Introduction to Aviation

Topic Objective:

At the end of this topic student would be able to:

- Elements of aerospace engineering
- The basis of these elements

Definition/Overview:

Aerospace engineering: Aerospace engineering is the branch of engineering behind the design, construction and science of aircraft and spacecraft. Aerospace engineering has broken into two major branches, aeronautical engineering and astronautical engineering. The former deals with craft that stay within Earth's atmosphere, and the latter deals with craft that operates outside of Earth's atmosphere. While "aeronautical" was the original term, the broader "aerospace" has superseded it in usage, as flight technology advanced to include craft operating in outer space. Aerospace engineering is often informally called rocket science. Modern flight vehicles undergo severe conditions such as differences in atmospheric pressure and temperature, or heavy structural load applied upon vehicle components. Consequently, they are usually the products of various technologies including aerodynamics, avionics, materials science and propulsion. These technologies are collectively known as aerospace engineering. Because of the complexity of the field, aerospace engineering is conducted by a team of engineers, each specializing in their own branches of science., The development and manufacturing of a flight vehicle demands careful balance and compromise between abilities, performance, available technology and costs. One person who was important in developing aviation was Alberto Santos Dumont, a pioneer who built the first machines that were able to fly. Some of the first ideas for powered flight may have come from Leonardo da Vinci, who, although he did not build any successful models, did develop many sketches and ideas for "flying machines".

Orville and Wilbur Wright flew the Wright Flyer I, the first airplane, on December 17, 1903 at Kitty Hawk, North Carolina. The origin of aerospace engineering can be traced back to the aviation pioneers around the late 19th century to early 20th centuries, although the work of Sir George Cayley has recently been dated as being from the last decade of the 18th century. Early knowledge of aeronautical engineering was largely empirical with some concepts and skills imported from other branches of engineering. Scientists understood some key elements of aerospace engineering, like fluid dynamics, in the 18th century. Only a decade after the successful flights by the Wright brothers, the 1910s saw the development of aeronautical engineering through the design of World War I military aircraft. The first definition of aerospace engineering appeared in February 1958. The definition considered the Earth's atmosphere and the outer space as a single realm, thereby encompassing both aircraft (*aero*) and spacecraft (*space*) under a newly coined word *aerospace*. The National Aeronautics and Space Administration was founded in 1958 as a response to the Cold War. United States aerospace engineers sent the American first satellite launched on January 31, 1958 in response the USSR launching Sputnik.

Key Points:

1. **Some of the elements of aerospace engineering are**

- Fluid mechanics - the study of fluid flow around objects. Specifically aerodynamics concerning the flow of air over bodies such as wings or through objects such as wind tunnels (see also lift and aeronautics).
- Astrodynamics - the study of orbital mechanics including prediction of orbital elements when given a select few variables. While few schools in the United States teach this at the undergraduate level, several have graduate programs covering this topic (usually in conjunction with the Physics department of said college or university).
- Statics and Dynamics (engineering mechanics) - the study of movement, forces, moments in mechanical systems.
- Mathematics - because aerospace engineering heavily involves mathematics.
- Electrotechnology - the study of electronics within engineering.
- Propulsion - the energy to move a vehicle through the air (or in outer space) is provided by internal combustion engines, jet engines and turbomachinery, or rockets (see also propeller and spacecraft propulsion). A more recent addition to this module is electric propulsion.

- Control engineering - the study of mathematical modelling of the dynamic behavior of systems and designing them, usually using feedback signals, so that their dynamic behavior is desirable (stable, without large excursions, with minimum error). This applies to the dynamic behavior of aircraft, spacecraft, propulsion systems, and subsystems that exist on aerospace vehicles.
- Aircraft structures - design of the physical configuration of the craft to withstand the forces encountered during flight. Aerospace engineering aims to keep structures lightweight.
- Materials science - related to structures, aerospace engineering also studies the materials of which the aerospace structures are to be built. New materials with very specific properties are invented, or existing ones are modified to improve their performance.
- Solid mechanics - Closely related to material science is solid mechanics which deals with stress and strain analysis of the components of the vehicle. Nowadays there are several Finite Element programs such as MSC Patran/Nastran which aid engineers in the analytical process.
- Aeroelasticity - the interaction of aerodynamic forces and structural flexibility, potentially causing flutter, divergence, etc.
- Avionics - the design and programming of computer systems on board an aircraft or spacecraft and the simulation of systems.
- Risk and reliability - the study of risk and reliability assessment techniques and the mathematics involved in the quantitative methods.
- Noise control - the study of the mechanics of sound transfer.
- Flight test - designing and executing flight test programs in order to gather and analyze performance and handling qualities data in order to determine if an aircraft meets its design and performance goals and certification requirements.

2. **The basis of most of these elements**

The basis of most of these elements lies in theoretical mathematics, such as fluid dynamics for aerodynamics or the equations of motion for flight dynamics. However, there is also a large empirical component. Historically, this empirical component was derived from testing of scale models and prototypes, either in wind tunnels or in the free atmosphere. More recently, advances in computing have enabled the use of computational fluid dynamics to simulate the behavior of fluid, reducing time and expense spent on wind-tunnel testing.

Additionally, aerospace engineering addresses the integration of all components that constitute an aerospace vehicle (subsystems including power, communications, thermal control, life support, etc.) and its life cycle (design, temperature, pressure, radiation, velocity, life time).

Topic Objective:

At the end of this topic student would be able to:

- The aviation system
- Aerodynamics
- Aircraft engines
- Flight mechanics
- Aircraft structures
- Aircraft systems

Definition/Overview:

Aeronautics: Aeronautics is the science involved with the study, design, and manufacture of flight-capable machines, or the techniques of operating aircraft. While the termliterally meaning "sailing the air"originally referred solely to the science of operating the aircraft, it has since been expanded to include technology, business and other aspects related to aircraft. One of the significant parts in aeronautics is a branch of physical science called aerodynamics, which deals with the motion of air and the way that it interacts with objects in motion, such as an aircraft. Aviation is a term sometimes used interchangeably with aeronautics, although "aeronautics" includes lighter-than-air craft such as airships, while "aviation" does not. Before scientific investigation of aeronautics started, people started thinking of ways to fly. In a Greek legend, Icarus and his father Daedalus built wings of feathers and wax and flew out of a prison. Icarus flew too close to the sun, the wax melted, and he fell in the sea and drowned. When people started to scientifically study how to fly, people began to understand the basics of air and aerodynamics. One of the earliest scientists to study aeronautics was Leonardo da Vinci.

Leonardo studied the flight of birds in developing engineering schematics for some of the earliest flying machines in the late fifteenth century AD. His schematics, however, such as the ornithopter ultimately failed as practical aircraft. The flapping machines that he designed were either too small to generate sufficient lift, or too heavy for a human to operate. Although the ornithopter continues to be of interest to hobbyists, it was replaced by the glider in the 19th century.

Key Points:

The aviation system

Aviation refers to activities involving man-made flying devices (aircraft), including the people, organizations, and regulatory bodies involved with them.

1. **Aerodynamics**

Aerodynamics is a branch of dynamics concerned with studying the motion of air, particularly when it interacts with a moving object. Aerodynamics is closely related to fluid dynamics and gas dynamics, with much theory shared between them. Aerodynamics is often used synonymously with gas dynamics, with the difference being that gas dynamics applies to all gases. Understanding the motion of air (often called a flow field) around an object enables the calculation of forces and moments acting on the object. Typical properties calculated for a flow field include velocity, pressure, density and temperature as a function of position and time. By defining a control volume around the flow field, equations for the conservation of mass, momentum, and energy can be defined and used to solve for the properties. The use of aerodynamics through mathematical analysis, empirical approximation and wind tunnel experimentation form the scientific basis for heavier-than-air flight.

Aerodynamic problems can be identified in a number of ways. The flow environment defines the first classification criterion. External aerodynamics is the study of flow around solid objects of various shapes. Evaluating the lift and drag on an airplane, the shock waves that form in front of the nose of a rocket or the flow of air over a hard drive head are examples of external aerodynamics. Internal aerodynamics is the study of flow through passages in solid objects. For instance, internal aerodynamics encompasses the study of the airflow through a jet engine or through an air conditioning pipe. The ratio of the problem's characteristic flow speed to the speed of sound comprises a second classification of aerodynamic problems. A problem is called subsonic if all the speeds in the problem are less than the speed of sound, transonic if speeds both below and above the speed of sound are present (normally when the characteristic speed is approximately the speed of sound), supersonic when the characteristic flow speed is greater than the speed of sound, and hypersonic when the flow speed is much greater than the speed of sound. Aerodynamicists disagree over the precise definition of hypersonic flow; minimum Mach numbers for hypersonic flow range from 3 to 12. The influence of viscosity in the flow dictates a third classification. Some problems involve only negligible viscous effects on the solution, in which case viscosity can be considered to be nonexistent. The approximations to these problems are called inviscid flows. Flows for which viscosity cannot be neglected are called viscous flows.

2. **Aircraft engines**

An aircraft engine is a propulsion system for an aircraft. Aircraft engines are almost always either lightweight piston engines or gas turbines. This article is an overview of the basic types of aircraft engines and the design concepts employed in engine development for aircraft.

3. **Flight mechanics**

Aircraft flight mechanics are relevant to gliders, helicopters and airplanes.

An Airplane (Airplane in US usage), is defined as: a power-driven heavier than air aircraft, deriving its lift chiefly from aerodynamic reactions on surface which remain fixed under given conditions of flight. (ICAO Document 9110)

4. **Aircraft structures**

Structural design is of critical importance to aircraft safety, but also plays a key role in aircraft cost and performance. Apart from that aircraft structures are a particular example of combining design tools, fabrication techniques, and specific materials to create more highly optimized physical structures. Structural technology has always been a key driver for aircraft advancement. The use by Chanute and the Wright Brothers of the braced box concept instead of the earlier, bird-like structural design approach was one of the factors that made manned flight possible, and the use of stressed- skin metal construction (such as the DC-3) made the commercial transport a viable economic proposition. Structural technology has a primary influence on aircraft empty weight, which directly drives purchase price and operating cost, as well as influencing range and payload.

5. **Aircraft systems**

At present, the increase in demand for air transport outstrips the rate of progress in technology advancement and this adds to pressure for improvement in sustainability performance that faces the air transport sector. Stretching environmental technology goals exist in Europe and the US but achievement of these goals will not offset the increase in growth, especially in the emerging markets. Manufacturers continue to invest heavily in researching and developing new technologies but progress is relatively slow. Safety is paramount and introducing new designs, materials and structures carries risk. Strong pressures exist already to drive for improved fuel efficiency and CO_2 improvement and public concerns about noise and air quality push industry either through international regulation or local rules. Omega experts are helping to inform future developments by examining the impacts associated with different technologies, linking technology models with climate impact assessments and exploring the barriers to introducing new technologies. We are also considering the potential for disruptive technologies that may offer longer-term step change advances. In these ways the partnership can support and hasten the quest for better environmental technologies and spur the debate with knowledge on impacts that eases decision-making. Advancing technology solutions is central to the environmental performance of the aviation sector. Omegas academic experts are working with manufacturers and Government to identify and examine medium-term and blue skies radical technologies and the environmental pathways that will speed their introduction.

Topic Objective:

At the end of this topic student would be able to:

- Temperature and layers
- Pressure and thickness
- Composition
- ppmv
- Heterosphere
- Density and mass
- Opacity
- Scattering
- Absorption
- Emission
- Circulation
- Evolution of Earth's Atmosphere
- Air pollution

Definition/Overview:

Atmosphere: Atmosphere is a layer of gases surrounding the planet Earth and retained by the Earth's gravity. It contains roughly (by molar content/volume) 78.08% nitrogen, 20.95% oxygen, 0.93% argon, 0.038% carbon dioxide; trace amounts of other gases, and a variable amount (average around 1%) of water vapor. This mixture of gases is commonly known as air. The atmosphere protects life on Earth by absorbing ultraviolet solar radiation and reducing temperature extremes between day and night. There is no definite boundary between the atmosphere and outer space. It slowly becomes thinner and fades into space. Three quarters of the atmosphere's mass is within 11 km of the planetary surface. In the United States, people who travel above an altitude of 80.5 km (50 statute miles) are designated astronauts. An altitude of 120 km (~75 miles or 400,000 ft) marks the boundary where atmospheric effects become noticeable during re-entry. The Krmn line, at 100 km (62 miles or 328,000 ft), is also frequently regarded as the boundary between atmosphere and outer space.

Key Points:

1. Temperature and layers

The temperature of the Earth's atmosphere varies with altitude; the mathematical relationship between temperature and altitude varies among five different atmospheric layers (ordered highest to lowest, the ionosphere is part of the thermosphere):

1.1. Exosphere

From 5001,000 km (310620 mi) up to 10,000 km (6,200 mi), contain free-moving particles that may migrate into and out of the magnetosphere or the solar wind.

