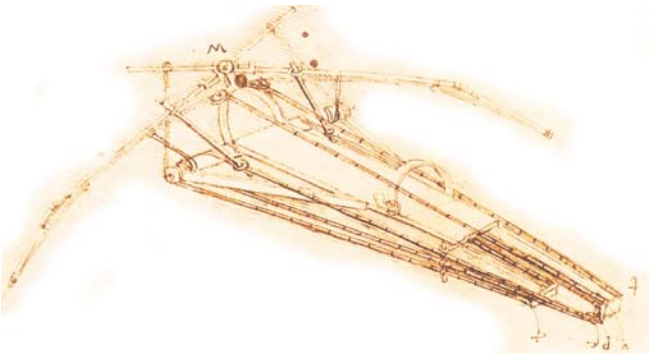

How does an airplane fly?

Basic principles

Environmental and safety issues

Authors:

Tony Arts, Cem Asma, Patricia Corieri,
Nicoletto De Pascale, Claudia Dobre,
Tania Kirmse, Michel Riethmuller

Pedagogic Advisors:

Frankie McKeon and Maarten Tas

SEVENTH FRAMEWORK PROGRAMME

REStARTS

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Preface

Raising European Students Awareness in Aeronautical Research Through School-Labs' is the main objective of the project REStARTS.

The objective of the project is to contribute in reversing the current trend of disinterest of young people towards aeronautics. In this project,the partners of the aeronautical research and training institutes develop informative material about current research topics in aeronautics including basic aerodynamic fundamentals like 'How does an airplane fly?' or special challenges the aeronautical research is facing like 'How greening air transport?' or 'How to ensure satisfaction, safety and security of the passengers?' .

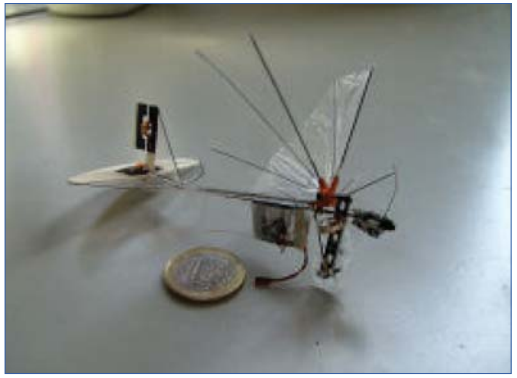
This demonstrates the direct link between research and society. The scientists work in cooperation with a pedagogic team and teachers of local schools to compile understandable teaching material, which also includes simple experiments to demonstrate the physical phenomena being investigated. The school lessons based on this material give a first impression of the challenges of the modern aeronautical research.

The school-labs established at the research institutes provide more sophisticated experiments and enable school classes to get a hands-on experience inscientific work. Additional visits of the laboratories of the project partners and their industrial partners complete the program. This will build bridges between school theory and applied research by delivering an insight to the work of research organisations. The ambition is to stimulate young people's interests in a R&D career in aeronautics and to create a European network of Aeronautical School-Labs.

Part 1

I. How does a plane fly ?

1



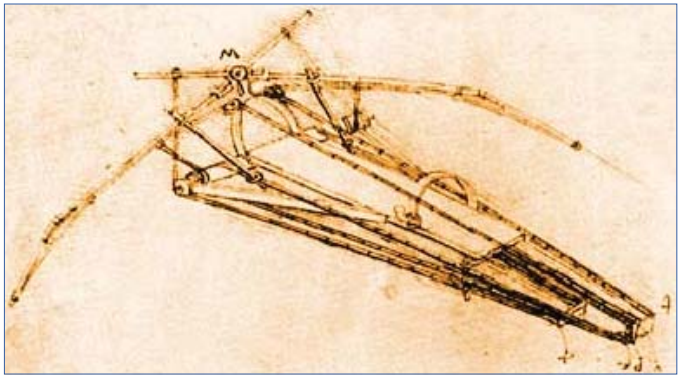
Micro Delphy from Delft University

1. The birth of airplanes and helicopters

The history of aeronautics is a beautiful illustration of the long technological way which had to be covered to carry out an old dream of the Man: to fly like the birds.

As the myth of Icare testifies, this dream goes back at least to Antiquity. One found the trace of several attempts at machines with beating wings imitating those of the birds. But they were always unfruitful. One of the best known inventions was that of Leonardo da Vinci (1480-1519) and was called in French l'ornithoptère. However, in reality this machine is unable to fly.

The discoveries are the fruit of an often enthralling work, requiring perseverance and whose intellectual advance is sometimes very complex and sinuous, often comprising outward journeys and returns. For example, the development of aeronautics was not done by adopting the principle of the beating wing. However, a new research orientation currently uses again this principle on the basis of "bionics". This discipline consists in analyzing the behaviors met in nature and reproducing



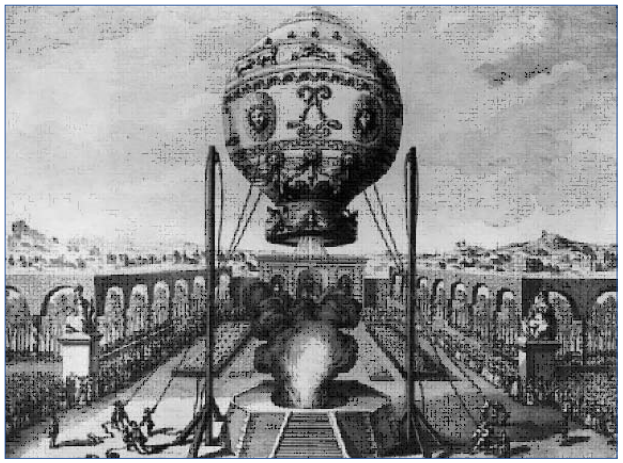
Leonardo's Human Powered Ornithopter ca. 1485

them in mechanisms, systems or materials. It is only very recently that the researchers succeeded in developing small autonomous planes, called "drones", with beating wings comparable to small insects. The studies of the behavior of the wings of birds revealed the complexity of their mechanism. Their shapes adapt permanently to the flying conditions, and this mainly for the light birds. For the heavier birds, most of the flight is done in gliding flight. When one thinks of the size and the weight of an A380 Airbus, one measures the limits of the comparison.

The first successful effort to transport the men in the airs was that of the Montgolfier brothers (Paris - November 1783). It is entirely by chance

that Joseph Montgolfier saw that hot air was lighter than cold air. While drying a shirt by a fireplace, the shirt inflated with hot air, and when narrowing the arrival of hot air, he could see it deflating. He then understood that he had just discovered what would enable him to carry out his dream and that of many others: to start the conquest of the sky. Before the flight of November 1783 with humans, they carried out tests with a sheep, a duck and a chicken to check viability with high-altitude.

As a child, Sir Georges Cayley (the U.K. - 1773-1857) was fascinated by the passion generated by the first flights of Montgolfières (French name of the invention of the Montgolfier brothers), but quickly he was persuaded that machines with fixed wings would be more powerful. Like his predecessors, he started by in-detail studying the flight of the birds but with a much more scientific approach: He studied the shapes of the wings, measured the weights, speeds of flights of the birds,… He built a system of revolving wing and measured the weight which it could raise for various speeds and various angles. These experiments enabled him to apprehend the theory showing the lift of a wing, basic principle of the flight. He applied this principle to build a sailplane (1849) with which he accomplished the first flight in 1853. On the basis of the new knowledge acquired through these experiments and with this new concept of lift, he defined the basic principle of the modern plane. He was the first who understood that it is necessary to dissociate the force that raises the wing of the plane, lift, from the force that propels the plane. The latter must be generated by an independent means, a propeller driven by an explosion or gas engine. Furthermore, a rudder will make it possible to control the direction of the plane. The first flight is allotted to the brothers Wilbur and Orville Wright, on December 17, 1905, in North Carolina (USA). Their plane, Flyer, took very largely advantage of the experiments undertaken by their contemporary as for example Octave Chanute (USA) which on the basis of the work of Lilienthal (Germany), developed very powerful biplane sailplanes whose stability made it possible to repeat the flights. The first part of their investigations thus started with the construction of sailplanes that they developed in close cooperation with Chanute, who helped them to progress in their projects. The experience gained with their sailplane allowed them to consider the motorized flight. Since they could



First human flight 1783 Paris

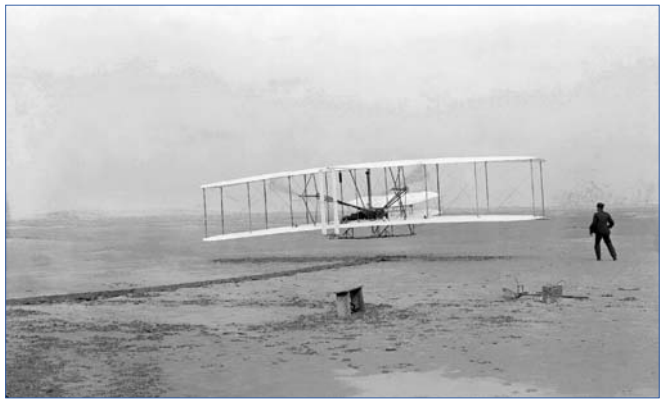
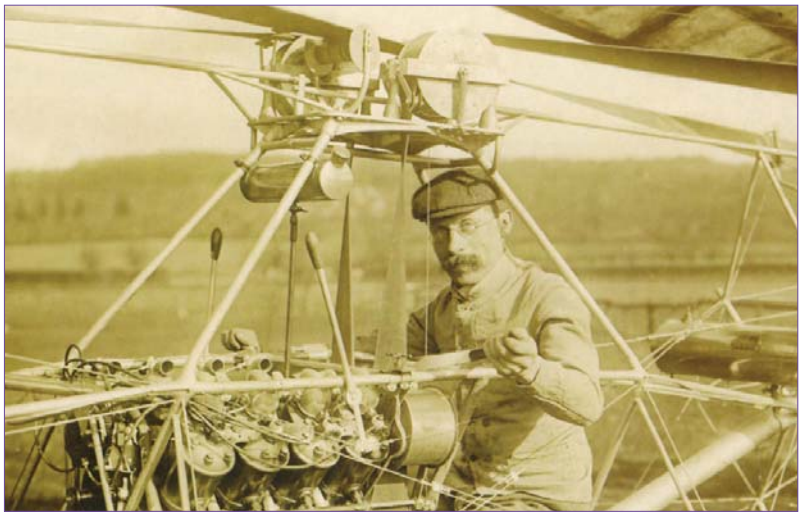


Fig 1.4 First motorised flight of the Wright s brothers, 1903

Triptych, the Virgin and St Benoit, 15th century

not find an automobile engine meeting their needs, the Wright brothers built their own engine. After a first attempt which resulted into an accident, they made a success of a first flight of 12 seconds during which the plane had covered a distance of 36 meters. After the Wright's, the development of aeronautics became exponential. At the beginning of its history, the researchers developed planes which went always faster and which flew higher. Between 1900 and 1970, the speed of the planes jumped from the order of 10 km/h to 2000 km/h, whereas in same time the altitude of flight raised from a few meters to 100 km. Today, the constraints of ecological and of cost nature bring another view on the development of civil aircrafts and the international programs are directed towards the construction of less polluting planes in terms of fuel consumption, but also of noise.

