.S. astronaut to egress his spacecraft while in orbit. White performed his spectacular space walk during the third orbit of the Gemini–Titan 4 flight.

SPACESUIT DESIGN

The current Space Shuttle EVA system, known as the Extravehicular Mobility Unit or EMU, consists of a spacesuit assembly (SSA), an integrated life support system (LSS), and the EMU support equipment. The SSA is a 29.6 kPa (4.3lb/in2), 100 percent oxygen spacesuit made of multiple fabric layers attached to an aluminum/fiberglass hard upper torso unit (known as the HUT). The SSA retains the oxygen pressure required for breathing and ventilation and protects the crew member against bright sunlight and temperature extremes

Russian Eva Spacesuit

1. The current spacesuit used for Mir space station EVAs is a derivative of the semi rigid suit used during the Salyut–Soyuz program. The Orlan spacesuit has undergone continuous modification and is a fifth-generation model currently used for EVA operations.
2. Similar to the American EMU, the Orlan spacesuit has an integrated life support system to enable EVA operations from Mir. As previously stated, the 100 percent oxygen spacesuit nominally operates at 40.6 kPa(5.88 lb/in2).
3. The spacesuit weighs approximately 70 kg (154 lb) [121], but that is only suit weight without a fully charged PLSS. It is an adjustable, universally sized suit with a metal upper torso and fabric arms and legs. Metal ball bearings and sizing adjustments are notable suit features.

Life Support Systems

1. In examining some of the normal physiological and potentially adverse aspects of human spaceflight, one need only peruse the list of human requirements given in the previous sections and speculate on the effects of partial or complete system failures.
2. Life support functions fall into two categories: non regenerative and regenerative, where the amount of system closure is denoted as ranging from open loop to closed loop. In an open-loop life support system, matter continuously flows in and out of the system. Air, water, and oxygen are supplied from stored sources.

THANK YOU