1.2. Exobase

Also known as the *critical level*, it is the lower boundary of the exosphere.

1.3. Ionosphere

The part of the atmosphere that is ionized by solar radiation stretches from 50 to 1,000 km (31 to 620 mi) and typically overlaps both the exosphere and the thermosphere. It plays an important part in atmospheric electricity and forms the inner edge of the magnetosphere. Because of its charged particles, it has practical importance because it influences, for example, radio propagation on the Earth. It is responsible for auroras.

1.4. Thermopause

The boundary above the thermosphere, it varies in height from 5001,000 km (310620 mi).

1.5. Thermosphere

From 8085 km (5053 mi; 260,000280,000 ft) to over 640 km (400 mi; 2,100,000 ft), temperature increasing with height. Although the temperature can rise to 1,500 C (2,730 F), a person would not feel warm because of the extreme low pressure. The International Space Station orbits in this layer, between 320 and 380 km (200 and 240 mi).

1.6. Mesopause

The temperature minimum at the boundary between the thermosphere and the mesosphere. It is the coldest place on Earth, with a temperature of −100 C (−148.0 F; 173.1 K).

1.7. Mesosphere

From the Greek word "μέσος" meaning middle. The mesosphere extends from about 50 km (31 mi; 160,000 ft) to the range of 8085 km (5053 mi; 260,000280,000 ft). Temperature decreases with height, reaching −100 C (−148.0 F; 173.1 K) in the upper mesosphere. This is also where most meteors burn up when entering the atmosphere.

1.8. Stratopause

The boundary between the mesosphere and the stratosphere, typically 50 to 55 km (31 to 34 mi; 160,000 to 180,000 ft). The pressure here is 1/1000th sea level.

1.9. Ozone Layer

Though part of the Stratosphere, the ozone layer is considered as a layer of the Earth in itself due to the fact that its physical and chemical composition is far different to the Stratosphere. Ozone in the earth's stratosphere is created by ultraviolet light striking oxygen molecules containing two oxygen atoms (O_2), splitting them into individual oxygen atoms (atomic oxygen); the atomic oxygen then combines with unbroken O_2 to create ozone, O_3. The ozone molecule is also unstable (although, in the stratosphere, long-lived) and when ultraviolet light hits ozone it splits into a molecule of O_2 and an atom of atomic oxygen, a continuing process called the ozone-oxygen cycle, thus creating an ozone layer in the stratosphere, the region from about 10 to 50 km (33,000 to 160,000 ft) above Earth's surface. About 90% of the ozone in our atmosphere is contained in the stratosphere. Ozone concentrations are greatest between about 20 and 40 km (66,000 and 130,000 ft), where they range from about 2 to 8 parts per million.

1.10. Troposphere

From the greek word "τρέπω" meaning to turn or change. The troposphere is the lowest layer of the atmosphere; it begins at the surface and extends to between 7 km (23,000 ft) at the poles and 17 km (56,000 ft) at the equator, with some variation due to weather factors. The troposphere has a great deal of vertical mixing because of solar heating at the area. This heating makes air masses less dense so they rise. When an air mass rises, the pressure upon it decreases so it expands, doing work against the opposing pressure of the surrounding air. To do work is to expend energy, so the temperature of the air mass decreases. As the temperature decreases, water vapor in the air mass may condense or solidify, releasing latent heat that further uplifts the air mass. This process determines the maximum rate of decline of temperature with height, called the adiabatic lapse rate. The troposphere contains roughly 80% of the total mass of the atmosphere. Fifty percent of the total mass of the atmosphere is located in the lower 5.6 km (18,000 ft) of the troposphere.

2. Pressure and thickness

The average atmospheric pressure, at sea level, is about 101.3 kilopascals (14.69 psi); total atmospheric mass is 5.148010^{18} kg (1.13510^{19} lb). Atmospheric pressure is a direct result of the total weight of the air above the point at which the pressure is measured. Air pressure varies with location and time, because the amount (and weight) of air above the earth varies with location and time. However, the *average* mass of the air above a square meter of the Earth's surface can be calculated from the total amount of air and the surface area of the Earth. The total air mass is 5148.0 teratonnes and area is 51007.2 megahectares. Thus 5148.0/510.072 = 10.093 tones (9.934 LT; 11.126 ST) per square meter or 14.356 pounds per square inch (98.98 kPa). This is about 2.5% below the officially standardized unit atmosphere (1 atm) of 101.325 kPa or 14.696 psi, and corresponds to the mean pressure not at sea level, but at the mean base of the atmosphere as contoured by the Earth's terrain. Were atmospheric density to remain constant with height the atmosphere would terminate abruptly at 7.81 km (25,600 ft). Instead, density decreases with height, dropping by 50% at an altitude of about 5.6 km (18,000 ft). For comparison the highest mountain, Mount Everest, is higher, at 8.8 km (29,000 ft), so air is less than half as dense at the summit as at sea level. This is why it is so difficult to climb without supplemental oxygen. This pressure drop is approximately exponential, so that pressure decreases by approximately half every 5.6 km (18,000 ft) and by 63.2% ($1 - 1 / e = 1 - 0.368 = 0.632$) every 7.64 km (25,100 ft), the average scale height of Earth's atmosphere below 70 km (43 mi; 230,000 ft). However, because of changes in temperature, average molecular weight, and gravity throughout the atmospheric column, the dependence of atmospheric pressure on altitude is modeled by separate equations for each of the layers listed above. Even in the exosphere, the atmosphere is still present. This can be seen by the effects of atmospheric drag on satellites. In summary, the equations of pressure by altitude in the above references can be used directly to estimate atmospheric thickness. However, the following published data are given for reference:

- 50% of the atmosphere by mass is below an altitude of 5.6 km (18,000 ft).
- 90% of the atmosphere by mass is below an altitude of 16 km (52,000 ft). The common altitude of commercial airliners is about 10 km (33,000 ft) and Mt. Everest's summit is 8,848 m (29,030 ft) above sea level.

- 99.99997% of the atmosphere by mass is below 100 km (62 mi; 330,000 ft). The highest X-15 plane flight in 1963 reached an altitude of 354,300 ft (108.0 km). Therefore, most of the atmosphere (99.9997%) is below 100 km (62 mi; 330,000 ft), although in the rarefied region above this there are auroras and other atmospheric effects.

3. Composition

Filtered air includes trace amounts of many of the chemical elements. Substantial amounts of argon, nitrogen, and oxygen are present as elementary gases. Note the major greenhouse gasses: water vapor, carbon dioxide, methane, nitrous oxide, and ozone. Many additional elements from natural sources may be present in tiny amounts in an unfiltered air sample, including contributions from dust, pollen and spores, sea spray, vulcanism, and meteoroids. Various industrial pollutants are also now present in the air, such as chlorine (elementary or in compounds), fluorine (in compounds), elementary mercury, and sulfur (in compounds such as sulfur dioxide [SO_2]).

COMPOSITION OF DRY ATMOSPHERE, BY VOLUME	
PPMV: parts per million by volume	
Gas	**Volume**
Nitrogen (N_2)	780,840 ppmv (78.084%)
Oxygen (O_2)	209,460 ppmv (20.946%)
Argon (Ar)	9,340 ppmv (0.9340%)
Carbon dioxide (CO_2)	383 ppmv (0.0383%)

Neon (Ne)	18.18 ppmv (0.001818%)
Helium (He)	5.24 ppmv (0.000524%)
Methane (CH_4)	1.745 ppmv (0.0001745%)
Krypton (Kr)	1.14 ppmv (0.000114%)
Hydrogen (H_2)	0.55 ppmv (0.000055%)
Nitrous oxide (N_2O)	0.3 ppmv (0.00003%)
Xenon (Xe)	0.09 ppmv ($9x10^{-6}$%)
Ozone (O_3)	0.0 to 0.07 ppmv (0%-$7x10^{-6}$%)
Nitrogen dioxide (NO_2)	0.02 ppmv ($2x10^{-6}$%)
Iodine (I)	0.01 ppmv ($1x10^{-6}$%)
Carbon monoxide (CO)	trace
Ammonia (NH_3)	trace
Not included in above dry atmosphere:	
Water vapor (H_2O)	~0.40% over full atmosphere, typically 1%-4% at surface

4. ppmv

The *parts per million by volume* figures above are by volume-fraction (V%), which for ideal gases is equal to mole-fraction (that is, the fraction of total molecules). Although the atmosphere is not an ideal gas, nonetheless the atmosphere behaves enough like an ideal gas that the volume-fraction is the same as the mole-fraction for the precision given.

By contrast, *mass-fraction* abundances of gases will differ from the volume values. The mean molar mass of air is 28.97 g/mol, while the molar mass of helium is 4.00, and krypton is 83.80. Thus helium is 5.2 ppm by *volume-fraction*, but 0.72 ppm by *mass-fraction* ([4/29] 5.2 = 0.72), and krypton is 1.1 ppm by *volume-fraction*, but 3.2 ppm by *mass-fraction* ([84/29] 1.1 = 3.2).

5. Heterosphere

Below the *turbopause*, at an altitude of about 100 km (62 mi; 330,000 ft) (not far from the mesopause), the Earth's atmosphere has a more-or-less uniform composition (apart from water vapor) as described above; this constitutes the *homosphere*. However, above the turbopause, the Earth's atmosphere begins to have a composition which varies with altitude. This is because, in the absence of mixing, the density of a gas falls off exponentially with increasing altitude but at a rate which depends on the molar mass. Thus higher mass constituents, such as oxygen and nitrogen, fall off more quickly than lighter constituents such as helium and hydrogen. Thus there is a layer, called the *heterosphere*, in which the Earth's atmosphere has varying composition. The precise altitude of the heterosphere and the layers it contains varies significantly with temperature.

6. Density and mass

The density of air at sea level is about 1.2 kg/m^3 (1.2 g/L). Natural variations of the barometric pressure occur at any one altitude as a consequence of weather. This variation is relatively small for inhabited altitudes but much more pronounced in the outer atmosphere and space because of variable solar radiation. The atmospheric density decreases as the altitude increases. This variation can be approximately modeled using the barometric formula. More sophisticated models are used by meteorologists and space agencies to predict weather and orbital decay of satellites. The average mass of the atmosphere is about 5 quadrillion metric tons or 1/1,200,000 the mass of Earth. According to the National Center for Atmospheric Research, "The total mean mass of the atmosphere is 5.148010^{18} kg with an annual range due to water vapor of 1.2 or 1.510^{15} kg depending on whether surface pressure or water vapor data are used; somewhat smaller than the previous estimate. The mean mass of water vapor is estimated as 1.2710^{16} kg and the dry air mass as 5.1352 0.000310^{18} kg."

7. Opacity

Solar radiation (or sunlight) is the energy the Earth receives from the Sun. The Earth also emits radiation back into space, but at longer wavelengths that we cannot see. Depending on its condition, the atmosphere can block radiation from coming in or going out. Important examples of this are clouds and the greenhouse effect.

8. Scattering

When light passes through our atmosphere, photons interact with it through *scattering*. If the light does not interact with the atmosphere, it is called *direct radiation* and is what you see if you were to look directly at the sun. *Indirect radiation* is light that has been scattered in the atmosphere. For example, on an overcast day when you can't see your shadow there is no direct radiation reaching you, it has all been scattered. As another example, due to a phenomenon called Rayleigh scattering, shorter (blue) wavelengths scatter more easily than longer (red) wavelengths. This is why the sky looks blue, you are seeing scattered blue light. This is also why sunsets are red. Because the sun is close to the horizon, the sun rays pass through more atmosphere than normal to reach your eye. All of the blue light has been scattered out, leaving the red light in a sunset.

9. Absorption

Absorption is another important property of the atmosphere. Different molecules absorb different wavelengths of radiation. For example, O_2 and O_3 absorb almost all wavelengths shorter than 300 nanometers. Water (H_2O) absorbs many wavelengths above 700 nm, but this depends on the amount of water vapor in the atmosphere. When a molecule absorbs a photon, it increases the energy of the molecule. We can think of this as heating the atmosphere, but the atmosphere also cools by emitting radiation, as discussed below.

When you combine the absorption spectra of the gasses in the atmosphere, you are left with "windows" of low opacity, allowing the transmission of only certain bands of light. The optical window runs from around 300 nm (ultraviolet-C) up into the range humans can see, the visible spectrum (commonly called light), at roughly 400700 nm and continues to the infrared to around 1100 nm. There are also infrared and radio windows that transmit some infrared and radio waves at longer wavelengths. For example, the radio window runs from about one centimeter to about eleven-meter waves.