Another category of aircraft develops in parallel: the helicopter. Since IVe century BC , the Chinese were flying small toys in the form of propeller on the principle of the helicopter to fascinate the children. This toy is shown opposite in a triptych representing the virgin and St Benoit dating from the 15th century. A significant advance occurred in 1907, year of the first true takeoff in the world. It seems that it was achieved in Normandy (France) in Coquainvilliers, close to Lisieux. This machine of 203 kilos was invented and controlled by Paul Cornu. For the first time, a machine is freed from the ground without elan with a man on board. This date of November 13, 1907 is quoted in all the stories of aviation, as being that of the first free flight of a helicopter with its pilot.



Paul Cornu flying his helicopter, 1907

2. Fundamental principles- aircraft flight

As stated it Sir Cayley to maintain a plane in flight, three elements must be assured: the lift of the plane, its propulsion and finally its stability. The plane in flight at cruising speed is subjected to 4 forces. These 4 principal forces operating the plane in flight are schematized on the figure below.

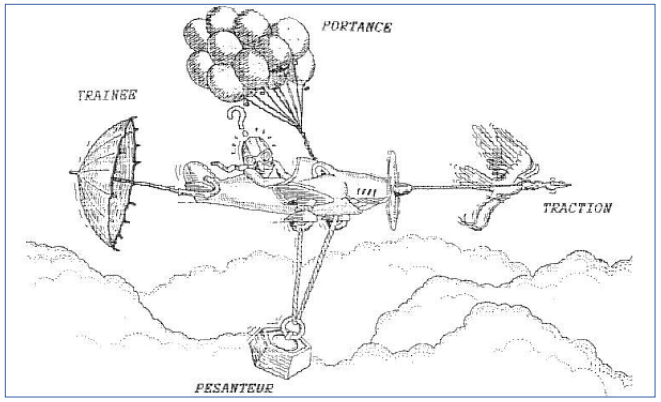
Two of these forces are generated by the relative movement of the air compared to the plane. The first one is the lift. This force is directed upwards and is acting perpendicular to the displacement of the plane. It is thanks to this force that the plane is maintained in the air. The second is the drag. It is exerted in the direction opposed to the displacement of the plane. It is due to the breaking action of the air on the plane and is opposed to the advance of the plane. The lift and the drag are called aerodynamic forces because they are resulting from the action of the air due to the displacement of the airplane.

The force due to gravity, the weight of the plane, is opposed to the lift. The balance of the lift and the weight leads to the fact that the plane is maintained at constant altitude. To ensure that the plane continues to move forward, it is necessary to provide a force that compensates for the force called drag. This force is called the thrust. The thrust is generated by the system of propulsion of the planes, the engines. In the case of the flight at cruising speed, the role of the engine is

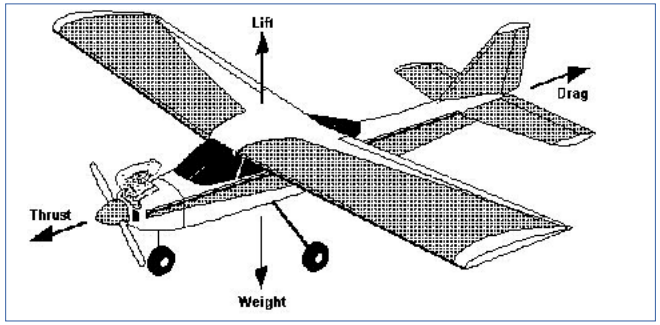
2

What is a force?

Let's define a force through its effects: when a force acts on a body, the latter will deform or its movement will change. The motion (direction and velocity) of the body can therefore be modified. Let's consider a billiard ball that is propelled with a given acceleration and direction by the effect of a force. If a body is submitted to an ensemble of forces that are balances (their sum is null) its movement will not be modified. It is the case of an airplane flying at constant speed and altitude. it is also the case for a standing person that is submitted on one side to the gravity force and on the other to the reaction of the ground.



Cartoon of the forces acting on a flying plane



Forces acting on a flying plane

thus to compensate for the force of drag, but not to make the plane climb. On the other hand, at the time of takeoff, the engine power will be used to bring the plane to the altitude of flight.

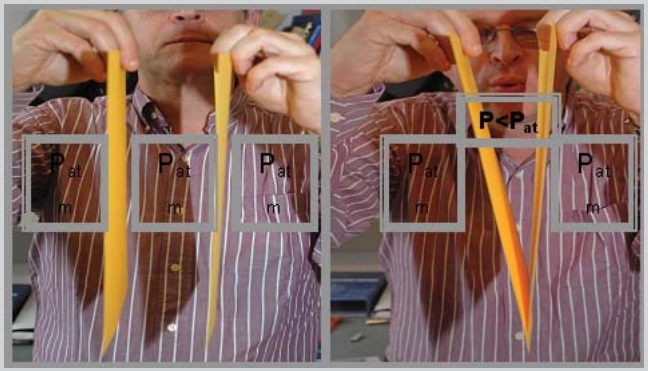
And what about sailplanes which do not have any engines? The lift of the sailplane is generally initiated by a plane which tows it until a certain altitude. Then, the sailplane is released and starts its autonomous flight. As it does not have any engine, it must follow a downward trajectory relative to the air to keep its speed. To avoid approaching the ground too quickly, it must find zones where the air follows an ascending direction. That enables him to continue its flight.

2.1 Lift and weight

To keep the plane in flight at constant altitude, a force of lift must balance the force due to gravity (weight of the plane). This force of lift is generated by the airflow around the plane, in particular the flow of air around its wings.

We now propose to explain how the air which flows around the wing of the plane manages to generate a force of lift directed upwards.

Let's start with a simple experiment. Take two paper sheets and hold them vertically. Take care to keep them 5 cm apart and blow between these sheets. What are you expecting to happen ? Begin the experiment after answering to this question only!



Put you hand inside a plastic bag making sure the air is able to enter it. Plunge your hand (and the bag) in a water bucket.

What are you feeling?

The water will push-out the air contained in the bag and suddenly your hand will be surrounded by a uniform feeling due to the pressure exerted by the water on your hand.

What is the pressure?

The most common definition of pressure is of a force distributes over a surface. This pressure is exerted perpendicularly to the surface.

Unlike Temperature, Pressure is difficult to feel. The air exerts a permanent pressure on our body and we do not feel it. The unpleasant feeling in our ears at takeoff and landing of the plane corresponds to a variation of pressure of the air in the aircraft. A fluid at rest will communicate to the bodies which it surrounds a pressure called static or hydrostatic.

The level of this pressure is function of thetype of fluid which surrounds the body and in particular of its density, height of fluid above the body and finally the value of the force of gravity.

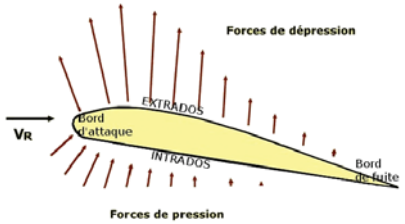
The two sheets will come closer to one another. Before blowing (in the absence of any air draught), the two sheets although motionless undergo on both sides the atmospheric pressure, which will be the same one on the two sides of the sheet. In a general way the atmospheric pressure is unperceivable. Let us carry out another experiment to feel the pressure which a fluid exerts on a body.

Having apprehended what is the pressure of a fluid when it is at rest, let's examine what occurs as soon as this fluid is put in motion (in our experiment the air between the two sheets). In 1738, Daniel Bernoulli applied the principle of conservation of energy to the fluids and stated that the energy of the fluid is made up of energy due to its velocity - kinetic energy on one hand and on the other hand of energy due to its pressure - potential energy and by principle of conservation the sum of these two energies is constant. What in other term means that if the static pressure increases, velocity will only be able to decrease and vice versa.

In our experiment, when we blow between the two sheets, the velocity of the air is increasing between the sheets. As a result the pressure becomes lower than the atmospheric pressure and the sheets are attracted one by the other. An identical phenomenon occurs on the wing of an airplane when a flow of air is surrounding it. The shape of the wing, called profile, is characterized by a larger camber on the upper part and a sharp trailing edge. In addition, in flight, the wing of the plane is slightly pulled up, compared to the trajectory of the plane as one can see it on the figure opposite, one says that the wing is in small incidence.

Vortices after tip of the wings

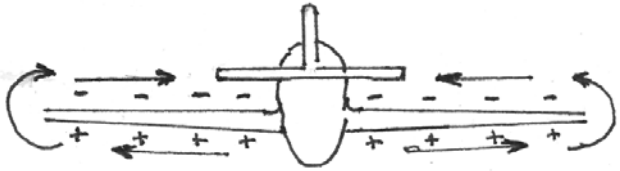
This particular shape and the incidence will generate a complex flow, characterized by higher speeds on the upper part of the wing.



According to the principle of Bernoulli that we have just experimented, the pressure on the upper part of the wing of the airplane strongly decreases. This produces a force acting upwards: The lift. The role of the pilot is to adjust the speed of the plane and its incidence to be under conditions where the lift force balances the weight of the plane.