10. Emission

Emission is the opposite of absorption; it is when an object emits radiation. Objects tend to emit amounts and wavelengths of radiation depending on their "black body" emission curves, therefore hotter objects tend to emit more radiation at shorter wavelengths. Colder objects emit less radiation at longer wavelengths. For example, the sun is approximately 6,000 K (5,730 C; 10,340 F), its radiation peaks near 500 nm, and is visible to the human eye. The Earth is approximately 290 K (17 C; 62 F), so its radiation peaks near 10,000 nm, and is much too long to be visible by humans. Because of its temperature, the atmosphere emits infrared radiation. For example, on clear nights the Earth's surface cools down faster than on cloudy nights. This is because clouds (H_2O) are strong absorbers and emitters of infrared radiation. This is also why it becomes colder at night at higher elevations. The atmosphere acts as a "blanket" to limit the amount of radiation the Earth loses into space. The *greenhouse effect* is directly related to this absorption and emission (or "blanket") effect. Some chemicals in the atmosphere absorb and emit infrared radiation, but do not interact with sunlight in the visible spectrum. Common examples of these chemicals are CO_2 and H_2O. If there are too much of these *greenhouse gasses*, sunlight heats the Earth's surface, but the gasses block the infrared radiation from exiting back to space. This imbalance causes the Earth to warm, and thus climate change.

11. Circulation

Atmospheric circulation is the large-scale movement of air, and the means (with ocean circulation) by which heat is distributed on the surface of the Earth.

The large-scale structure of the atmospheric circulation varies from year to year, but the basic structure remains fairly constant. However, individual weather systems - midlatitude depressions or tropical convective cells - occur "randomly". It is accepted that weather cannot be predicted beyond a fairly short limit; perhaps a month in theory, or about ten days in practice (see Chaos theory and Butterfly effect). Nonetheless, the average of these systems (the climate) is stable over longer periods of time.

12. Evolution of Earth's Atmosphere

The history of the Earth's atmosphere prior to one billion years ago is poorly understood; it is an active area of scientific research. The following discussion presents a plausible scenario. The modern atmosphere is sometimes referred to as Earth's "third atmosphere", in order to distinguish the current chemical composition from previous compositions. The original atmosphere was primarily helium and hydrogen. Heat from the still-molten crust, the sun, and a probably enhanced solar wind, dissipated this atmosphere. About 4.4 billion years ago, the surface had cooled enough to form a crust. It was heavily populated with volcanoes which released steam, carbon dioxide, and ammonia. This led to the early "second atmosphere", which was primarily carbon dioxide and water vapor, with some nitrogen but virtually no oxygen. This second atmosphere had approximately 100 times as much gas as the current atmosphere, but as it cooled much of the carbon dioxide was dissolved in the seas and precipitated out as carbonates. The later "second atmosphere" contained largely nitrogen and carbon dioxide. However, simulations run at the University of Waterloo and University of Colorado in 2005 suggest that it may have had up to 40% hydrogen. It is generally believed that the greenhouse effect, caused by high levels of carbon dioxide and methane, kept the Earth from freezing.

One of the earliest types of bacteria was the cyanobacteria, which formed into colonies called stromatolites. Fossil evidence indicates that bacteria shaped like these existed approximately 3.3 billion years ago and were the first oxygen-producing evolving phototropic organisms. They were responsible for the initial conversion of the earth's atmosphere from an anoxic state to an oxic state (that is, from a state without oxygen to a state with oxygen) during the period 2.7 to 2.2 billion years ago. Being the first to carry out oxygenic photosynthesis, they were able to produce oxygen while sequestering carbon dioxide in organic molecules, playing a major role in oxygenating the atmosphere. This is often referred to as the *Oxygen Catastrophe*. The increase in the concentration of oxygen in the atmosphere required time because iron and other elements in the Earth's crust reacted with oxygen, removing it from the atmosphere. Photosynthesizing plants later evolved and continued releasing oxygen and sequestering carbon dioxide. Over time, excess carbon became locked in fossil fuels, sedimentary rocks (notably limestone), and animal shells. As oxygen was released, it reacted with ammonia to release nitrogen. Bacteria also converted ammonia into nitrogen, but most of the nitrogen currently in the atmosphere resulted from sunlight-powered photolysis of ammonia released steadily over the aeons from volcanoes. As more plants appeared, the levels of oxygen increased significantly, while carbon dioxide levels dropped. At first the oxygen combined with various elements, but eventually oxygen accumulated in the atmosphere, contributing to Cambrian explosion and further evolution. With the appearance of an ozone layer (ozone is an allotrope of oxygen) lifeforms were better protected from ultraviolet radiation. This oxygen-nitrogen atmosphere is the "third atmosphere". Between 200 and 250 million years ago, up to 35% of the atmosphere was oxygen (as found in bubbles of ancient atmosphere preserved in amber). This modern atmosphere has a composition which is enforced by oceanic blue-green algae as well as geological processes. O_2 does not remain naturally free in an atmosphere but tends to be consumed by inorganic chemical reactions, and by animals, bacteria, and even land plants at night. CO_2 tends to be produced by respiration and decomposition and oxidation of organic matter. Due to this, O_2 would vanish within a few million years by chemical reactions, and CO_2 dissolves in water and would be gone in millennia if not replaced. Both are maintained by biological productivity and geological forces seemingly working hand-in-hand to maintain reasonably steady levels over millions of years. Currently, anthropogenic greenhouse gases are increasing in the atmosphere and this is a causative factor in global warming.

13. Air pollution

Air pollution is the human introduction of chemicals, particulate matter, or biological materials that cause harm or discomfort to organisms, into the atmosphere. Stratospheric ozone depletion is believed to be caused by air pollution (chiefly from chlorofluorocarbons). Worldwide, air pollution is responsible for large numbers of deaths and respiratory disease. Enforced air quality standards, like the Clean Air Act in the United States, have reduced the presence of some pollutants. While major stationary sources are often identified with air pollution, the greatest source of emissions is actually mobile sources, principally the automobile. Gases such as carbon dioxide, methane, and fluorocarbons contribute to global warming, and these gases, or excess amounts of some emitted from fossil fuel burning, have recently been identified by the United States and many other countries as pollutants.

In Section 2 of this course you will cover these topics: Basic Aerodynamics Airfoils, Wings, And Other Aerodynamics Shapes
You may take as much time as you want to complete the topic coverd in section 2. There is no time limit to finish any Section, However you must finish All Sections before semester end date.
If you want to continue remaining courses later, you may save the course and leave. You can continue later as per your convenience and this course will be avalible in your area to save and continue later.

Topic Objective:

At the end of this topic student would be able to:

- Continuity assumption

- Laws of Conservation
- Incompressible aerodynamics
- Subsonic flow
- Compressible aerodynamics
- Transonic flow
- Supersonic flow
- Hypersonic flow
- Associated terminology
- Boundary layers
- Turbulence
- Aerodynamics in other fields

Definition/Overview:

Aerodynamics: Aerodynamics is a branch of dynamics concerned with studying the motion of air, particularly when it interacts with a moving object. Aerodynamics is closely related to fluid dynamics and gas dynamics, with much theory shared between them. Aerodynamics is often used synonymously with gas dynamics, with the difference being that gas dynamics applies to all gases. Understanding the motion of air (often called a flow field) around an object enables the calculation of forces and moments acting on the object. Typical properties calculated for a flow field include velocity, pressure, density and temperature as a function of position and time. By defining a control volume around the flow field, equations for the conservation of mass, momentum, and energy can be defined and used to solve for the properties. The use of aerodynamics through mathematical analysis, empirical approximation and wind tunnel experimentation form the scientific basis for heavier-than-air flight. Aerodynamic problems can be identified in a number of ways. The flow environment defines the first classification criterion. External aerodynamics is the study of flow around solid objects of various shapes. Evaluating the lift and drag on an airplane, the shock waves that form in front of the nose of a rocket or the flow of air over a hard drive head are examples of external aerodynamics. Internal aerodynamics is the study of flow through passages in solid objects. For instance, internal aerodynamics encompasses the study of the airflow through a jet engine or through an air conditioning pipe. The ratio of the problem's characteristic flow speed to the speed of sound comprises a second classification of aerodynamic problems. A problem is called subsonic if all the speeds in the problem are less than the speed of sound, transonic if speeds both below and above the speed of sound are present (normally when the characteristic speed is approximately the speed of sound), supersonic when the characteristic flow speed is greater than the speed of sound, and hypersonic when the flow speed is much greater than the speed of sound. Aerodynamicists disagree over the precise definition of hypersonic flow; minimum Mach numbers for hypersonic flow range from 3 to 12. Most aerodynamicists use numbers between 5 and 8. The influence of viscosity in the flow dictates a third classification. Some problems involve only negligible viscous effects on the solution, in which case viscosity can be considered to be nonexistent. The approximations to these problems are called inviscid flows. Flows for which viscosity cannot be neglected are called viscous flows. Images and stories of flight have appeared throughout recorded history, with perhaps the most noted of these being the story of Icarus and Daedalus. Although observations of some aerodynamic effects like wind resistance (a.k.a. drag) were recorded by the likes of Aristotle and Galileo Galilei, very little effort was made to develop governing laws for understanding the nature of flight prior to the 17th century.

Key Points:

1. Continuity assumption

Gases are composed of molecules which collide with one another and solid objects. If density and velocity are taken to be well-defined at infinitely small points, and are assumed to vary continuously from one point to another, the discrete molecular nature of a gas is ignored.
The continuity assumption becomes less valid as a gas becomes more rarefied. In these cases, statistical mechanics is a more valid method of solving the problem than aerodynamics.

2. Laws of Conservation

Aerodynamic problems are often solved using conservation laws as applied to a fluid continuum. In many basic problems, three conservation principles are used:

- Continuity: If a certain mass of fluid enters a volume, it must either exit the volume or change the mass inside the volume.

- Conservation of Momentum: Application of Newton's second law of motion to a continuum.
- Conservation of Energy: Although energy can be converted from one form to another, the total energy in a given system remains constant.

3. Incompressible aerodynamics

An incompressible flow is characterized by a constant density despite flowing over surfaces or inside ducts. A flow can be considered incompressible as long as its speed is low. For higher speeds, the flow will begin to compress as it comes into contact with surfaces. The Mach number is used to distinguish between incompressible and compressible flows.

4. **Subsonic flow**

Subsonic (or low-speed) aerodynamics is the study of inviscid, incompressible and irrotational aerodynamics where the differential equations used are a simplified version of the governing equations of fluid dynamics.. It is a special case of subsonic aerodynamics. In solving a subsonic problem, one decision to be made by the aerodynamicist is whether to incorporate the effects of compressibility. Compressibility is a description of the amount of change of density in the problem. When the effects of compressibility on the solution are small, the aerodynamicist may choose to assume that density is constant. The problem is then an incompressible low-speed aerodynamics problem. When the density is allowed to vary, the problem is called a compressible problem. In air, compressibility effects are usually ignored when the Mach number in the flow does not exceed 0.3 (about 335 feet per second or 228 miles per hour or 102 meters per second at 60^{o}F). Above 0.3, the problem should be solved using compressible aerodynamics.

5. Compressible aerodynamics

According to the theory of aerodynamics, a flow is considered to be compressible if its change in density with respect to pressure is non-zero along a streamline. This means that - unlike incompressible flow - changes in density must be considered. In general, this is the case where the Mach number in part or all of the flow exceeds 0.3. The Mach .3 value is rather arbitrary, but it is used because gas flows with a Mach number below that value demonstrate changes in density with respect to the change in pressure of less than 5%. Furthermore, that maximum 5%

density change occurs at the stagnation point of an object immersed in the gas flow and the density changes around the rest of the object will be significantly lower. Transonic, supersonic, and hypersonic flows are all compressible.

6. Transonic flow

The term Transonic refers to a range of velocities just below and above the local speed of sound (generally taken as Mach 0.81.2). It is defined as the range of speeds between the critical Mach number, when some parts of the airflow over an aircraft become supersonic, and a higher speed, typically near Mach 1.2, when all of the airflow is supersonic. Between these speeds some of the airflow is supersonic, and some is not.

7. Supersonic flow

Supersonic aerodynamic problems are those involving flow speeds greater than the speed of sound. Calculating the lift on the Concorde during cruise can be an example of a supersonic aerodynamic problem. Supersonic flow behaves very differently from subsonic flow. Fluids react to differences in pressure; pressure changes are how a fluid is "told" to respond to its environment. Therefore, since sound is in fact an infinitesimal pressure difference propagating through a fluid, the speed of sound in that fluid can be considered the fastest speed that "information" can travel in the flow. This difference most obviously manifests itself in the case of a fluid striking an object. In front of that object, the fluid builds up a stagnation pressure as impact with the object brings the moving fluid to rest. In fluid traveling at subsonic speed, this pressure disturbance can propagate upstream, changing the flow pattern ahead of the object and giving the impression that the fluid "knows" the object is there and is avoiding it. However, in a supersonic flow, the pressure disturbance cannot propagate upstream. Thus, when the fluid finally does strike the object, it is forced to change its properties -- temperature, density, pressure, and Mach number -- in an extremely violent and irreversible fashion called a shock wave. The presence of shock waves, along with the compressibility effects of high-velocity (see Reynolds number) fluids, is the central difference between supersonic and subsonic aerodynamics problems.