2.2 Propulsion : Drag and Thrust

Up to now we only considered the force of lift which requires the profile of wing. Actually, the air moving relatively to the surface of the wing and of the body of the airplane exerts a force of friction "which grows like the square" of the velocity. The faster the plane flies, the larger becomes this force of friction. This force of drag is opposed to the movement of the plane and will have to be compensated by the thrust provided by the engine. Do not forget that the planes are equipped with a fuselage, necessary to the transport of passengers and freight. Although it contributes by a small amount to the lift that is necessary to balance the weight of the aircraft, it increases in a significant way the resistance to advance. In addition, one takes advantage of their presence to attach to the fuselage various devices necessary to control the manoeuvres in flight and on the ground. They are the control and the high-lift control surfaces, empennages, landing gears,… They all contribute to increase the resistance to advance and are included in the total friction Drag.



There also exists a force of drag known as induced drag, which is also opposed to the movement. This phenomenon occurs at the end of the wings. We saw that the upper part of the wing was in depression and the lower part of the wing was in overpressure. What occurs at the ends from the wing? The air tends to bypass the wing to move from the high to the low pressure areas. This will produce vortices at the tip of the wings. as seen on the opposite photograph.

These vortices are strong energy consumers and they will generate a significant increase of the drag called the induced drag. The larger the lift, the more important is the induced drag.

It is easily understood that this drag will be smaller as the span of the wing of the airplane is larger. It is the case of the sailplanes which do not have engines and which must consume as little as possible of their potential energy to remain in the air for the longest possible time, On the planes of recent design, it is possible, thanks to the existence of new composite materials, to curve the ends of the wings. This device called Winglet and presented opposite on Laserjet 60, was very largely developed for business aircrafts and sailplane, and is know common on the new models of larger airplanes. The manufacturers of planes make constant efforts to reduce the consumption of the planes and to decrease their polluting emissions. This kind of device contributes to it.

The vortices generated by the tips of the wings also have an impact on the management of the air traffic. Indeed, these vortices have larger lifespan as the airplanes are heavier.

These vortices disappear after a certain time under the effect of turbulence of the atmospheric wind and their natural dissipation. It will thus be necessary to wait for a sufficient time before the takeoff of the following plane to prevent that it could be destabilized by the vortices generated by the plane which has just taken off.

Another element which generates drag is the landing gear. It is the reason why as soon as it is no longer necessary, it is retracted in the fuselage of the plane. During the approach of an airport, it is only lowered a short time before landing, when the airplane already significantly decelerated. Its deployment always generates a significant noise due to its disturbing effect on the flow around the plane.

The lift and the drag are related to the properties of physics and to the flows around the plane. It still is necessary to understand the system implemented to generate the force that maintains the plane in flight. This force of propulsion is generated by the engine of the airplane which is the fruit of long research projects and technological developments.

Winglets on a plane

As chapter 3 describes the principle of the engine of the airplanes, we will not return in the details. Let us introduce directly the principle of the propulsion by a very simple experiment.

Before passing to the chapter describing the intricate working of the engines that propels the aircrafts, let's make a small experiment. As shown on the sketch, it will consist in inflating a rubber balloon and to glue on it a plastic straw while keeping it blown. The straw is then slipped on a string that is taut between to fixed points. Put the balloon at the middle point of the string and let it go, allowing the air to escape. Watch the balloon. Comment the way the balloon goes.

The action of inflating the balloon is equivalent to increasing the pressure inside it above the ambient atmospheric pressure. As long as one maintains the fingers on the open end of the balloon, the forces due to overpressure are exerted on the wall of the balloon. At the opening of the end, since the pressure is more important inside than outside, the air will be put in motion to reach a balance of the pressures. A force is created as a consequence of the acceleration of the ejected air. By effect of reaction an opposite force is exerted on the balloon and the latter is propelled in opposite direction. This is an illustration of the well-known principle of action-reaction stated by Newton: "to each action (Force), will correspond an equal and opposite action". This experiment illustrates the basic principle of the operation of the so-called jet airplanes.

2.3 Stability and manoeuvrability of the airplanes

Let us start by making the distinction between the stability and the manoeuvrability of the plane:

• its manoeuvrability (its control) is ensured by the movements of moving parts of the plane making it possible to change its altitude, speed and direction.

• its stability is its property to be maintained at its altitude and to resist a displacement (due to a gust of wind for example) and in the event of perturbation to develop a force restoring the initial flying conditions. Until now we only considered the case of the airplane in cruising flight at constant speed and altitude. In this case we saw that the plane is subjected to 4 balanced forces (Lift-Weight, Thrust-Drag) applied in its centre of gravity.

Manoeuvrability of the airplane

In addition to its displacement in horizontal direction, it is possible to consider side movements (rare for the planes) and rotation movements around the three axes. The movements (represented on the opposite figure) around the three axes are respectively called roll, pitch and yaw. These movements are characterized by rotations. Contrary to a car, a boat or a train, the planes are able to be driven according to the 3 axes. This movement occurs around the centre of gravity of the plane. The centre of gravity of the plane is the average position where the weight of the plane is applied. On the traditional planes, three types of devices are at the base of the control of the flight: the ailerons, the rudder and the horizontal stabilizers.

The ailerons are acting in opposition. This means that when the right-hand side aileron is raised, the left one drops, making it possible to control the movement of **roll**. This movement of roll is produced owing to the fact that on the side where the aileron is lowered, the lift of the wing will increase, whereas on the side where the aileron is raised the lift decreases. This creates an imbalance of the forces on the right and on the left of the wing and the plane is inclining on the right or left-hand side.

The movement of **yaw** is a movement in which, when looking from the top, the nose of the plane moves from right to left (or left to right), and the plane turns around its centre of gravity in a horizontal plane. This movement of yaw is controlled by the rudder generally located in the tail of the plane. This device functions on the same principle as the rudder of a boat.

The **pitching** of the plane is the movement where the plane turns around its centre of gravity and where the nose of the plane moves in a vertical plan (from top to bottom or upwards). Pitching is controlled thanks to horizontal stabilizers also located in the tail of the airplane.

Stability of the airplane

We have just described how the pilot can voluntarily control the displacement of his plane. It remains to evoke the notion of the stability of the plane. One generally speaks about two types of concepts: static stability and dynamic stability. By definition, the plane is balanced (one also says trimmed) in flight

when the resultants of the forces and the couples around the centre of gravity are null. A modification of one of the parameters of flight caused either by an atmospheric disturbance (wind, turbulence), or by an action on the controls, modifies these forces and moments temporarily. If their resultants tend to bring back the apparatus towards a position of balance, the aerodyne is regarded as statically stable. If not, it is statically unstable. It is important to note that this definition implies a tendency. One makes also the distinction between stability with free controls or controls blocked, according to whether the controls can move freely or that they are maintained in a fixed position during the movement which follows the disturbance. Before takeoff, the pilot will have to adjust various controls to ensure this stability according to the load of the airplane.

The gravity center ?

A fixed point in a material body through which the resultant force of gravitational attraction acts. The resultant of all forces or attractions produced by the Earth's gravity on a body constitutes its weight. This weight is considered to be concentrated at the center of gravity in mechanical studies of a rigid body. The location of the center of gravity for a body remains fixed in relation to the body regardless of the orientation of the body. If supported at its center of gravity, a body would remain balanced in its initial position.

3. Airplane propulsion

Foreword

The objective of this document is to provide a simple description of the way an aircraft engine which is commonly called a jet engine is working. Many systems of propulsion have been developed in aeronautics. We will concentrate here on the gas turbine, which is most commonly used in civil aviation. This document also covers the technologies now in use to limit the emission of polluting gases. The use of specialist vocabulary and mathematical formulae is avoided as far as possible to concentrate on a clear and concise description of the fundamental principles.

3.1 The aircraft engine – basic definitions

Before discussing the main subject, it is necessary to establish some basic definitions.

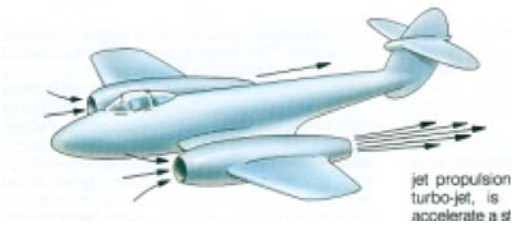
The Merriam-Webster dictionary defines an engine as a machine for converting any of various forms of energy into mechanical force and motion. The engine is thus an energy transformer. Energy (also called work, and quantified in Joules) can itself be interpreted as a force in motion. In the well-known case of a car engine, the thermal energy coming from the combustion of petrol and air is transformed into mechanical energy which is applied to the wheels of the vehicle (the force allowing to turn the wheels).The more familiar notion of power, quantified in Watts (or in horse-power by our parents and grandparents – 1 horse power = 736 Watts) expresses the quantity of energy used in one unit of time.

This transformation is unfortunately not perfect and is necessarily accompanied by certain losses. This introduces the notion of efficiency. The efficiency is defined as the ratio between the result obtained (the mechanical energy transmitted to the wheels in the example of a car engine) and the means used to produce it (thermal energy contained in the petrol-air mixture in this example). Its value is always less than 1 (or 100%). As an example, a petrol engine and a diesel engine give respectively efficiencies of the order of 35% and 46%. In a traffic jam, this efficiency can reduce to 15%. The lost energy is generally transformed into heat.

3

The functional objective of the aircraft engine is thus to produce a large quantity of air (a large flow rate) exiting the engine at high speed (a speed much higher than the speed of the aircraft).

In flight, an aircraft does not have wheels in contact with the ground. We therefore need to define the way of generating energy to allow it to advance. The principle of aeronautical propulsion is a direct application of Newton's third law of motion (principle of opposite action or action-reaction) which says that any body A exerting a force on a body B experiences a force of equal intensity, exerted on it by body B. In the case of aeronautical propulsion, the body A is atmospheric air which is accelerated through the engine. The force – the action – necessary to accelerate this air has an equal effect, but in the opposite direction – the reaction -, applied to the object producing this acceleration (the body B, that is the engine, and hence the aircraft to which it is attached).

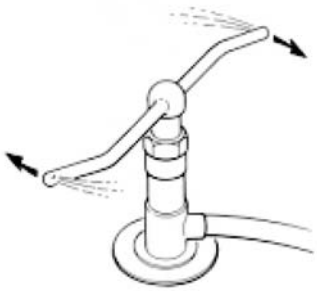


Principle of aeronautical propulsion

Figure on the bottom left "Principle of aeronautical propulsion" illustrates this principle.

It is possible to imagine much simpler examples based on the same principle. The first, probably the most simple, is that of the fairground balloon, which is first inflated then released. The air (body A) is ejected from the balloon (body B) through a small opening and at high speed. The balloon is propelled in the opposite direction to the ejected air – this is the reaction (see the experience proposed at paragraph 2.2). The second example is that of a rotating watering system (Figure on the next page "Watering system driven by the reaction of water jets").

The speed of water (body A) is increased by its passage through small ejection holes. The two arms of the watering system (body B) are pushed in the opposite direction (reaction), thus driving the rotation.

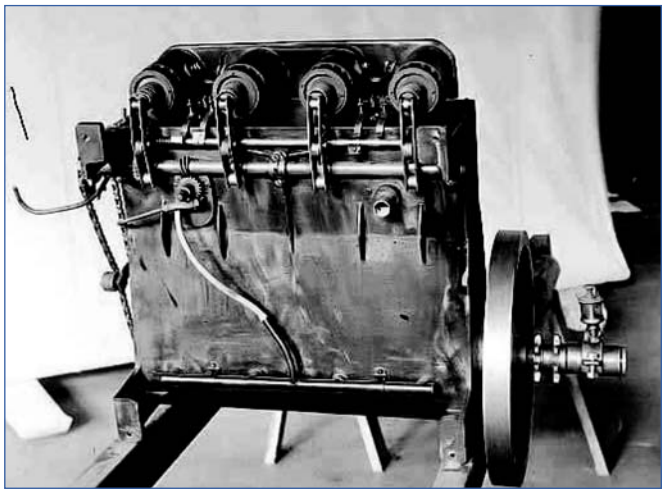


Watering system driven by the reaction of water jets

3.2 The gas turbine: architecture and functional principle

The first motorised flight of an aircraft dates from 17th December 1903 (Fig on the top right) and was carried out by the brothers Wilbur and Orville Wright on the beach of Kitty Hawk in North Carolina (USA). The flight lasted 12 seconds and a distance of 36 metres was covered.

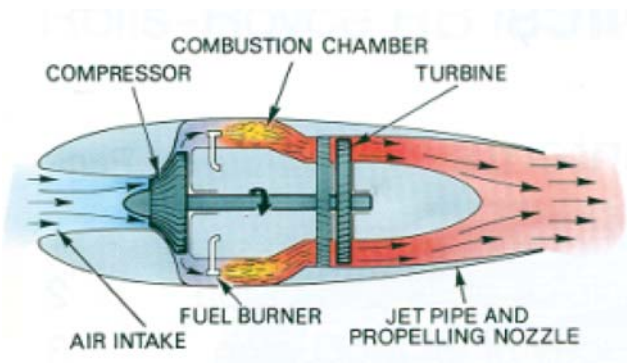
The application of the gas turbine to aeronautical propulsion dates from the 1930s. This engine (the gas turbine) was developed independently in Great Britain by Sir Frank Whittle (first patent in 1930, first flight on 7th April 1941) and in Germany by Hans Joachim Pabst von Ohain (first patent in 1936, first flight on 27th August 1939). We can see that the progress in aeronautics occurred at an incredible speed.



First motorised flight by the Wright brothers (1903) Wright brothers engine

The gas turbine used as an aircraft engine by Sir Frank Whittle is presented in Figure on the right and Figure at bottom shows a photo of the aircraft in flight with this engine installed.

The Globstar E28/39 aircraft equipped with Sir Frank Whittle s engine (1941).



Sir Frank Whittle s gas turbine engine

The example proposed here is the simplest architecture that can be imagined for an engine. This architecture is composed of 5 main parts:

• the air intake
• the compressor
• the combustion chamber
• the turbine
• the outlet (jet pipe and propelling nozzle)

The purpose of the following paragraphs is to describe briefly these components. Their integration serves to:

1. suck atmospheric air into the engine (air intake and compressor)
2. increase the energy of this air by means of the compressor (increasing the pressure) and the combustion chamber (increasing the temperature by burning a mixture of air and kerosene).
3. transforming this energy into speed (kinetic energy) by means of the outlet tube in order to apply the principle of aeronautical propulsion described above.

The air intake

The air intake is one of the most visible parts of an aircraft engine. A typical photo of this component is shown in Figure 6.

Air intake

This envelope which precedes the main part of the engine is attached to a strut, which is itself fixed to a wing or the fuselage. The main purposes of this nacelle are:

• to present as little air resistance (drag) as possible
• to guarantee optimal functioning of the engine during the different phases of flight (take-off, cruise, landing),
• to limit the acoustical disturbance of the engine by absorbing some of the noise,
• to protect the inlet parts of the engine from phenomena relating to icing (the local temperature at 10 000 metres altitude is between -40° and -50°C).

The compressor

The compressor, situated just behind the air intake, is the first element which allows transformation of energy, in this case from mechanical energy into energy in the form of pressure. This machine is presented in Figure below, where the flow is from left to right.

The compressor is composed of a series of fixed blades, both fixed (stators – coloured in grey in the figure) and moving (rotors – coloured in blue, yellow and red in the figure). The function of these blades is to transform the mechanical energy which turns the rotors into pressure

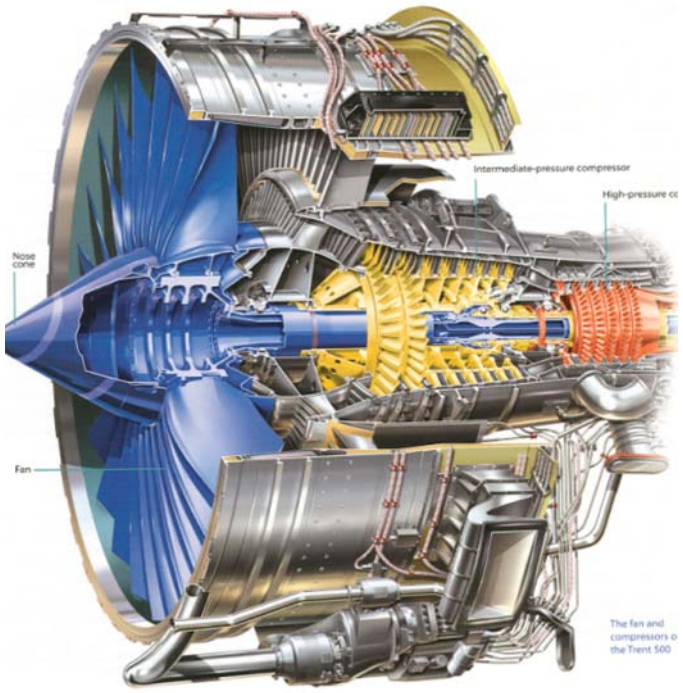
energy. This transformation operates by directing in a precise way the flow which develops in the channels defined by the blades and the envelope of the engine. The rotor which is best known is the one coloured in blue in Figure 7; this is also called the fan and can be seen at the entrance of the engine (Figure on the right).

Air from the atmosphere is sucked into the engine by the compressor in the same way that a ventilator fan (which is nothing else but a type of compressor) sucks air into a polluted room.

The compressor of a modern engine allows pressures typically 30 or 40 times greater to be reached at the outlet of this element. The fan turns at a rotational speed of the order of 5000 revolutions per minute: the largest diameters are of the order of 3.25 metres, the length of the blades of the largest fans is greater than 1.20 metres. The centrifugal force undergone by these rotating blades is comparable to the weight of a railway carriage (80 000kg) being attached to the end of one of these blades.

The combustion chamber

The combustion chamber, situated just downstream from the compressor, is the element in which thermal energy is added to the pressure energy accumulated at the outlet of the compressor. The transformation of energy considered here comes from the combustion of the air/kerosene mixture (the combustible used in most aircraft engines) which generates an increase in the temperature of the air passing through the engine.



The compressor from the engine of a modern civil transport aircraft.

Fan of the engine of a modern civil transport aircraft (seen from front).

Calculations show that the efficiency of the engine will be better if the temperature at the outlet of the combustion chamber is higher. In the most recent engines, temperatures of the order of 2100°C are achieved. To understand this temperature, it is useful to remember that the temperature of the flame of a wood fire is only about 1000°C. The materials used for the construction of a combustion chamber contain an important fraction of nickel and chrome. The melting temperature of these two metals is less than this 2100°C and protection and cooling of the metal parts is therefore absolutely necessary. A description of such technologies is outside the scope of this document.

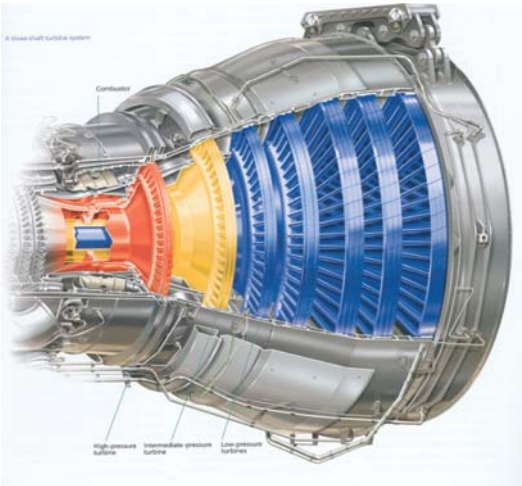
In summary then, at the outlet of the combustion chamber, there is a mixture of burnt air and kerosene at very high temperature and pressure. This energy (in the form of pressure and temperature) results from the transformation of mechanical energy necessary to turn the compressor and the transformation of chemical energy contained within the kerosene, which is stored in the fuel tanks of the aircraft. We now need to define the source of mechanical energy required to turn the compressor. This is the role of the turbine.

The turbine

The turbine is situated at the outlet of the combustion chamber. Its function is to transform the energy available in the form of pressure and temperature into mechanical energy. In other words, the turbine is the "motor" which turns the compressor. The pressure and temperature of the air-kerosene mixture will decrease during passage through this element. This part of the machine is presented in left figure.

As for the compressor, the turbine is composed of a series of blades, both fixed (stators – coloured in grey in the figure) and moving (rotors – coloured in red, yellow and blue in the figure). The function of these rotors is to transform the temperature and pressure energy into mechanical energy which turns the compressor. This transformation is also made by precisely directing the flow which develops in the channels defined by the blades and the envelope of the engine. As an example, the red rotor in Figure 9 is generally composed of 30 to 40 blades. Each one of these generates the same energy as is generated by the entire engine of a Formula One car!