8. Hypersonic flow

In aerodynamics, hypersonic speeds are speeds that are highly supersonic. In the 1970s, the term generally came to refer to speeds of Mach 5 (5 times the speed of sound) and above. The hypersonic regime is a subset of the supersonic regime. Hypersonic flow is characterized by high temperature flow behind a shock wave, viscous interaction, and chemical dissociation of gas.

9. Associated terminology

The incompressible and compressible flow regimes produce many associated phenomena, such as boundary layers and turbulence.

10. Boundary layers

The concept of a boundary layer is important in many aerodynamic problems. The viscosity and fluid friction in the air is approximated as being significant only in this thin layer. This principle makes aerodynamics much more tractable mathematically.

11. Turbulence

In aerodynamics, turbulence is characterized by chaotic, stochastic property changes in the flow. This includes low momentum diffusion, high momentum convection, and rapid variation of pressure and velocity in space and time. Flow that is not turbulent is called laminar flow.

12. Aerodynamics in other fields

Aerodynamics is important in a number of applications other than aerospace engineering. It is a significant factor in any type of vehicle design, including automobiles. It is important in the prediction of forces and moments in sailing. It is used in the design of large components such as hard drive heads. Structural engineers also use aerodynamics, and particularly aeroelasticity, to calculate wind loads in the design of large buildings and bridges. Urban aerodynamics seeks to help town planners and designers improve comfort in outdoor spaces, create urban microclimates and reduce the effects of urban pollution. The field of environmental aerodynamics studies the ways atmospheric circulation and flight mechanics affect ecosystems. The aerodynamics of internal passages is important in heating/ventilation, gas piping, and in automotive engines where detailed flow patterns strongly affect the performance of the engine.

Topic Objective:

At the end of this topic student would be able to:

- Airfoil terminology
- Thin airfoil theory
- Derivation of thin airfoil theory

Definition/Overview:

Airfoil: An airfoil-shaped body moved through a fluid produces a force perpendicular to the motion called lift. Subsonic flight airfoils have a characteristic shape with a rounded leading edge, followed by a sharp trailing edge, often with asymmetric camber. Airfoils designed with water as the working fluid are also called hydrofoils. A fixed-wing aircraft's wings, horizontal, and vertical stabilizers are built with airfoil-shaped cross sections, as are helicopter rotor blades. Airfoils are also found in propellers, fans, compressors and turbines. Sails are also airfoils, and the underwater surfaces of sailboats, such as the centerboard and keel, are similar in cross-section and operate on the same principles as airfoils. Swimming and flying creatures and even many plants and sessile organisms employ airfoils; common examples being bird wings, the bodies of fishes, and the shape of sand dollars. An airfoil-shaped wing can create downforce on an automobile or other motor vehicle, improving traction. Any object with an angle of attack in a moving fluid, such as a flat plate, a building, or the deck of a bridge, will generate an aerodynamic force (called lift) perpendicular to the flow. Airfoils are more efficient lifting shapes, able to generate more lift (up to a point), and to generate lift with less drag.

Key Points:

1. Airfoil terminology

- The *mean camber line* is a line drawn midway between the upper and lower surfaces.

- The *chord line* is a straight line connecting the leading and trailing edges of the airfoil, at the ends of the mean camber line.
- The *chord* is the length of the chord line and is the characteristic dimension of the airfoil section.
- The *maximum thickness* and the location of maximum thickness are expressed as a percentage of the chord.
- For symmetrical airfoils both *mean camber line* and *chord line* pass from centre of gravity of the airfoil and they touch at leading and trailing edge of the airfoil.
- The *aerodynamic center* is the chord wise length about which the pitching moment is independent of the lift coefficient and the angle of attack.
- The *center of pressure* is the chord wise location about which the pitching moment is zero.

2. Thin airfoil theory

Thin airfoil theory is a simple theory of airfoils that relates angle of attack to lift. It was devised by German mathematician Max Munk and further refined by British aerodynamicist Hermann Glauert and others in the 1920s. The theory idealizes the flow around an airfoil as two-dimensional flow around a thin airfoil. It can be imagined as addressing an airfoil of zero thickness and infinite wingspan. Thin airfoil theory was particularly notable in its day because it provided a sound theoretical basis for the following important properties of airfoils in two-dimensional flow:

- on a symmetric airfoil, the center of pressure lies exactly one quarter of the chord behind the leading edge
- on a cambered airfoil, the aerodynamic center lies exactly one quarter of the chord behind the leading edge
- the slope of the lift coefficient versus angle of attack line is units per radian

As a consequence of (3), the section lift coefficient of a symmetric airfoil of infinite wingspan is:

where is the section lift coefficient, is the angle of attack in radians, measured relative to the chord line. (The above expression is also applicable to a cambered airfoil where is the angle of attack measured relative to the zero-lift line instead of the chord line.) Also as a consequence of (3), the section lift coefficient of a cambered airfoil of infinite wingspan is:

where is the section lift coefficient when the angle of attack is zero. Thin airfoil theory does not account for the stall of the airfoil which usually occurs at an angle of attack between 10 and 15 for typical airfoils.

3. Derivation of thin airfoil theory

The airfoil is modeled as a thin lifting mean-line (camber line). The mean-line, y(x), is considered to produce a distribution of vorticity γ(*s*) along the line, s. By the Kutta condition, the vorticity is zero at the trailing edge. Since the airfoil is thin, x (chord position) can be used instead of s, and all angles can be approximated as small.

From the Biot-Savart law, this vorticity produces a flow field *w*(*s*) where

where x is the location at which induced velocity is produced, x' is the location of the vortex element producing the velocity and c is the chord length of the airfoil. Since there is no flow normal to the curved surface of the airfoil, w(x) balances that from the component of main flow V which is locally normal to the plate the main flow is locally inclined to the plate by an angle α − *dy* / *dx*. That is

This integral equation can by solved for γ(*x*), after replacing x by , as a Fourier series in $A_n sin(n\theta)$ with a modified lead term $A_0(1 + cos(\theta)) / sin(\theta)$ That is

(These terms are known as the Glauert integral). The coefficients are given by and By the KuttaJoukowski theorem, the total lift force F

is proportional to and its moment M about the leading edge to

The calculated Lift coefficient depends only on the first two terms of the

Fourier series, as The moment M about the leading edge depends only

on A_0,A_1 and A_2 , as

The moment about the 1/4 chord point will thus be, .

From this it follows that the center of pressure is aft of the 'quarter-chord' point 0.25 c, by

The aerodynamic center, AC, is at the quarter-chord point.

The AC is where the pitching moment M' does not *vary* with angle of attack, i.e.

- In Section 3 of this course you will cover these topics:
  - Elements Of Airplane Performance
  - Principles Of Stability And Control

- You may take as much time as you want to complete the topic coverd in section 3.
There is no time limit to finish any Section, However you must finish All Sections before semester end date.

- If you want to continue remaining courses later, you may save the course and leave.
You can continue later as per your convenience and this course will be avalible in your area to save and continue later.

Topic Objective:

At the end of this topic student would be able to:

- A hot air balloon in flight
- Aeroplanes wing configuration.
- Seaplanes and Floatplanes
- Rotorcraft, or rotary-wing aircraft
- Helicopters
- Autogyros or gyroplanes
- Gyrodynes
- Compound rotorcraft
- Other methods of lift

Definition/Overview:

Aeroplanes: Aeroplanes or airplanes are technically called fixed-wing aircraft.
The forerunner of the aeroplane is the kite. A kite depends upon the tension between the cord which anchors it to the ground and the force of the wind currents. Kites were the first kind of aircraft to fly, and were invented in China around 500 BC. Much aerodynamic research was done with kites before test aircraft, wind tunnels and computer modelling programs became available.

Key Points:

1. A hot air balloon in flight

Aerostats use buoyancy to float in the air in much the same way that ships float on the water. They are characterized by one or more large gasbags or canopies, filled with a relatively low density gas such as helium, hydrogen or hot air, which is less dense than the surrounding air. When the weight of this is added to the weight of the aircraft structure, it adds up to the same weight as the air that the craft displaces. Small hot air balloons called sky lanterns date back to the 3rd century BC and were only the second type of aircraft to fly, the first being kites. Originally a "balloon" was any aerostat, while the term "airship" was used for large powered aircraft designsusually fixed-wingthough none had yet been built. The advent of powered balloons, called dirigible balloons, and later of rigid hulls allowing a great increase in size, began to change the way these words were used. Huge powered aerostats, characterized by a rigid outer framework and separate aerodynamic skin surrounding the gas bags, were produced, the

Zeppelins being the largest and most famous. There were still no aeroplanes or non-rigid balloons large enough to be called airships, so "airship" came to be synonymous with these monsters. Then several accidents, such as the Hindenburg disaster in 1937, led to the demise of these airships. Nowadays a balloon is an unpowered aerostat, whilst an airship is a powered one. A powered, steerable aerostat is called a dirigible. Sometimes this term is applied only to non-rigid balloons, and sometimes dirigible balloon is regarded as the definition of an airship (which may then be rigid or non-rigid). Non-rigid dirigibles are characterized by a moderately aerodynamic gasbag with stabilizing fins at the back. These soon became known as blimps. During the Second World War, this shape was widely adopted for tethered balloons; in windy weather this both reduces the strain on the tether and stabilizes the balloon. The nickname blimp was adopted along with the shape. In modern times any small dirigible or airship is called a blimp, though a blimp may be unpowered as well as powered. Heavier than airaerodynes Heavier-than-air aircraft must find some way to push air or gas downwards, so that a reaction occurs (by Newton's laws of motion) to push the aircraft upwards. This dynamic movement through the air is the origin of the term aerodyne. There are two ways to produce dynamic upthrust: aerodynamic lift, and powered lift in the form of engine thrust. Aerodynamic lift is the most common, with aeroplanes being kept in the air by the forward movement of wings, and rotorcraft by spinning wing-shaped rotors sometimes called rotary wings. A wing is a flat, horizontal surface, usually shaped in cross-section as an aerofoil. To fly, the wing must move forwards through the air; this movement of air over the aerofoil shape deflects air downward to create an equal and opposite upward force, called lift, according to Newton's third law of motion. A flexible wing is a wing made of fabric or thin sheet material, often stretched over a rigid frame. A kite is tethered to the ground and relies on the speed of the wind over its wings, which may be flexible or rigid, fixed or rotary. With powered lift, the aircraft directs its engine thrust vertically downwards. The initialism VTOL (vertical takeoff and landing) is applied to aircraft that can take off and land vertically. Most are rotorcraft. Others, such as the Hawker Siddeley Harrier, take off and land vertically using powered lift and transfer to aerodynamic lift in steady flight. Similarly, STOL stands for short take off and landing. Some VTOL aircraft often operate in a short take off/vertical landing regime known as STOVL.A pure rocket is not usually regarded as an aerodyne, because it does not depend on the air for its lift (and can even fly into space), however many aerodynamic lift vehicles have been powered or assisted by rocket motors. Rocket-powered missiles which obtain aerodynamic lift at very high speed due to airflow over their bodies are a marginal case.