Calculations show that the complete transformation of the energy available in the form of pressure and temperature and the energy available in the kerosene gives more mechanical energy than is needed to turn the compressor (typically twice as much). The turbine serves then to transform only the quantity of energy strictly required to achieve this function. The 50% available energy which remains in the air/kerosene mixture is transformed into kinetic energy (the speed necessary to guarantee propulsion of the aircraft).



Turbine of the engine of a modern civil transport aircraft.

The outlet tube

This last element, situated at the back of the turbine, is the outlet tube. In this tube the last transformation of energy takes place with the aim of creating a jet of air exiting the engine at high speed, thus allowing the propulsion of the aircraft according to the principle of action/reaction. This transformation is achieved by a controlled variation of the cross-section of the outlet tube. A typical example is shown in the centre of Figure "Outlet Tube", which is a photo of the back of a aircraft engine.

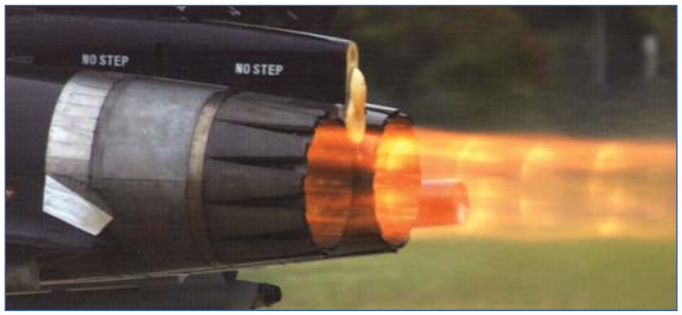
In the case of Concorde (a now discontinued supersonic civil transport aircraft) and in the case of a number of military aircrafts, a final transformation of energy, afterburning, is made in the outlet tube. The principle of this transformation is to inject extra kerosene in the tube, mixing this with the flow and burning the mixture. The extra energy obtained gives an even higher speed to the jet of air exiting the engine and hence an even great propulsive power. A photo of the outlet jet, with afterburn, is shown in bottom left.

This technology is mainly used for aircraft flying at speeds greater than the speed of sound.

3.3 The gas turbine: effect on the environment (CO2 emission)

Carbon dioxide (CO2) is a chemical compound with a molecule composed of one carbon atom and two oxygen atoms. It is generated by the combustion of the air/kerosene mixture. Kerosene is an extract of petrol – it is a fossil fuel and therefore contains carbon. Above a certain concentration in air, this gas becomes dangerous, or even mortal. The threshold concentration for exposure is 3% for a duration of 15 minutes.

The second harmful property of CO2 is that it is a greenhouse gas. When solar radiation reaches the earth's atmosphere, a part (about 30%) is directly reflected, sent back into space, by air, by white clouds and by the bright surface



Outlet jet with afterburn

Outlet tube

of the earth, particularly in white and glacial regions such as the Arctic and Antarctica. The incident rays that are not reflected back into space are absorbed by the atmosphere (about 20%) and/or by the earth's surface (about 50%). This part of the radiation absorbed by the surface of the earth brings heat, i.e. energy, to the ground. This heat energy is in turn reemitted, day and night, in the direction of the atmosphere as infrared radiation. This infrared radiation is then partially absorbed by greenhouse gases, which heat the atmosphere. Finally this heat in the atmosphere is reemitted in all directions and notably towards the earth. It is this radiation of heat back towards the earth that forms the greenhouse effect and is an extra source of heat for the earth's surface. The increase in the concentration of CO2 in the earth's atmosphere, therefore, contributes to climate warming. The process is summarised in Figure below.

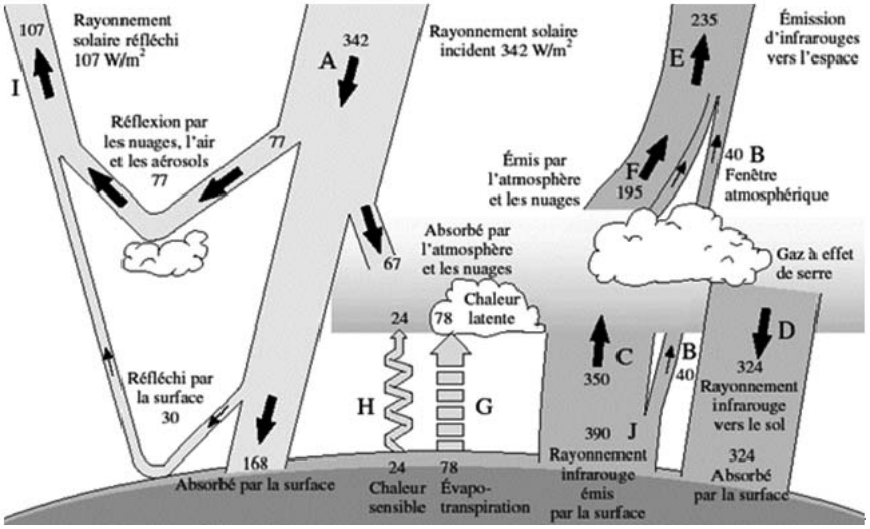
In order to understand the importance of the effect of CO2 with respect to aeronautical propulsion, it is useful to consider the following data:

- the proportion of CO2 in the atmosphere (2007): 0.04%
- the contribution of CO2 to the greenhouse effect: 55%
- the contribution of air transport to CO2 emissions: 2.5%

Another example can be used. Consider a journey from Charleroi to Carcassonne:

1. In a Boeing 737 with 160 passengers
2. In a diesel car
3. In a powerful motorbike

The amount of CO2 production is as follows:



Exchange of energy between the earth and space the greenhouse effect

1. The aircraft produces 79.5 kg of CO2 per passenger (duration of journey: 1h35)
2. The diesel car produces between 80 and 120kg of CO2 (duration of journey: 9h30)
3. The motorbike produces 120kg of CO2.

One of the principal objectives of the industry which constructs aircraft engines is to reduce this production of CO2. Many directions are available to:

• reduce the consumption of fuel
• increase the efficiency of the components of engines find alternative fuels

Reduction of consumption

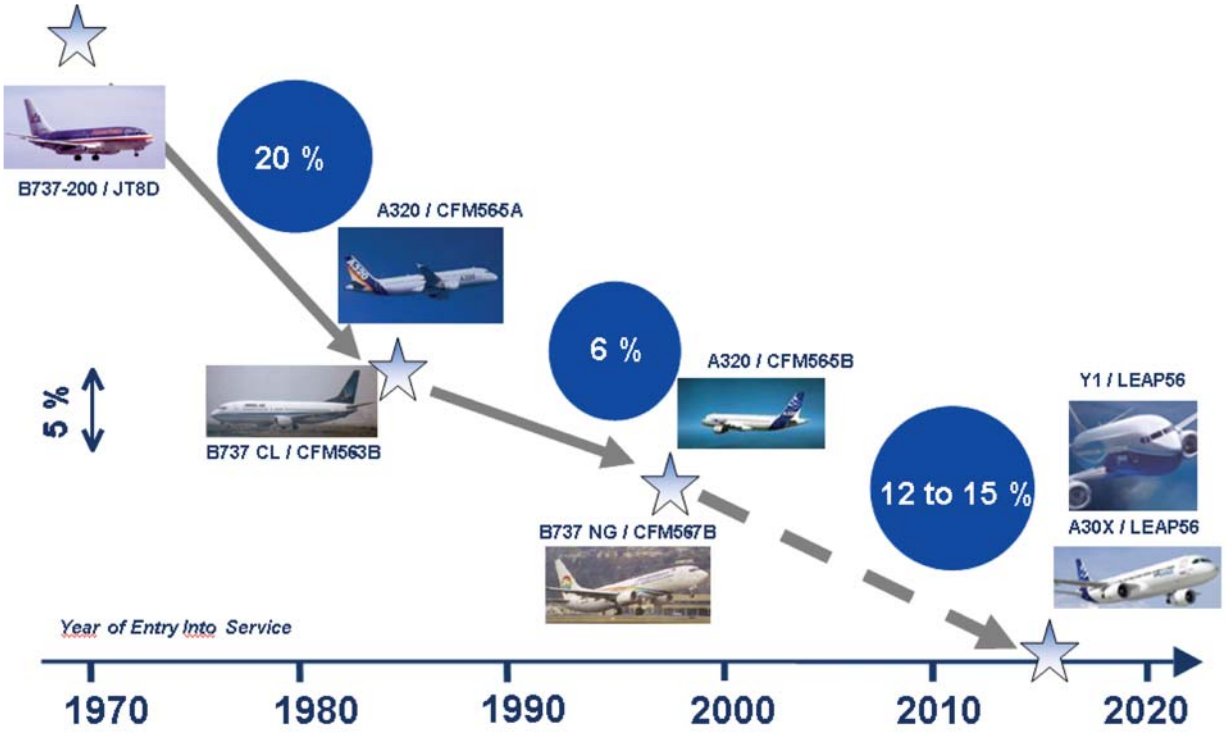
This Figure shows the reduction in fuel consumption obtained over the last 40 years for standard civil aviation engines. It is clear that an economy of about 40% has been achieved overthis period.

Today, the most modern engines have a consumption of less than 3 litres of kerosene per 100km per passenger.

Improvement of efficiency

The turbojet is the type of engine which probably has the highest power/weight ratio. Put differently, for a given power, it is the smallest (or lightest) engine. For example, one engine of a Boeing 777 (GE90), which is currently the world's largest aircraft engine, is twice as powerful as the engines of the Titanic ship and 1000 times more powerful than a formula one car engine.

The research carried out today by industry, helped by research institutes and universities, aims to obtain a better efficiency from the different components of a turbojet. These studies consider:



Reduction of fuel consumption over the last 40 years

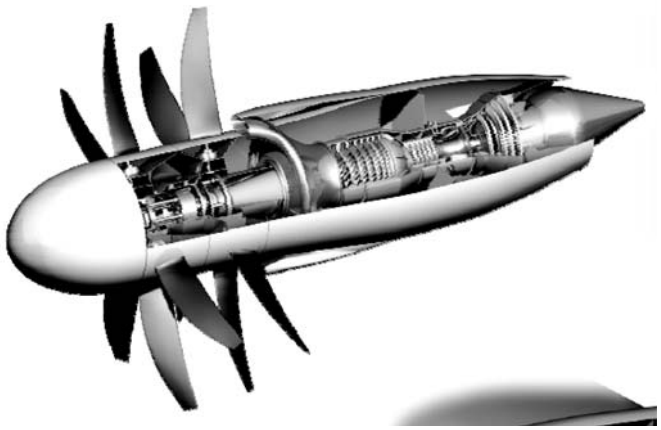
• The aerodynamic form of the different elements: the air resistance should be as low as possible. This concerns mainly the shape of the winglets of the compressor and the turbine.