2. Aeroplanes wing configuration.

In a conventional configuration, the main wings are placed in front of a smaller *stabilizer* surface or *tailplane*. The canard reverses this, placing a small *foreplane* stabilizer forward of the wings, near the nose of the aircraft. Canards are becoming more common as supersonic aerodynamics grows more mature and because the forward surface contributes lift during straight-and-level flight. The tandem wing type has two wings of similar size, one at the front and one at the back. In a tailless design, the lift and horizontal control surfaces are combined. The ultimate expression of this is the flying wing, where there is no central fuselage, and perhaps even no separate vertical control surface (e.g., the B-2 Spirit). Sometimes two or more wings are stacked one above the other. A biplane has two wings and a triplane three, while quadruplanes (four) and above have been tried but have never been successful. Up until the 1930s, biplanes were the most common. Triplanes were only occasionally made, especially for a brief period during the First World War due to their high manoeuvrability as fighters. Since the Second World War, most aeroplanes have been monoplanes. A sesquiplane is similar to a biplane, but with the lower wing much reduced in size. A monoplane has only one wing. Monoplanes are further classified as high-wing, mid-wing or low-wing according to where on the fuselage the wing is attached, or parasol wing if the wing passes above the fuselage. Most multi-plane designs are braced, with struts and/or wires holding the wings in place. Some monoplanes, especially early designs, are also braced, because this allows a much lighter weight than a clean, unbraced cantilever design. But bracing causes a large amount of drag at higher speeds, so it has not been used for faster designs since the 1930s. Most low-speed aeroplanes have a straight wing, which may be constant-chord, or tapered so that it decreases in chord towards the tip. For flight near or above the speed of sound, a swept wing is usually used, where the wing angles backwards towards the tips. A notable variation is the delta wing, which is shaped like a triangle: the leading edge is sharply swept, but the trailing edge is straight; one common form is the cropped delta, which merges into the *tapered swept* category, and an especially graceful form is the double-curved ogival delta found for example on Concorde. Another variation is the crescent wing, seen for example on the Handley Page Victor, which is sharply swept inboard, with reduced sweep for the outboard section. A variable-geometry wing, or swing-wing, can change the angle of sweep in flight. It has been employed in a few examples of combat aircraft, the first production type being the General Dynamics F-111. An feature on some swept wings is a leading-edge root extension (LERX) at the wing root, which if greatly extended forward becomes a chine, as seen in the Lockheed SR-71 Blackbird. Other planforms have been experimented with, including reverse taper, forward sweep, M-wing and W-wing which reverse sweep half way along, annular and circular.

3. Seaplanes and **Floatplanes**

Seaplanes and Floatplanes differ in that a seaplane has the bottom of its fuselage shaped hydrodynamically and it sits directly on the water when at rest, while a floatplane has two or more floats attached below the rest of the aircraft so that the fuselage remains clear of the water at all times. Some people consider wing-in-ground-effect vehicles to be aeroplanes, others do not. These craft "fly" close to the surface of the ground or water. An example is the Russian ekranoplan also nicknamed the "Caspian Sea Monster". Man-powered aircraft also rely on ground effect to remain airborne, but this is only because they are so underpowered - the airframe is theoretically capable of flying much higher. (Hovercraft are not considered to be aircraft, since they rely wholly on the pressure of air on the ground beneath, and have no aerodynamic lifting surface).

4. Rotorcraft, or rotary-wing aircraft

Rotorcraft, or rotary-wing aircraft, use a spinning rotor with aerofoil section blades (a *rotary wing*) to provide lift. Types include helicopters, autogyros and various hybrids such as gyrodynes and compound rotorcraft.

5. Helicopters

Helicopters have powered rotors. The rotor is driven (directly or indirectly) by an engine and pushes air downwards to create lift. By tilting the rotor forwards, the downwards flow is tilted backwards, producing thrust for forward flight.

6. Autogyros or gyroplanes

Autogyros or gyroplanes have unpowered rotors, with a separate power plant to provide thrust. The rotor is tilted backwards. As the autogyro moves forward, air blows upwards through it, making it spin.(cf. Autorotation)

This spinning dramatically increases the speed of airflow over the rotor, to provide lift. Juan de la Cierva (a Spanish civil engineer) used the product name *autogiro*, and Bensen used *gyrocopter*. Rotor kites, such as the Focke Achgelis Fa 330 are unpowered autogyros, which must be towed by a tether to give them forward ground speed or else be tether-anchored to a static anchor in a high-wind situation for kited flight.

7. Gyrodynes

Gyrodynes are a form of helicopter, where forward thrust is obtained from a separate propulsion device rather than from tilting the rotor. The definition of a 'gyrodyne' has changed over the years, sometimes including equivalent autogyro designs. The most important characteristic is that in forward flight air does not flow significantly either up or down through the rotor disc but primarily across it. The Heliplane is a similar idea.

8. Compound rotorcraft

Compound rotorcraft has wings which provide some or all of the lift in forward flight. Compound helicopters and compound autogyros have been built, and some forms of gyroplane may be referred to as compound gyroplanes. Tiltrotor aircraft (such as the V-22 Osprey) have their rotors horizontal for vertical flight, and pivot the rotors vertically like a propeller for forward flight. The Coleopter had a cylindrical wing forming a duct around the rotor. On the ground it sat on its tail, and took off and landed vertically like a helicopter. The whole aircraft would then have tilted forward to fly as a propeller-driven aeroplane using the duct as a wing (though this transition was never achieved in practice.)

Some rotorcraft have reaction-powered rotors with gas jets at the tips, but most have one or more lift rotors powered from engine-driven shafts.

9. Other methods of lift

- A lifting body is the opposite of a flying wing. In this configuration the aircraft body is shaped to produce lift. If there are any wings, they are too small to provide all the lift. Lifting bodies are not efficient: the aircraft must travel at high speed to generate enough lift to fly. The most famous lifting body design is the Space Shuttle, while some supersonic missiles obtain lift from the airflow over a tubular body.
- Powered lifts rely entirely on engine thrust to hold them up in the air. There are few practical applications. Experimental designs have been built for personal fan-lift hover platforms and jetpacks or for VTOL research (for example the flying bedstead). VTOL jet aircraft such as the Harrier jump-jet take off and land vertically in powered-lift configuration, then transition to conventional configuration for forward flight.
- The Fan Wing is a recent innovation and represents a completely new class of aircraft. This uses a fixed wing with a cylindrical fan mounted span wise just above. As the fan spins, it creates airflow backwards over the upper surface of the wing, creating lift. The fan wing is (2005) in development in the United Kingdom.

Some types of aircraft, such as balloons, kites and gliders, do not have any propulsion. Balloons drift with the wind, though normally the pilot can control the altitude either by heating the air or by releasing ballast, giving some directional control (since the wind direction changes with altitude). A wing-shaped hybrid balloon can glide directionally when rising or falling; but a spherically-shaped balloon does not have such directional control. Flying with Gravity

Kites are tethered to the ground or other object (fixed or mobile) or other means that maintains tension in the kite line; and rely on virtual or real wind blowing over and under them to generate lift and drag. Kytoons are balloon kites that are shaped and tethered to obtain kiting deflections, and can be lighter-than-air, neutrally buoyant, or heavier-than air.

Gliders gain their initial flying speed from some launch mechanism, and then gain additional energy from gravity and from updrafts such as thermal currents. Takeoff may be by launching forwards and downwards from a high location, or by pulling into the air on a towline, by a ground-based winch or vehicle, or by a powered "tug" aircraft. For a glider to maintain its forward air speed and lift, it must descend in relation to the air (but not necessarily in relation to the ground). The first practical, controllable example was designed and built by the British scientist and pioneer George Cayley who is universally recognized as the first aeronautical engineer.

Topic Objective:

At the end of this topic student would be able to:

- Composition of Gases
- Subsonic flow
- Transonic flow
- Hypersonic flow
- Associated terminology
- Boundary layers
- Turbulence
- Aerodynamics in other fields
- Sources of Routing Information
- Local Interface Information
- Static routes
- Installing Unicast Routes

Definition/Overview:

Control: In routing, the control plane is the part of the router architecture that is concerned with drawing the network map or the information in a (possibly augmented) routing table that defines what to do with incoming packets. Control plane functions, such as participating in routing protocols, run in the architectural control element. In most cases, the routing table will contain a list of destination addresses and the outgoing interface(s) associated with them. Control plane logic also can define certain packets to be discarded, as well as preferential treatment of certain packets for which a high quality of service is defined by such mechanisms as differentiated services. Depending on the specific router implementation, there may be a separate Forwarding Information Base that is populated (i.e., loaded) by the Control Plane, but used by the Forwarding Plane to look up packets, at very high speed, and decide how to handle them. A major function of the control plane is deciding which routes go into the main routing table. "Main" refers to the table that holds the unicast routes that are active. If the router also does multicast routing, there may be an additional routing table for multicast routes. Several routing protocols such as OSPF and BGP maintain internal data bases of candidate routes that they will promote if a route fails or routing policy is changed. Several different information sources may provide information on a route to a given destination, but the router must select the "best" route to install into the routing table. In some cases, there may be multiple routes of equal "quality", and the router may install all of them and load-share across them.

Key Points:

1. **Composition of Gases**

Gases are composed of molecules which collide with one another and solid objects. If density and velocity are taken to be well-defined at infinitely small points, and are assumed to vary continuously from one point to another, the discrete molecular nature of a gas is ignored. The continuity assumption becomes less valid as a gas becomes more rarefied. In these cases, statistical mechanics is a more valid method of solving the problem than aerodynamics. Aerodynamic problems are solved using the conservation laws, or equations derived from the conservation laws. In aerodynamics, three conservation laws are used:

- Conservation of mass: Matter is not created or destroyed. If a certain mass of fluid enters a volume, it must either exit the volume or increase the mass inside the volume. In a steady-state process mass cannot accumulate inside the volume and this law is expressed in the continuity equation.
- Conservation of momentum: Also called Newton's third law of motion. The initial momentum (mass times velocity) of a system must equal the final momentum of the system.
- Conservation of energy: Although it can be converted from one form to another, the total energy in a given system remains constant.

An incompressible flow is characterized by a constant density despite flowing over surfaces or inside ducts. A flow can be considered incompressible as long as its speed is low. For higher speeds, the flow will begin to compress as it comes into contact with surfaces. The Mach number is used to distinguish between incompressible and compressible flows.

2. Subsonic flow

Subsonic (or low-speed) aerodynamics is the study of inviscid, incompressible and irrotational aerodynamics where the differential equations used are a simplified version of the governing equations of fluid dynamics. It is a special case of subsonic aerodynamics. In solving a subsonic problem, one decision to be made by the aerodynamicist is whether to incorporate the effects of compressibility. Compressibility is a description of the amount of change of density in the problem. When the effects of compressibility on the solution are small, the aerodynamicist may choose to assume that density is constant. The problem is then an incompressible low-speed aerodynamics problem. When the density is allowed to vary, the problem is called a compressible problem. In air, compressibility effects are usually ignored when the Mach number in the flow does not exceed 0.3 (about 335 feet per second or 228 miles per hour or 102 meters per second at 60^{o}F). Above 0.3, the problem should be solved using compressible aerodynamics. According to the theory of aerodynamics, a flow is considered to be compressible if its change in density with respect to pressure is non-zero along a streamline. In short, this means that, unlike incompressible flow, changes in density must be considered. In general, this is the case where the Mach number in part or all of the flow exceeds 0.3. The Mach .3 value is rather arbitrary, but it is used because gas flows with a Mach number below that value demonstrate changes in density with respect to the change in pressure of less than 5%. Furthermore, that maximum 5% density change occurs at the stagnation point of an object immersed in the gas flow and the density changes around the rest of the object will be significantly lower. Transonic, supersonic, and hypersonic flows are all compressible.

3. Transonic flow

The term Transonic refers to a range of velocities just below and above the local speed of sound (generally taken as Mach 0.81.2). It is defined as the range of speeds between the critical Mach number, when some parts of the airflow over an aircraft become supersonic, and a higher speed, typically near Mach 1.2, when all of the airflow is supersonic. Between these speeds some of the airflow is supersonic, and some is not.

Supersonic aerodynamic problems are those involving flow speeds greater than the speed of sound. Calculating the lift on the Concorde during cruise can be an example of a supersonic aerodynamic problem. Supersonic flow behaves very differently from subsonic flow. Fluids react to differences in pressure; pressure changes are how a fluid is "told" to respond to its environment. Therefore, since sound is in fact an infinitesimal pressure difference propagating through a fluid, the speed of sound in that fluid can be considered the fastest speed that "information" can travel in the flow. This difference most obviously manifests itself in the case of a fluid striking an object. In front of that object, the fluid builds up a stagnation pressure as impact with the object brings the moving fluid to rest. In fluid traveling at subsonic speed, this pressure disturbance can propagate upstream, changing the flow pattern ahead of the object and giving the impression that the fluid "knows" the object is there and is avoiding it. However, in a supersonic flow, the pressure disturbance cannot propagate upstream. Thus, when the fluid finally does strike the object, it is forced to change its properties -- temperature, density, pressure, and Mach number -- in an extremely violent and irreversible fashion called a shock wave. The presence of shock waves, along with the compressibility effects of high-velocity (see Reynolds number) fluids, is the central difference between supersonic and subsonic aerodynamics problems.

4. Hypersonic flow

In aerodynamics, hypersonic speeds are speeds that are highly supersonic. In the 1970s, the term generally came to refer to speeds of Mach 5 (5 times the speed of sound) and above. The hypersonic regime is a subset of the supersonic regime. Hypersonic flow is characterized by high temperature flow behind a shock wave, viscous interaction, and chemical dissociation of gas.

5. Associated terminology

The incompressible and compressible flow regimes produce many associated phenomena, such as boundary layers and turbulence.

6. Boundary layers

The concept of a boundary layer is important in many aerodynamic problems. The viscosity and fluid friction in the air is approximated as being significant only in this thin layer. This principle makes aerodynamics much more tractable mathematically.