• The weight of the components: the different elements should be as light as possible. The weight of the GE90 engine mentioned above is about 7.5 tons. Significant efforts are being made to reduce this weight by developing or trying new materials. For example, the blades of the fan of the GE90 are made of composite material. If they had been made of titanium, as for the great majority of other engines, the GE90 would weigh 300kg more.

• The architecture of the engines: the constructors are thinking now about the architecture of the engines of tomorrow. The main projects considered today concern the "open rotor", the counter-rotating fan, and the fan with gearbox. The first concept (See "Schematic view of the Open Rotor") is radically different from what we see today. It has a low consumption, but high noise; the second concept concerns limiting the weight of the engine, but increases the technological difficulty, because it involves turning the rows of the fan in an opposite direction; the third concept allows to decouple the speeds of rotation of the turbine and of the compressor and thus to make this more compact, and hence lighter. An optimum should therefore be found between the advantages and disadvantages of these ideas.

Research on alternative fuels

Aircraft engines now have greater and greater efficiency. The aerodynamic, thermal and mechanical performance of the different components is getting better and better and the weight of the engines is ever decreasing. Research and development in all these domains is more and more advanced. However, the overwhelming majority of turbojets still use kerosene as fuel. Kerosene is a derivative of petrol and is composed of a large number of hydrocarbons (molecules containing chains of carbon).



Schematic view of the Open Rotor

The industrial companies which make aircraft engines have at last decided to invest in the search for and application of alternative fuels.

A first reason to use such fuels is to reduce the production of CO2 as well as pollutants such as sulphur oxides (SOx) and nitrous oxides (NOx), and to thus improve air quality, especially in the regions around airports. A second reason is related to the price of petrol. In 1999 a barrel of petrol cost 10 dollars. Today it costs nearly 75 dollars. Moreover, petrol cannot be produced eternally. It is therefore necessary to find alternatives.

The basic principles for the use of alternative fuels, or bio-fuels, are the following:

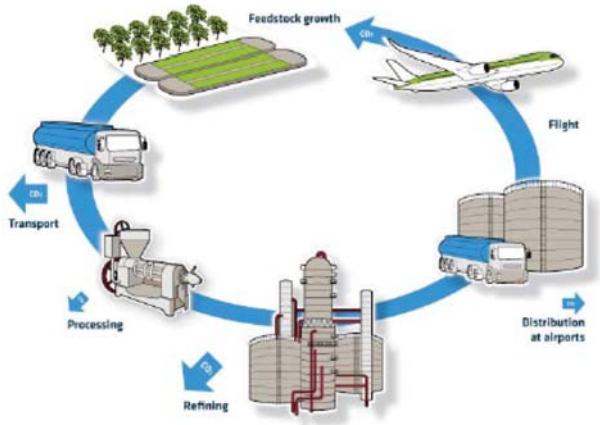
• They are produced from renewable biological resources such as plants (which is strictly speaking true also for petrol except that petrol takes millions of years to make). The CO2 produced by combustion is thus dispersed in the atmosphere.

• The CO2 in the atmosphere is absorbed by plants (biomass) when they grow. This same CO2 returns into the atmosphere when the bio-fuel is burned. The global impact is thus zero (See "Production, transport ans use of bio fuels.").

• The first generation bio-fuels have already been in use for a number of years in applications other than aeronautics such as transport, heating and the production of electrical energy. These first generation bio-fuels are extracted mainly from food products. A number of classes can be distinguished including "oils" (sunflower, rape, castor, etc.), "alcohol" (sugar cane, beetroot, maize, wheat, etc.), "gas" (methane produced by solid waste from water treatment plants, manure and household waste) and finally "charcoal". A large proportion of these raw materials comes from food resources.

• Second generation bio-fuels come from new, purely energetic sources, not used by the food industry. They are made from wood (lignite and cellulose), transformed into gas or alcohol, from algae, from inedible plants, or from oil-producing oil trees, which are also used to combat desertification.

• Third generation bio-fuels are extracted from algae (also called algal fuels). This subject is still in a research phase. Some scientists claim that these micro-algae could be between 30 and 100 times more efficient in oil production than terrestrial oleaginous plants.



Production, transport and use of bio fuels.

In the field of aviation it is the second generation bio-fuels that are used today. The first test flight was made in 2008 on a Boeing 747. One of the four engines of this plane was fed by a 50/50 mixture of kerosene and a bio-fuel derived from the "oil" class. The mixture did not affect adversely the functioning of the engine – it even showed a reduction in consumption of between 1% and 2%. Many research projects, of which some are funded by the European Commission, aim to obtain the certification of these mixtures in 2010-2011 and the certification of bio-fuels used alone before 2015.

It is, however, revealing to note that these biofuels emit 75% less CO2 than kerosene (taking account, of course, of the CO2 absorbed by the plants during their growth). The cost of such fuels is currently of the order of 80 or 90 dollars/barrel, which is not much more than the price of a barrel of petrol.

4. Phases of a flight

Image courtesy of Federal Aviation Administration (FAA)

4.1 Taxi

Taxiing refers to the movement of an aircraft on the ground, under its own power. The aircraft moves on wheels. An airplane uses taxiways to taxi from one place on an airport to another; for example, when moving from a terminal to the runway.

The aircrafts always moves on the ground following the yellow lines, to avoid any collision with the surrounding buildings, vehicles or other aircrafts. The taxiing motion has a speed limit. Before making a turn, the pilot reduces the speed further to prevent tire skids. Just like cars, there is a certain list of priorities during taxiing. The aircrafts that are landing or taking off have higher priority. The other aircrafts have to wait for these aircrafts before they start or continue taxiing.

The thrust to propel the aircraft forward comes from its propellers or jet engines. Steering is achieved by turning a nose wheel or tail wheel/rudder; the pilot controlling the direction travelled with their feet. The use of engine thrust near terminals is restricted due to the possibility of jet blast damage. This is why the aircrafts are pushed back from the buildings by a vehicle before they can start their own engines for taxiing.

4.2 Take-off

Takeoff is the phase of flight in which an aircraft goes through a transition from moving along the ground (taxiing) to flying in the air, usually starting on a runway. Usually the engines are run at full power during takeoff. Following the taxi motion, the aircraft stops at the starting line of the runway. Before takeoff, the engines, particularly piston engines, are routinely run up at high power to check for engine-related problems. This makes a considerable noise. When the pilot releases the brakes, the aircraft starts accelerating rapidly until the necessary speed for take-off is achieved.

The takeoff speed required varies with air density, aircraft weight, and aircraft configuration (flap and/or slat position, as applicable). Air density is affected by factors such as field elevation and air temperature.

Operations with transport category aircraft employ the concept of the takeoff V-Speeds, V1 and V2. These speeds are determined not only by the above factors affecting takeoff performance, but also by the length and slope of the runway. Below V1, in case of critical failures, the takeoff should be aborted; above V1 the pilot continues the takeoff and returns for landing. After the co-pilot calls V1, Then, V2 (the safe takeoff speed) is called. This speed must be maintained after an engine failure to meet performance targets for rate of climb and angle of climb.

The speeds needed for takeoff are relative to the motion of the air (indicated airspeed). A head wind will reduce the ground speed needed for takeoff, as there is a greater flow of air over the wings. This is why the aircrafts always take off against the wind. Side wind is not preferred as it would disturb the stability of the aircraft. Typical takeoff air speeds for jetliners are in the 130–155 knot range (150–180 mph, 240–285 km/h). For a given aircraft, the takeoff speed is usually directly proportional to the aircraft weight; the heavier the weight, the greater the speed needed.

Some aircraft have difficulty generating enough lift at the low speeds encountered during takeoff. These are therefore fitted with high-lift devices, often including slats and usually flaps, which increase the camber of the wing, making it more effective at low speed, thus creating more lift. These have to be deployed from the wing before performing any maneuver.

At the beginning of the climb phase, the wheels are retracted into the aircraft and the undercarriage doors are closed. This operation is audible by the passengers as a noise coming from below the floor.

4.3 Climb

Following take-off, the aircraft has to climb to a certain altitude (typically 30,000 ft or 10 km) before it can cruise at this altitude in a safe and economic way. A climb is carried out by increasing the lift of wings supporting the aircraft until their lifting force exceeds the weight of the aircraft. Once this occurs, the aircraft will climb to a higher altitude until the lifting force and weight are again in balance. The increase in lift may be accomplished by increasing the angle of attack of the wings, by increasing the thrust of the engines to increase speed (thereby increasing lift), by increasing the surface area or shape of the wing to produce greater lift, or by some combination of these techniques. In most cases, engine thrust and angle of attack are simultaneously increased to produce a climb.

Because lift diminishes with decreasing air density, a climb, once initiated, will end by itself when the diminishing lift with increasing altitude drops to a point that equals the weight of the aircraft. At that point, the aircraft will return to level flight at a constant altitude.

During climb phase, it is normal that the engine noise diminishes. This is because the engines are operated at a lower power level after the take-off. It is also possible to hear a whirring noise or a change in the tone of the noise during climb. This is the sound of the flaps that are retracting. A wing with retracted flap produces less noise.

4.4 Cruise

Cruise is the level portion of aircraft travel where flight is most fuel efficient. It occurs between ascent and descent phases and is usually the majority of a journey. Technically, cruising consists of heading (direction of flight) changes only at a constant airspeed and altitude. It ends as the aircraft approaches the destination where the descent phase of flight commences in preparation for landing.

For most commercial passenger aircraft, the cruise phase of flight consumes the majority of fuel. As this lightens the aircraft considerably, higher altitudes are more efficient for additional fuel economy. However, for operational and air traffic control reasons it is necessary to stay at the cleared flight level. Typical cruising speed for long-distance commercial passenger flights is 475-500 knots (878-926 km/h; 547-578 mph).

Commercial or passenger aircraft are usually designed for optimum performance at their cruise speed. There is also an optimum cruise

altitude for a particular aircraft type and conditions including payload weight, center of gravity, air temperature, humidity, and speed. This altitude is usually where the drag is minimum and the lift is maximum. As in any phase of the flight, the aircraft in cruise mode is always in communication with an Air Traffic Control (ATC) station. Although the general tendency is to follow a straight line towards the destination, there may be some deviations from the flight plan for weather, turbulence or air traffic reasons, after receiving clearance from ATC.

4.5 Descent

A descent during air travel is any portion where an aircraft decreases altitude. Descents are an essential component of an approach to landing. Other partial descents might be to avoid traffic, poor flight conditions (turbulence or bad weather), clouds (particularly under visual flight rules), to see something lower, to enter warmer air (in the case of extreme cold), or to take advantage of wind direction of a different altitude. Normal descents take place at a constant airspeed and constant angle of descent (3 degree final approach at most airports). The pilot controls the angle of descent by varying engine power and pitch angle (lowering the nose) to keep the airspeed constant.

At the beginning of and during the descent phase, the engine noise diminishes further as the engines are operated at low power settings. However, towards the end of the descent phase, the passenger can feel further accelerations and an increase in the noise. This is to realize the "final approach" before taking "landing position".

4.6 Landing

Landing is the last part of a flight, where the aircraft returns to the ground. Aircraft usually land

at an airport on a firm runway, generally constructed of asphalt concrete, concrete, gravel or grass. To land, the airspeed and the rate of descent are reduced to where the object descends at a slow enough rate to allow for a gentle touch down. Landing is accomplished by slowing down and descending to the runway. This speed reduction is accomplished by reducing thrust and/or inducing a greater amount of drag using flaps, landing gear or speed brakes. As the plane approaches the ground, the pilot will execute a flare (roundout) to induce a gentle landing.

Although the pilots are trained to perform the landing operation, there are "Instrument Landing Systems" in most of the airports to help

pilots land the aircrafts. An instrument landing system (ILS) is a ground-based instrument approach system that provides precision guidance to an aircraft approaching and landing on a runway, using a combination of radio signals and, in many cases, high-intensity lighting arrays to enable a safe landing during instrument meteorological conditions (IMC), such as low ceilings or reduced visibility due to fog, rain, or blowing snow.

At the beginning of the landing phase, the passengers will hear the opening of the doors of the landing gears. As the landing gears are deployed, they will create an additional drag and an additional noise. Immediately after touch-down, the passengers can hear a blowing sound, sometimes with increasing engine sound. This is the engine's thrust reverses, helping the aircraft to slow down to taxi speeds by redirecting the airflow of the engines forward. Once the aircraft is decelerated to low speed, it can taxi to the terminal building.

Part II

II. Greening Air Transport

1

1. Noise

While we notice airliners at a cruise altitude of 11 km only as condensation trail in the sky, the noise produced by starting and approaching airplanes in the vicinity of airports is annoying, especially for the residents close to airports. Therefore, the reduction of aircraft noise is a big challenge for aeronautical research. Although a lot of technical advances improved the situation within the last decades, the growth of air transport and the increasing expansions of airports require continuous research activities to exploit all possibilities for further improvements.

To think of noise reduction, it is necessary to understand how sounds are produced, propagated through a medium and how to assess them. Noise is not only specific to air transport, but can also be observed in everyday life. For sure, traffic noise of cars and trains plays a major role, but also the noise level in music clubs, at pop concerts, of MP3-players and diverse machinery. Their impact on people's health should be taken into account.

Noise around us

Any sound, not matter what the source, is caused by something vibrating. Without vibration, there can be no sound. These vibrations cause the air particles next to the source to vibrate, and those air particles, in turn, cause the particles next to them to vibrate, and so on and so on, creating a sound wave. Just like a wave in water, the farther out the sound wave moves, the weaker it gets, until it completely dissipates.

If the original vibration creates a strong enough wave, it eventually reaches your ears and registers as a sound. You hear a sound because air vibrates against your eardrums, causing them to vibrate also. These vibrations are analyzed by your brain and registered as music, traffic, birds singing, etc.

The perception of sounds in day-to-day life is of major importance for human well-being. Communication through speech, sounds from playing children, music, and natural sounds in parklands, parks and gardens are all examples of sounds essential for satisfaction in every day life.

Sources of noise

When unwanted sound created by human beings hits our ears and disturbs the environment, noise pollution is created. All transportation systems (cars, trains, motorcycles, planes, helicopters) create noise pollution. Besides transportation noise, noise can come from barking dogs, loud music, air-conditioners, factories, power tools and construction work.

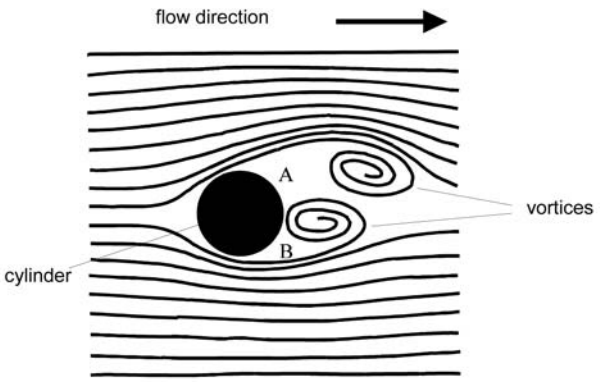
1.1. What is sound and how it is generated?

Sounds are connected with vibrations. If vibratory objects, e.g. a tuning fork, the string of a guitar or the membrane of a drum, move rapidly back and forth, they produce a sound or a tone.

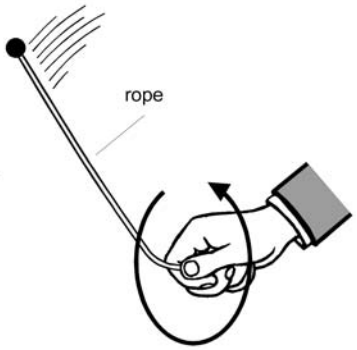
A simple demonstration is a rubber band spanned over a box – it is a kind of a simplified guitar. The larger the deflexion of the rubber band the louder is its sound. Changing the thickness or the tension of the band, the frequency of its oscillation and so the pitch of the sound is changed. Similar observations can be made by using a scale ruler and cantilevering it over a table. The vibrations of a tuning fork can be visualised as well, e.g. by holding the handle of the intoned fork in a glass filled with water and watching the water surface.

Acoustic sources are connected with mechanical vibrations. Their properties can be described by means of their amplitude (maximum deflection) and their frequency (number of oscillations per time unit).

The faster the vibration the higher is the produced tone. The larger the deflexion of the object the louder is the generated sound. This mechanism is well observable at music instruments. Touching the instruments, one can feel their fast see-saw action. Stopping the vibration results in disappearance of the sound. Air can also be excited to vibrations, e.g. by blowing or turbulences. Examples for this are the flute as musical instrument and blowing over partially filled bottles. The airflow around an object like e.g. an aircraft can produce noise as well.



A rope in fast rotation produces a buzzing sound. Because the sections of the rope have different speeds, the induced sound consists of different frequencies and no clear tone is emitted. If the rope rotates quite slowly, the flow stays laminar without the presence of vortices and no noise is emitted.



Sound gun

Bandwidth is the difference between the upper and the lower frequencies in a continuous set of frequencies. This typically measured in hertz, and may sometimes refer to passband bandwidth, depending on context.

At high air speeds the flow around an object becomes turbulent and produces vortices. A simple example is the flow around a cylindrical body. Left and right-turning vortices are formed in the wake of the cylinder. At stationary flow conditions the vortices separate alternately forming the so called von-Karman-vortex street. The temporal offset of the separation on side A and B (see figure 2) induce a vibration to the body, which lead to the production of sound in the surrounding air. With increasing air speed the separation frequency increases and the tone pitch becomes higher.

1.2 Sound pressure

Sound pressure or acoustic pressure is the local pressure deviation from the ambient (average, or equilibrium) atmospheric pressure caused by a sound wave. Sound pressure can be measured using a microphone in air and a hydrophone in water. The SI unit for sound pressure p is the pascal (symbol: Pa).

Sound pressure level (SPL) or sound level is a logarithmic measure of the effective sound pressure of a sound relative to a reference value. It is measured in decibels (dB) above a standard reference level.

White noise is thenoise created when all audible frequencies of sounds are combined at the same time and and the same density. It is similar in nature to withe light, which occurs when alla the colors of the spectrum are brought together. Whithe noise incorporates over 20.000 frequencies. The actual sound produced by white noise is compatible to rainsfall or ocean waves. It is gentle tone tnar can be found in nature. White noise combines all frequencies of sound ranging from very low tones to hight pitches.

Environmental noise is therefore measured with reference to a decibel scale, dB.

When noise is at 45 decibels, no human being can sleep, and at 120 decibels the ear is in pain and hearing begins to be damaged at 85 decibels.

The human ear is more sensitive to sound in the frequency range 1 kHz to 4 kHz than to sound at very low or high frequencies. To compensate, sound meters are normally fitted with filters adapting the measured sound response to the human sense of sound. Common filters are: dB(A), dB(B) , dB(C) dB(A): The decibel A filter is widely used.

Using the dBA-filter, the sound level meter is less sensitive to very high and very low frequencies. Measurements made with this scale are expressed as dB (A).

dB(B) and dB(C): The decibel C filter is practically linear over several octaves and is suitable for subjective measurements at very high sound pressure levels. The decibel B filter is between C and A. The B and C filters are seldom used.

The frequencies spectrum of a time-domain signal is a representation of that signal in the frequency domain. the frequency spectrum can be generated via a Fournier transform of the signal, and the resulting values are usualy presented as amplitude and phase, both plotted versus frequency.

Any signal that can be represented as amplitude that varies with time has a corresponding frequency spectrum. This includes familiar concepts such as visible light (color), musical notes, radio/TV channels.

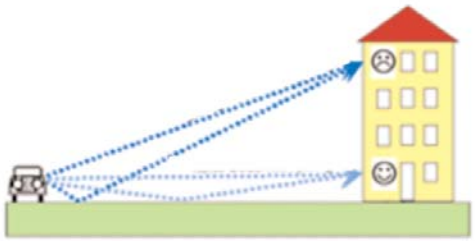
A source of light can have many colors mixed together and in different amounts (intensities). A rainbow, or prism, sends the different frequencies in different directions, making them individually visible at different angles. A graph of the intensity plotted against the frequency (showing the amount of each color) is the frequency spectrum of the light.