7. Turbulence

In aerodynamics, turbulence is characterized by chaotic, stochastic property changes in the flow. This includes low momentum diffusion, high momentum convection, and rapid variation of pressure and velocity in space and time. Flow that is not turbulent is called laminar flow.

8. Aerodynamics in other fields

Aerodynamics is important in a number of applications other than aerospace engineering. It is a significant factor in any type of vehicle design, including automobiles. It is important in the prediction of forces and moments in sailing. It is used in the design of large components such as hard drive heads. Structural engineers also use aerodynamics, and particularly aeroelasticity, to calculate wind loads in the design of large buildings and bridges. Urban aerodynamics seeks to help town planners and designers improve comfort in outdoor spaces, create urban microclimates and reduce the effects of urban pollution. The field of environmental aerodynamics studies the ways atmospheric circulation and flight mechanics affect ecosystems. The aerodynamics of internal passages is important in heating/ventilation, gas piping, and in automotive engines where detailed flow patterns strongly affect the performance of the engine.

9. Sources of Routing Information

There are three general sources of routing information:

- Information on the status of directly connected hardware and software-defined interfaces
- Manually configured static routes
- Information from (dynamic) routing protocols

10. Local Interface Information

Routers forward traffic that enters on an input interface and leaves on an output interface, subject to filtering and other local rules. While routers usually forward from one physical (e.g., Ethernet, serial) to another physical interface, it is also possible to define multiple logical interfaces on a physical interface. A physical Ethernet interface, for example, can have logical interfaces in several virtual LANs defined by IEEE 802.1q VLAN headers.

When an interface has an address configured in a subnet, such as 192.0.2.1 in the 192.0.2.0/24 (i.e., subnet mask 255.255.255.0) subnet, and that interface is considered "up" by the router, the router thus has a directly connected route to 192.0.2.0/24. If a routing protocol offered another router's route to that same subnet, the routing table installation software will normally ignore the dynamic route and prefer the directly connected route.

There also may be software-only interfaces on the router, which it treats as if they were locally connected. For example, most implementations have a "null" software-defined interface. Packets having this interface as a next hop will be discarded, which can be a very efficient way to filter traffic. Routers usually can route traffic faster than they can examine it and compare it to filters, so, if the criterion for discarding is the packet's destination address, "blackholing" the traffic will be more efficient than explicit filters.

Other software defined interfaces that are treated as directly connected, as long as they are active, are interfaces associated with tunneling protocols such as generic routing encapsulation (GRE) or Multi-Protocol Label Switching (MPLS).

11. Static routes

Router configuration rules may contain static routes. A static route minimally has a destination address, a prefix length or subnet mask, and a definition where to send packets for the route. That definition can refer to a local interface on the router, or a next-hop address that could be on the far end of a subnet to which the router is connected. The next-hop address could also be on a subnet that is directly connected, and, before the router can determine if the static route is usable, it Gases must do a recursive lookup of the next hop address in the local routing table. If the next-hop address is reachable, the static route is usable, but if the next-hop is unreachable, the route is ignored.

Static routes also may have preference factors used to select the best static route to the same destination. One application is called a floating static route, where the static route is less preferred than a route from any routing protocol. The static route, which might use a dialup link or other slow medium, activates only when the dynamic routing protocol(s) cannot provide a route to the destination.

Static routes that are more preferred than any dynamic route also can be very useful, especially when using traffic engineering principles to make certain traffic go over a specific path with an engineered quality of service.

12. Installing Unicast Routes

Different implementations have different sets of preferences for routing information, and these are not standardized among IP routers. It is fair to say that subnets on directly connected active interfaces are always preferred. Beyond that, however, there will be differences.

Implementers generally have a numerical preference, which Cisco calls an "administrative distance", for route selection. The lower the preference, the more desirable the route. Cisco's IOS implementation makes exterior BGP the most preferred source of dynamic routing information, while Nortel RS makes intra-area OSPF most preferred.

The general order of selecting routes to install is:

- If the route is not in the routing table, install it.
- If the route is "more specific" than an existing route, install it in addition to the existing routes. "More specific" means that it has a longer prefix. A /28 route, with a subnet mask of 255.255.255.240, is more specific than a /24 route, with a subnet mask of 255.255.255.0.
- If the route is of equal specificity to a route already in the routing table, but comes from a more preferred source of routing information, replace the route in the table.
- If the route is of equal specificity to a route in the routing table, comes from a source of the same preference,
    - Discard it if the route has a higher metric than the existing route
    - Replace the existing route if the new route has a lower metric
    - If the routes are of equal metric and the router supports load-sharing, add the new route and designate it as part of a load-sharing group.

In Section 4 of this course you will cover these topics: Space Flight (Astronautics) Propulsion
You may take as much time as you want to complete the topic coverd in section 4. There is no time limit to finish any Section, However you must finish All Sections before semester end date.
If you want to continue remaining courses later, you may save the course and leave. You can continue later as per your convenience and this course will be avalible in your area to save and continue later.

Topic Objective:

At the end of this topic student would be able to:

- Reaching space
- Sub-orbital spaceflight
- Orbital spaceflight
- Direct ascent
- Reentry and landing/splashdown
- Landing
- Recovery
- Expendable launch systems
- Reusable launch systems
- Space disasters
- Space weather

Definition/Overview:

Spaceflight: Spaceflight is the use of space technology to fly a spacecraft into and through outer space. Spaceflight is used in space exploration, and also in commercial activities like space tourism and satellite telecommunications. Additional non-commercial uses of spaceflight include space observatories, reconnaissance satellites and other earth observation satellites. A spaceflight typically begins with a rocket launch, which provides the initial thrust to overcome the force of gravity and propels the spacecraft from the surface of the Earth. Once in space, the motion of a spacecraft -- both when unpropelled and when under propulsion -- is covered by the area of study called astrodynamics. Some spacecraft remain in space indefinitely, some disintegrate during atmospheric reentry, and others reach a planetary or lunar surface for landing or impact. The realistic proposal of space travel goes back to Konstantin Tsiolkovsky. His most famous work, (The Exploration of Cosmic Space by Means of Reaction Devices), was published in 1903, but this theoretical work was not widely influential outside of Russia. 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 Rocket, on a test flight on October 3, 1942. On October 4, 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.

Key Points:

1. Reaching space

The most commonly used definition of outer space is everything beyond the Krmn line, which is 100 kilometers (62 mi) above the Earth's surface. (The United States sometimes defines outer space as everything beyond 50 miles (80 km) in altitude.) In order for a projectile to reach outer space from the surface, it needs a minimum delta-v. This velocity is much lower than escape velocity. It is possible, indeed routine, for a spacecraft to leave a celestial body without reaching the surface escape velocity of a body by propelling itself after take-off. However, it is more fuel-efficient for a craft to burn its fuel close to the ground as possible, keeping escape velocity a consideration.

2. 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 (70,746 mi) before reentering the Earth's atmosphere 43 hours after launch. On May 17, 2004, Civilian Space eXploration Team launched the GoFast Rocket on a suborbital flight, the first amateur spaceflight. On June 21, 2004, SpaceShipOne was used for the first privately-funded human spaceflight.

3. Orbital spaceflight

A minimal orbital spaceflight requires 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 as important as altitude. In order to perform a stable and lasting flight in space, the spacecraft must reach the minimal orbital speed required for a closed orbit.

4. Direct ascent

Achieving a closed orbit is not essential to interplanetary voyages, for which spacecraft need to reach escape velocity. Early Russian space vehicles successfully achieved very high altitudes without going into orbit. In its early Apollo mission planning NASA considered using a direct ascent to the moon, but abandoned that idea later due to weight considerations. Many robotic space probes to the outer planets use direct ascent -- they do not orbit the earth before departing.

However, plans for future human spaceflight often include final vehicle assembly in Earth orbit, such as the America's Project Orion and Russia's Kliper/Parom tandom.

5. Reentry and landing/splashdown

Vehicles in orbit have large amounts of kinetic energy. This energy must be discarded if the vehicle is to land safely without vaporizing in the atmosphere. Typically this process requires special methods to protect against aerodynamic heating. The theory behind reentry is due to Harry Julian Allen. Based on this theory, reentry vehicles present blunt shapes to the atmosphere for reentry. Blunt shapes mean that less than 1% of the kinetic energy ends up as heat that reaches the vehicle and the heat energy instead ends up in the atmosphere.

6. Landing

The Mercury, Gemini, and Apollo capsules all landed in the sea. These capsules were designed to land at relatively slow speeds. Russian capsules for Soyuz make use of braking rockets as were designed to touch down on land. The Space Shuttle glides into a touchdown at high speed.

7. Recovery

After a successful landing the spacecraft, its occupants, and cargo can be recovered. In some cases, recovery has occurred before landing: while a spacecraft is still descending on its parachute, it can be snagged by a specially designed aircraft. This was the technique used to recover the film canisters from the Corona spy satellites.

8. Expendable launch systems

All current spaceflight except NASA's Space Shuttle and the SpaceX Falcon 1 use multi-stage expendable launch systems to reach space.

9. Reusable launch systems

The first reusable spacecraft, the X-15, was air-launched on a suborbital trajectory on July 19, 1963. The first partially reusable orbital spacecraft, the Space Shuttle, was launched by the USA on the 20th anniversary of Yuri Gagarin's flight, on April 12, 1981. During the Shuttle era, six orbiters were built, all of which have flown in the atmosphere and five of which have flown in space. The *Enterprise* was used only for approach and landing tests, launching from the back of a Boeing 747 and gliding to deadstick landings at Edwards AFB, California. The first Space Shuttle to fly into space was the *Columbia*, followed by the *Challenger*, *Discovery*, *Atlantis*, and *Endeavour*. The *Endeavour* was built to replace the *Challenger* when it was lost in January 1986. The *Columbia* broke up during reentry in February 2003. The first (and so far only) automatic partially reusable spacecraft was the Buran (Snowstorm), launched by the USSR on November 15, 1988, although it made only one flight. This spaceplane was designed for a crew and strongly resembled the U. S. Space Shuttle, although its drop-off boosters used liquid propellants and its main engines were located at the base of what would be the external tank in the American Shuttle. Lack of funding, complicated by the dissolution of the USSR, prevented any further flights of Buran. Per the Vision for Space Exploration, the Space Shuttle is due to be retired in 2010 due mainly to its old age and high cost of the program reaching over a billion dollars per flight. The Shuttle's human transport role is to be replaced by the partially reusable Crew Exploration Vehicle (CEV) no later than 2014. The Shuttle's heavy cargo transport role is to be replaced by expendable rockets such as the Evolved Expendable Launch Vehicle (EELV) or a Shuttle Derived Launch Vehicle.

Scaled Composites SpaceShipOne was a reusable suborbital spaceplane that carried pilots Mike Melvill and Brian Binnie on consecutive flights in 2004 to win the Ansari X Prize. The Spaceship Company will build its successor SpaceShipTwo. A fleet of SpaceShipTwos operated by Virgin Galactic should begin reusable private spaceflight carrying paying passengers in 2008.

10. Space disasters

All launch vehicles contain a huge amount of energy that is needed for some part of it to reach orbit. There is therefore some risk that this energy can be released prematurely and suddenly,

with significant effects. When a Delta II rocket exploded 13 seconds after launch on January 17, 1997, there were reports of store windows 10 miles (16 km) away being broken by the blast?
In addition, once in space, while space is a fairly predictable environment, there are risks of accidental depressurization, and the potential for failure of equipment that is often very newly developed.

11. Space weather

Space weather is the concept of changing environmental conditions in outer space. It is distinct from the concept of weather within a planetary atmosphere, and deals with phenomena involving ambient plasma, magnetic fields, radiation and other matter in space (generally close to Earth but also in interplanetary, and occasionally interstellar space). "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."
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.

Topic Objective:

At the end of this topic student would be able to:

- Artificial satellites
- Effectiveness of propulsion systems
- Rocket with a high exhaust ve
- Delta-v and propellant use
- Power use and propulsive efficiency
- Example

- This test engine accelerates ions using electrostatic forces
- Electromagnetic methods

Definition/Overview:

Propulsion: Spacecraft propulsion is any method used to change the velocity of spacecraft and artificial satellites. There are many different methods. Each method has drawbacks and advantages, and spacecraft propulsion is an active area of research. However, most spacecraft today are propelled by exhausting a gas from the back/rear of the vehicle at very high speed through a supersonic de Laval nozzle. This sort of engine is called a rocket engine. All current spacecraft use chemical rockets (bipropellant or solid-fuel) for launch, though some (such as the Pegasus rocket and SpaceShipOne) have used air-breathing engines on their first stage. Most satellites have simple reliable chemical thrusters (often monopropellant rockets) or resistojet rockets for orbital station-keeping and some use momentum wheels for attitude control. Soviet bloc satellites have used electric propulsion for decades, and newer Western geo-orbiting spacecraft are starting to use them for north-south stationkeeping. Interplanetary vehicles mostly use chemical rockets as well, although a few have experimentally used ion thrusters (a form of electric propulsion) to great success.

Key Points:

1. **Artificial satellites**

Artificial satellites must be launched into orbit, and once there they must be placed in their nominal orbit. Once in the desired orbit, they often need some form of attitude control so that they are correctly pointed with respect to the Earth, the Sun, and possibly some astronomical object of interest. They are also subject to drag from the thin atmosphere, so that to stay in orbit for a long period of time some form of propulsion is occasionally necessary to make small corrections (orbital stationkeeping). Many satellites need to be moved from one orbit to another from time to time, and this also requires propulsion. When a satellite has exhausted its ability to adjust its orbit, its useful life is over. Spacecraft designed to travel further also need propulsion methods. They need to be launched out of the Earth's atmosphere just as satellites do. Once there, they need to leave orbit and move around. For interplanetary travel, a spacecraft must use its engines to leave Earth orbit. Once it has done so, it must somehow make its way to its destination. Current interplanetary spacecraft do this with a series of short-term trajectory adjustments. In between these adjustments; the spacecraft simply falls freely along its orbit. The simplest fuel-efficient means to move from one circular orbit to another is with a Hohmann transfer orbit: the spacecraft begins in a roughly circular orbit around the Sun. A short period of thrust in the direction of motion accelerates or decelerates the spacecraft into an elliptical orbit around the Sun which is tangential to its previous orbit and also to the orbit of its destination. The spacecraft falls freely along this elliptical orbit until it reaches its destination, where another short period of thrust accelerates or decelerates it to match the orbit of its destination. Special methods such as aerobraking are sometimes used for this final orbital adjustment.

Some spacecraft propulsion methods such as solar sails provide very low but inexhaustible thrust; an interplanetary vehicle using one of these methods would follow a rather different trajectory, either constantly thrusting against its direction of motion in order to decrease its distance from the Sun or constantly thrusting along its direction of motion to increase its distance from the Sun. Spacecraft for interstellar travel also need propulsion methods. No such spacecraft has yet been built, but many designs have been discussed. Since interstellar distances are very great, a tremendous velocity is needed to get a spacecraft to its destination in a reasonable amount of time. Acquiring such a velocity on launch and getting rid of it on arrival will be a formidable challenge for spacecraft designers.

2. Effectiveness of propulsion systems

When in space, the purpose of a propulsion system is to change the velocity, or v, of a spacecraft. Since this is more difficult for more massive spacecraft, designers generally discuss momentum, mv. The amount of change in momentum is called impulse. So the goal of a propulsion method in space is to create an impulse. When launching a spacecraft from the Earth, a propulsion method must overcome a higher gravitational pull to provide a net positive acceleration. In orbit, any additional impulse, even very tiny, will result in a change in the orbit path. The rate of change of velocity is called acceleration, and the rate of change of momentum is called force. To reach a given velocity, one can apply a small acceleration over a long period of time, or one can apply a large acceleration over a short time. Similarly, one can achieve a given impulse with a large force over a short time or a small force over a long time. This means that for maneuvering in space, a propulsion method that produces tiny accelerations but runs for a long time can produce the same impulse as a propulsion method that produces large accelerations for a short time. When launching from a planet, tiny accelerations cannot overcome the planet's gravitational pull and so cannot be used. The Earth's surface is situated fairly deep in gravity well and it takes a velocity of 11.2 kilometers/second (escape velocity) or more to escape from it. As human beings evolved in a gravitational field of 1g (9.8 m/s), an ideal propulsion system would be one that provides a continuous acceleration of 1g (though human bodies can tolerate much larger accelerations over short periods). The occupants of a rocket or spaceship having such a propulsion system would be free from all the ill effects of free fall, such as nausea, muscular weakness, reduced sense of taste, or leaching of calcium from their bones. The law of conservation of momentum means that in order for a propulsion method to change the momentum of a space craft it must change the momentum of something else as well. A few designs take advantage of things like magnetic fields or light pressure in order to change the spacecraft's momentum, but in free space the rocket must bring along some mass to accelerate away in order to push itself forward. Such mass is called reaction mass. In order for a rocket to work, it needs two things: reaction mass and energy. The impulse provided by launching a particle of reaction mass having mass m at velocity v is mv. But this particle has kinetic energy $mv/2$, which must come from somewhere. In a conventional solid, liquid, or hybrid rocket, the fuel is burned, providing the energy, and the reaction products are allowed to flow out the back, providing the reaction mass. In an ion thruster, electricity is used to accelerate ions out the back. Here some other source must provide the electrical energy (perhaps a solar panel or a nuclear reactor), while the ions provide the reaction mass. When discussing the efficiency of a propulsion system, designers often focus on effectively using the reaction mass. Reaction mass must be carried along with the rocket and is irretrievably consumed when used. One way of measuring the amount of impulse that can be obtained from a fixed amount of reaction mass is the specific impulse, the impulse per unit weight-on-Earth (typically designated by I_{sp}). The unit for this value is seconds. Since the weight on Earth of the reaction mass is often unimportant when discussing vehicles in space, specific impulse can also be discussed in terms of impulse per unit mass. This alternate form of specific impulse uses the same units as velocity (e.g. m/s), and in fact it is equal to the effective exhaust velocity of the engine (typically designated v_e). Confusingly, both values are sometimes called specific impulse. The two values differ by a factor of g_n, the standard acceleration due to gravity 9.80665 m/s ($I_{sp}g_n = v_e$).

3. **Rocket with a high exhaust ve**

A rocket with a high exhaust velocity can achieve the same impulse with less reaction mass. However, the energy required for that impulse is proportional to the square of the exhaust velocity, so that more mass-efficient engines require much more energy, and are typically less energy efficient. This is a problem if the engine is to provide a large amount of thrust. To generate a large amount of impulse per second, it must use a large amount of energy per second. So highly (mass) efficient engines require enormous amounts of energy per second to produce high thrusts. As a result, most high-efficiency engine designs also provide very low thrust.

4. Delta-v and propellant use

If the exhaust velocity is constant then the total Δv of a vehicle can be calculated using the rocket equation, where M is the mass of propellant, P is the mass of the payload (including the rocket structure), and v_e is the velocity of the rocket exhaust. This is known as the Tsiolkovsky rocket equation:

For historical reasons, as discussed above, v_e is sometimes written as $v_e = I_{sp}g_o$ where I_{sp} is the specific impulse of the rocket, measured in seconds, and g_o is the gravitational acceleration at sea level.

For a high delta-v mission, the majority of the spacecraft's mass needs to be reaction mass. Since a rocket must carry all of its reaction mass, most of the initially-expended reaction mass goes towards accelerating reaction mass rather than payload. If the rocket has a payload of mass P, the spacecraft needs to change its velocity by Δv, and the rocket engine has exhaust velocity v_e, then the mass M of reaction mass which is needed can be calculated using the rocket equation and the formula for I_{sp}:

For Δv much smaller than v_e, this equation is roughly linear, and little reaction mass is needed. If Δv is comparable to v_e, then there needs to be about twice as much fuel as combined payload and structure (which includes engines, fuel tanks, and so on). Beyond this, the growth is exponential; speeds much higher than the exhaust velocity require very high ratios of fuel mass to payload and structural mass.

For a mission, for example, when launching from or landing on a planet, the effects of gravitational attraction and any atmospheric drag must be overcome by using fuel. It is typical to combine the effects of these and other effects into an effective mission delta-v. For example a launch mission to low Earth orbit requires about 9.3-10 km/s delta-v. These mission delta-vs are typically numerically integrated on a computer.

5. Power use and propulsive efficiency

Although solar power and nuclear power are virtually unlimited sources of *energy*, the maximum *power* they can supply is substantially proportional to the mass of the powerplant. For fixed power, with a large v_e which is desirable to save propellant mass, it turns out that the maximum acceleration is inversely proportional to v_e. Hence the time to reach a required delta-v is proportional to v_e. Thus the latter should not be too large. It might be thought that adding power generation is helpful, however this takes mass away from payload, and ultimately reaches a limit as the payload fraction tends to zero.

For all reaction engines (such as rockets and ion drives) some energy must go into accelerating the reaction mass. Every engine will waste some energy, but even assuming 100% efficiency, to accelerate a particular mass of exhaust the engine will need energy amounting to which is simply the energy needed to accelerate the exhaust. This energy is not necessarily lost- some of it usually ends up as kinetic energy of the vehicle, and the rest is wasted in residual motion of the exhaust.

[Fig 3: Due to energy carried away in the exhaust the energy efficiency of a reaction engine varies with the speed of the exhaust relative to the speed of the vehicle, this is called propulsive efficiency]

Comparing the rocket equation (which shows how much energy ends up in the final vehicle) and the above equation (which shows the total energy required) shows that even with 100% engine efficiency, certainly not all energy supplied ends up in the vehicle - some of it, indeed usually most of it, ends up as kinetic energy of the exhaust.

The exact amount depends on the design of the vehicle, and the mission. However there are some useful fixed points:

- If the I_{sp} is fixed, for a mission delta-v, there is a particular I_{sp} that minimizes the overall energy used by the rocket. This comes to an exhaust velocity of about ⅔ of the mission delta-v (see the energy computed from the rocket equation). Drives with a specific impulse that is both high and fixed such as Ion thrusters have exhaust velocities that can be enormously higher than this ideal for many missions.
- If the exhaust velocity can be made to vary so that at each instant it is equal and opposite to the vehicle velocity then the absolute minimum energy usage is achieved. When this is achieved, the exhaust stops in space ^ and has no kinetic energy; and the propulsive efficiency is 100%- all the energy ends up in the vehicle (in principle such a drive would be 100% efficient, in practice there would be thermal losses from within the drive system and residual heat in the exhaust). However in most cases this uses an impractical quantity of propellant, but is a useful theoretical consideration. Another complication is that unless the vehicle is moving initially, it cannot accelerate, as the exhaust velocity is zero at zero speed.

Some drives (such as VASIMR or Electrodeless plasma thruster) actually can significantly vary their exhaust velocity. This can help reduce propellant usage or improve acceleration at different stages of the flight. However the best energetic performance and acceleration is still obtained when the exhaust velocity is close to the vehicle speed. Proposed ion and plasma drives usually have exhaust velocities enormously higher than that ideal (in the case of VASIMR the lowest quoted speed is around 15000 m/s compared to a mission delta-v from high Earth orbit to Mars of about 4000m/s).

6. **Example**

Suppose we want to send a 10,000 kg space probe to Mars. The required Δ*v* from LEO is approximately 3000 m/s, using a Hohmann transfer orbit. (A manned craft would need to take a faster route and use more fuel). For the sake of argument, let us say that the following thrusters may be used:

ENGINE	EFFECTIVE EXHAUST VELOCITY (KM/S)	SPECIFIC IMPULSE (S)	FUEL MASS (KG)	ENERGY REQUIRED (GJ)	ENERGY PER KG OF PROPELLANT	MINIMUM POWER/THRUST	POWER GENERATOR MASS/THRUST*
Solid rocket	1	100	190,000	95	500 kJ	0.5 kW/N	N/A
Bipropellant rocket	5	500	8,200	103	12.6 MJ	2.5 kW/N	N/A
Ion thruster	50	5,000	620	775	1.25 GJ	25 kW/N	25 kg/N
Advance electrically powered drive	1,000	100,000	30	15,000	500 GJ	500 kW/N	500 kg/N

Observe that the more fuel-efficient engines can use far less fuel; its mass is almost negligible (relative to the mass of the payload and the engine itself) for some of the engines. However, note also that these require a large total amount of energy. For Earth launch, engines require a thrust to weight ratio of more than unity. To do this they would have to be supplied with Gigawatts of power equivalent to a major metropolitan generating station. From the table it can be seen that this is clearly impractical with current power sources. Instead, a much smaller, less powerful generator may be included which will take much longer to generate the total energy needed. This lower power is only sufficient to accelerate a tiny amount of fuel per second, and would be insufficient for launching from the Earth but in orbit, where there is no friction, over long periods the velocity will be finally achieved. For example. it took the Smart 1 more than a year to reach the Moon, while with a chemical rocket it takes a few days. Because the ion drive needs much less fuel, the total launched mass is usually lower, which typically results in a lower overall cost. Mission planning frequently involves adjusting and choosing the propulsion system according to the mission delta-v needs, so as to minimize the total cost of the project, including trading off greater or lesser use of fuel and launch costs of the complete vehicle. Most rocket engines are internal combustion heat engines (although non combusting forms exist). Rocket engines generally produce a high temperature reaction mass, as a hot gas. This is achieved by combusting a solid, liquid or gaseous fuel with an oxidizer within a combustion chamber. The extremely hot gas is then allowed to escape through a high-expansion ratio nozzle. This bell-shaped nozzle is what gives a rocket engine its characteristic shape. The effect of the nozzle is to dramatically accelerate the mass, converting most of the thermal energy into kinetic energy. Exhaust speeds as high as 10 times the speed of sound at sea level is common.

Ion propulsion rockets can heat plasma or charged gas inside a magnetic bottle and release it via a magnetic nozzle, so that no solid matter need come in contact with the plasma. Of course, the machinery to do this is complex, but research into nuclear fusion has developed methods, some of which have been proposed to be used in propulsion systems, and some have been tested in a lab.

See rocket engine for a listing of various kinds of rocket engines using different heating methods, including chemical, electrical, solar, and nuclear.

7. **This test engine accelerates ions using electrostatic forces**

Rather than relying on high temperature and fluid dynamics to accelerate the reaction mass to high speeds, there are a variety of methods that use electrostatic or electromagnetic forces to accelerate the reaction mass directly. Usually the reaction mass is a stream of ions. Such an engine very typically uses electric power, first to ionize atoms, and then uses a voltage gradient to accelerate the ions to high exhaust velocities.

For these drives, at the highest exhaust speeds, energetic efficiency and thrust are all inversely proportional to exhaust velocity. Their very high exhaust velocity means they require huge amounts of energy and thus with practical power sources provide low thrust, but use hardly any fuel. For some missions, particularly reasonably close to the Sun, solar energy may be sufficient, and has very often been used, but for others further out or at higher power, nuclear energy is necessary; engines drawing their power from a nuclear source are called nuclear electric rockets. With any current source of electrical power, chemical, nuclear or solar, the maximum amount of power that can be generated limits the amount of thrust that can be produced to a small value. Power generation adds significant mass to the spacecraft, and ultimately the weight of the power source limits the performance of the vehicle. Current nuclear power generators are approximately half the weight of solar panels per watt of energy supplied, at terrestrial distances from the Sun. Chemical power generators are not used due to the far lower total available energy. Beamed power to the spacecraft shows some potential. However, the dissipation of waste heat from any power plant may make any propulsion system requiring a separate power source infeasible for interstellar travel.

8. **Electromagnetic methods**

- Ion thrusters (accelerate ions first and later neutralize the ion beam with an electron stream emitted from a cathode called a neutralizer)
  - Electrostatic ion thruster
  - Field Emission Electric Propulsion
  - Hall effect thruster
  - Colloid thruster
- Plasma thrusters (where both ions and electrons are accelerated simultaneously, no neutralizer is required)

1. Magnetoplasmadynamic thruster
2. Helicon Double Layer Thruster
3. Electrodeless plasma thruster
4. Pulsed plasma thruster
5. Pulsed inductive thruster
6. Variable specific impulse magnetoplasma rocket (VASIMR)

- Mass drivers (for propulsion)

In Section 5 of this course you will cover these topics: Flight Vehicle Structures And Materials Hypersonic Vehicles
You may take as much time as you want to complete the topic coverd in section 5. There is no time limit to finish any Section, However you must finish All Sections before semester end date.
If you want to continue remaining courses later, you may save the course and leave. You can continue later as per your convenience and this course will be avalible in your area to save and continue later.

Topic Objective:

At the end of this topic student would be able to:

- Statically Determinate Structures
- Theory and Methods For Solving Statically Indeterminate Structures
- Beam Bending and Shear Stresses.
- Theory Of Elasticity And Thermoelasticity
- Introduction To Practical Aircraft Stress Analysis
- Flight Vehicle Materials And Their Properties

Definition/Overview:

Aircraft structures: Just as aircraft structures had transitioned from natural composites (wood) to aluminum in the 1930s, the emergence of advanced composites in the 1960s promised another revolution. In January 1967, a major milestone in the development of advanced composite aircraft structures was marked by a flight-test of a boron/epoxy left-hand inboard airflow director door, a 1 ft. x 6 ft. x in. thick actuated panel located on the lower surface of the wing of the test aircraft . A decade of materials development and subsequent flight demonstration of a component predicated the impending transition from metals to advanced composites.

Key Points:

1. **Statically Determinate Structures**

- Equilibrium of Force Systems. Truss Structures. Externally Braced Wings. Landing Gear.
- Properties of Sections - Centroids, Moments of Inertia, etc.
- General Loads on Aircraft.
- Beams - Shear and Moments. Beam - Column Moments.
- Torsion - Stresses and Deflections.
- Deflections of Structures. Castigliano's Theorem. Virtual Work. Matrix Methods.

2. **Theory And Methods For Solving Statically Indeterminate Structures**

- Statically Indeterminate Structures.
- Theorem of Least Work. Virtual Work. Matrix Methods.
- Bending Moments in Frames and Rings by Elastic Center Method.
- Column Analogy Method.
- Continuous Structures - Moment Distribution Method.
- Slope Deflection Method.

3. **Beam Bending And Shear Stresses.**

- Bending Stresses.
- Bending Shear Stresses - Solid and Open Sections - Shear Center.
- Shear Flow in Closed Thin-Walled Sections.
- Membrane Stresses in Pressure Vessels.
- Bending of Plates.
- Theory of the Instability of Columns and Thin Sheets.

4. **Introduction To Practical Aircraft Stress Analysis**

- Introduction to Wing Stress Analysis by Modified Beam Theory.
- Introduction to Fuselage Stress Analysis by Modified Beam Theory.
- Loads and Stresses on Ribs and Frames.
- Analysis of Special Wing Problems. Cutouts. Shear Lag. Swept Wing.
- Analysis by the "Method of Displacements".

5. **Theory Of Elasticity And Thermoelasticity**

- The 3-Dimensional Equations of Thermoelasticity.
- The 2-Dimensional Equations of Elasticity and Thermoelasti city.
- Selected Problems in Elasticity and Thermoelasticity.

6. **Flight Vehicle Materials And Their Properties**

- Basic Principles and Definitions.
- Mechanical and Physical Properties of Metallic Materials for Flight Vehicle Structure

Topic Objective:

At the end of this topic student would be able to:

- Thin Shock Layer
- Entropy Layer
- Viscous Interaction

- Radiation-dominated regime
- Effects
- Categorization of airflow relies
- Regimes
- Two-temperature ideal gas
- Dissociated gas
- Ionized gas
- High Temperature Flow

Definition/Overview:

Hypersonic Vehicles: In aerodynamics, hypersonic speeds are speeds that are highly supersonic. In the 1970s, the term generally came to refer to speeds of Mach 5 (5 times the speed of sound) and above. The hypersonic regime is a subset of the supersonic regime. Supersonic airflow is decidedly different from subsonic flow. Nearly everything about the way an aircraft flies changes dramatically as an aircraft accelerates to supersonic speeds. Even with this strong demarcation, there is still some debate as to the definition of "supersonic". One definition is that the aircraft, as a whole, is traveling at Mach 1 or greater. More technical definitions state that you are only supersonic if the airflow over the entire aircraft is supersonic, which occurs around Mach 1.2 on typical designs. The range Mach 0.75 to 1.2 is therefore considered transonic. Considering the problems with this simple definition, the precise Mach number at which a craft can be said to be fully hypersonic is even more elusive, especially since physical changes in the airflow (molecular dissociation, ionization) occur at quite different speeds. Generally, a combination of effects become important "as a whole" around Mach 5. The hypersonic regime is often defined as speeds where ramjets do not produce net thrust. This is a nebulous definition in itself, as there exists a proposed change to allow them to operate in the hypersonic regime (the Scramjet). While the definition of hypersonic flow can be quite vague and is generally debatable (especially due to the lack of discontinuity between supersonic and hypersonic flows), a hypersonic flow may be characterized by certain physical phenomena that can no longer be analytically discounted as in supersonic flow.

Key Points:

1. **Thin Shock Layer**

As Mach numbers increase, the density behind the shock also increases, which corresponds to a decrease in volume behind the shock wave due to conservation of mass. Consequently, the shock layer, that volume between the body and the shock wave, is thin at high Mach numbers.

2. **Entropy Layer**

As Mach numbers increase, the entropy change across the shock also increases, which results in a strong entropy gradient and highly vertical flow that mixes with the boundary layer.

3. **Viscous Interaction**

A portion of the large kinetic energy associated with flow at high Mach numbers transforms into internal energy in the fluid due to viscous effects. The increase in internal energy is realized as an increase in temperature. Since the pressure gradient normal to the flow within a boundary layer is zero, the increase of temperature through the boundary layer coincides with a decrease in density. Thus, the boundary layer over the body grows and can often merge with the thin shock layer.

4. **High Temperature Flow**

High temperatures discussed previously as a manifestation of viscous dissipation cause non-equilibrium chemical flow properties such as dissociation and ionization of molecules resulting in convective and radiative heating.

5. **Effects**

The hypersonic flow regime is characterized by a number of effects which are not found in typical aircraft operating at low subsonic Mach numbers. The effects depend strongly on the speed and type of vehicle under investigation.

6. **Categorization of airflow relies**

The categorization of airflow relies on a number of similarity parameters, which allow the simplification of a nearly infinite number of test cases into groups of similarity. For transonic and compressible flow, the Mach and Reynolds numbers alone allow good categorization of many flow cases. Hypersonic flows, however, require other similarity parameters. Firstly, the analytic equations for the Oblique shock angle become nearly independent of Mach number at high (~10) Mach numbers. Secondly, the formation of strong shocks around aerodynamic bodies mean that the freestream Reynolds number is less useful as an estimate of the behavior of the boundary layer over a body (although it is still important). Finally, the increased temperature of hypersonic flows means that real gas effects become important. For this reason, research in hypersonics is often referred to as aerothermodynamics, rather than aerodynamics. The introduction of real gas effects mean that more variables are required to describe the full state of a gas. Whereas a stationary gas can be described by three variables (pressure, temperature, adiabatic index), and a moving gas by four (velocity), a hot gas in chemical equilibrium also requires state equations for the chemical components of the gas, and a gas in nonequilibrium solves those state equations using time as an extra variable. This means that for a nonequilibrium flow, something between 10 and 100 variables may be required to describe the state of the gas at any given time. Additionally, rarefied hypersonic flows (usually defined as those with a Knudsen number above one) do not follow the Navier-Stokes equations.Hypersonic flows are typically categorized by their total energy, expressed as total enthalpy (MJ/kg), total pressure (kPa-MPa), stagnation pressure (kPa-MPa), stagnation temperature (K), or velocity (km/s).Wallace D. Hayes developed a similarity parameter, similar to the Whitcomb area rule, which allowed similar configurations to be compared.

7. Regimes

Hypersonic flow can be approximately separated into a number of regimes. The selection of these regimes is rough, due to the blurring of the boundaries where a particular effect can be found.

8. Perfect gas

In this regime, the gas can be regarded as an ideal gas. Flow in this regime is still Mach number dependent. Simulations start to depend on the use of a constant-temperature wall, rather than the adiabatic wall typically used at lower speeds. The lower border of this region is around Mach 5, where Ramjets become inefficient, and the upper border around Mach 10-12.

9. Two-temperature ideal gas

This is a subset of the perfect gas regime, where the gas can be considered chemically perfect, but the rotational and vibrational temperatures of the gas must be considered separately, leading to two temperature models. See particularly the modeling of supersonic nozzles, where vibrational freezing becomes important.

10. Dissociated gas

In this regime, multimolecular gases begin to dissociate as they come into contact with the bow shock generated by the body. The type of gas selected begins to have an effect on the flow. Surface catalycity plays a role in the calculation of surface heating, meaning that the selection of the surface material also begins to have an effect on the flow. The lower border of this regime is where the first component of a gas mixture begins to dissociate in the stagnation point of a flow (Nitrogen~2000 K). The upper border of this regime is where the effects of ionization start to have an effect on the flow.

11. Ionized gas

In this regime the ionized electron population of the stagnated flow becomes significant, and the electrons must be modeled separately. Often the electron temperature is handled separately from the temperature of the remaining gas components. This region occurs for freestream velocities around 10-12 km/s. Gases in this region are modeled as non-radiating plasmas.

12. Radiation-dominated regime

Above around 12 km/s, the heat transfer to a vehicle changes from being conductively dominated to radiatively dominated. The modeling of gases in this regime is split into two classes:

- Optically thin: where the gas does not re-absorb radiation emitted from other parts of the gas
- Optically thick: where the radiation must be considered as a separate source of energy.

The modeling of optically thick gases is extremely difficult, since, due to the calculation of the radiation at each point, the computation load theoretically expands exponentially as the number of points considered increases.