When all the visible frequencies are present in equal amounts, the perceived color of the light is white, and the spectrum is a flat line. Therefore, flat-line spectrums in general are often referred to as white, whether they represent light or sound or something else. Similarly, a source of sound can have many different frequencies mixed together.

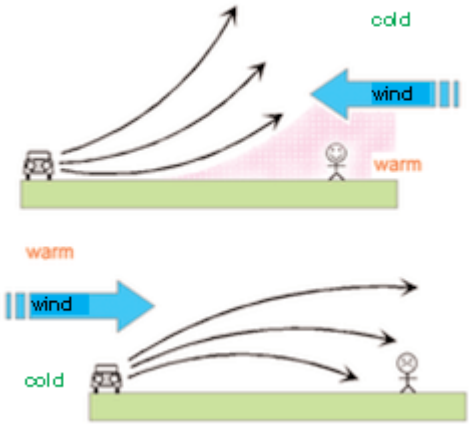
Sound in our environment that we refer to as noise often comprise many different frequencies. When the frequency spectrum of a sound signal is flat, it is called white noise.

Loudnes is that attribute of auditory sensation in terms of which sounds can be ordrered on a scale extending from quiet to loud.

Loudness is another characteristic of sound; it is a subjective measure. Filters such as A-weighting attempt to adjust sound measurements to correspond to loudness as perceived by the typical human. But, loudness perception is a much more complex process than A-weighting. As the perception of loudness varies from person to person it cannot be universally measured using any single metric.



Reflection of sound waves on ground



Refraction of sound waves

1.3 Visualization of Vibrations

Vibrations can be visualised in vibration plots, in which the deflexion (amplitude) is plotted versus the time. The vibration plots of acoustic sources enable a closer analysis of the properties of the emitted sound. The amplitude is a measure for the sound level or loudness of sound. The frequency defined as the number of oscillations per time unit, describes the tone pitch. The higher the frequency the faster is the vibration and the higher is the tone.

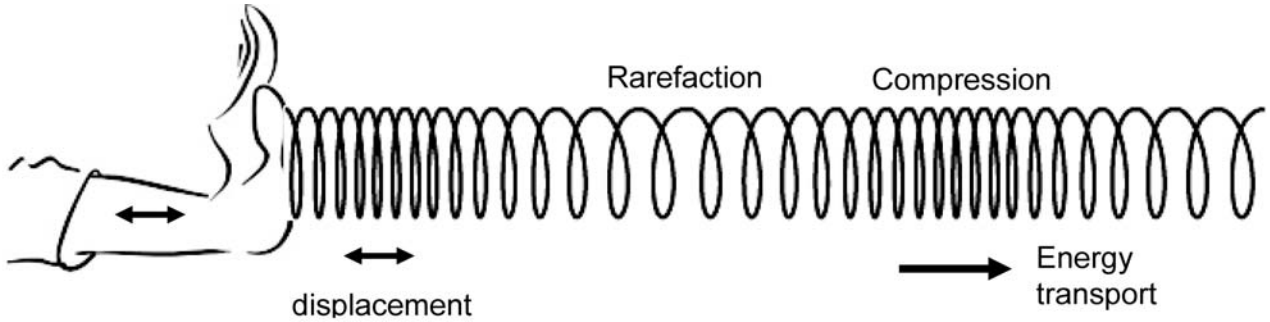
1.4 How are sounds transmitted and how do sounds propagate?

Due to the vibration of an acoustic source the air molecules in its vicinity are excited to vibrations too. The air molecules vibrate locally which creates zones of compressions and rarefaction of the air particles resulting in local pressure fluctuations. By collisions with neighbouring particles these perturbations travel through the air as a sound wave. The sound wave doesn't transport matter like an air flow but energy by air molecules exciting each other. While water waves oscillate transversally to their propagation direction, sound waves in the air propagate in longitudinal waves. The motion of the particles is in a direction parallel to the direction of the energy transport. It can be visualised by a magnet roll model or a slinky. In a free field a sound wave propagates homogeneously in all directions.

The vibrations propagate through the air and can excite other objects. The small air movements can not be observed with the human eyes directly, but their influence on other objects can be demonstrated by simple methods, e.g. a soundgun. This effect is used for hearing. The sound is bundled in the ear canal and excites the ear-drum. The induced vibrations were amplified in the inner ear and translated in electric signals which can be analysed further by the brain.

Vibrations generated by a sound source travel through the air and can excite vibrations of other objects. The vibrations propagate in all directions. Sound can also travel through liquids and solids but not through vacuum..

In contrast to electromagnetic waves, sound waves depend on a transmitting medium. Sound can travel through gases, liquids and solids, but not through vacuum. There are no sounds in outer space although some science fiction movies may imply it. A bell ringing in a vacuum tank can not be heard.



Longitudinal wave created in a slinky

Sounds travelling through solids seem to be louder then sounds transmitted through air, because in most cases the sound is transmitted through smaller cross-sections compared to an omni-directional transmission in air. Due to this bundling of the sound waves in the solids more energy is transported to the receiver.

Speed of sound

The sound needs a certain time to travel through a media. The speed of the sound waves depends on the media they pass through. The speed of sound in air at 20°C amounts to 343 m/s. With this information the distance of a thunder storm can be determined. The light of a flash reaches the eyes immediately. Counting the seconds between the lightning and its thunder and dividing it by three gives a rough estimate of the distance to the thunderstorm in kilometres.

The propagation of sound in air over long distances depends on different factors. If the noise of a remote motorway is still annoying or the words of a distant caller can be understood depends on different mechanisms. It can be influenced by constructional situations as well as for example by the weather. Like light, sound waves can be diffracted and refracted.

Absorption of air

When travelling through the atmosphere the sound energy is partially absorbed by molecular friction and other molecule properties. The

absorption factor depends on the air temperature, the air humidity and the frequency of the sound wave. Usually it is given in dB/100m. With increasing temperature as well as with increasing humidity the absorption of sound decreases. Higher frequencies are absorbed much stronger than lower frequencies. That is why lower tones can travel longer distances than higher tones.

Refraction

Because the sound speed depends on the temperature, the temperature layering of the air influences the sound propagation. It is quite similar to the refraction of light. If the temperature decreases with increasing altitude, the sound is refracted upwards and at a certain distance of the source an area of reduced audibility occurs. For sound sources at ground level the distance of those acoustic shadow zones is about 200m. Contrary, an air temperature increasing with the altitude (inversion) results in a downward refraction of the sound waves. This causes a good audibility over large distances. In an analogous manner the sound propagation opposite to the wind direction results in an acoustic shadow zone of reduced audibility, whereas propagation in the wind direction causes a large range of audibility. The reason is that in both cases the wind velocity increases with increasing height due to the friction in the atmospheric boundary layer. The fluctuations in the sound level due to the weather condition at distances of 500 to 1000m can amount up to 20 to 30 dB.

Diffraction

Diffraction is a mechanism enabling sound waves to enter shadow zones, e.g. in shadowed areas behind buildings or through a small slot of an open window. Large low-frequency waves are diffracted stronger than short high-frequency waves.

Reflection

If sound waves strike the ground or a wall, they are reflected. Depending on the acoustic properties of the ground more or less sound energy is absorbed by the ground or the waves are reflected with a phase shift. A fluffy, porous surface, e.g. fresh snowfall absorbs more sound energy than hard and flat surfaces like a concrete wall. The highest ground absorption can be reached with the combination of a soft ground and a flat incidence angle, meaning the sound source and receiver are located close to the ground.

1.5 What makes sounds become noise and how to assess it ?

We define noise as an unwanted sound, annoying to people. Noise influences the human efficiency negatively and can cause damage to one's health. Noise is not an exactly measurable physical quantity, but is perceived distinctly by every person. However, to measure the noise physically, Graham Bell (1847-1922) invented the logarithmic sound pressure level (SPL) or sound level Lp, inspired by the human ear. It is a measure of the effective sound pressure p of a sound relative to a reference value p0 =2*10-5 Pa, which is the threshold of human hearing (the quietest sound we can hear). It is measured in decibels (dB) above a standard reference level and defined by:

$$Lp = 10 \cdot \log_{10}\left(\frac{p^2}{p_0^2}\right) dB$$

The sound pressure changes with the distance to the sound source. In a free field it is inversely proportional to the distance of a point-shaped sound source. In conclusion the measured sound pressure level also depends on the location of the measurement. The sound pressure describing the pressure fluctuations is small compared to the air pressure of 101.325 kPa at sea level. An overview of sound pressures and sound pressure levels are given in the table.

Situation	Distance to sound source measurement location	Sound pressure p (Pa)	Sound pressure p Level L_p (dB)
Jet plane	30m	630	150
Gunshot	1m	200	140
Threshold of Pain	At the ear	100	134
Damage of hearing at short term exposure	At the ear	>20	120
Fighter jet	100m	6.3 - 200	110-140
Compresse air hammer/ music club	1m/At the ear	2	100
Damage of hearing at long term exposure	At the ear	>0.36	85
Main Road	10m	0.2 - 0.63	80 -90
Car	10m	0.02 - 0.2	60 -80
Television at room volume	1m	0.02	ca. 60
Spaeking person (normal chat)	1m	$2 - 10^2 - 2 - 10^2$	40-60
Very quiet Room	At the ear	$2 - 10^4 - 6.3 - 10^4$	20-30
Rustling of leaves quiet breathing	At the ear	6.32^{-5}	10
Threshold of human hearing at 2kHz	At the ear	$2 - 10^{-5}$(20 uPa)	10

Examples of sound pressure and sound pressure levels

The logarithmic scale causes unusual relations when calculating sound levels. Thus using two similar in phase oscillating sound sources instead of only one, the sound level increases by 3dB. At free sound propagation a doubling of the distance to the sound source causes a reduction of the sound level by 6 dB, e.g. 68 dB in 100 m distance, 74 dB in 50 m distance and 80 dB in 25 m distance to the sound source. The sensitivity of the human ears to high and

low tones is lower. If the frequency dependency of the human hearing is taken into account using the so called A-weighting curve the sound level in dB(A) is obtained. Our ears can detect sounds from 0 dB(A), the threshold of human hearing. At 120 dB(A) the threshold of pain for human hearing is reached.

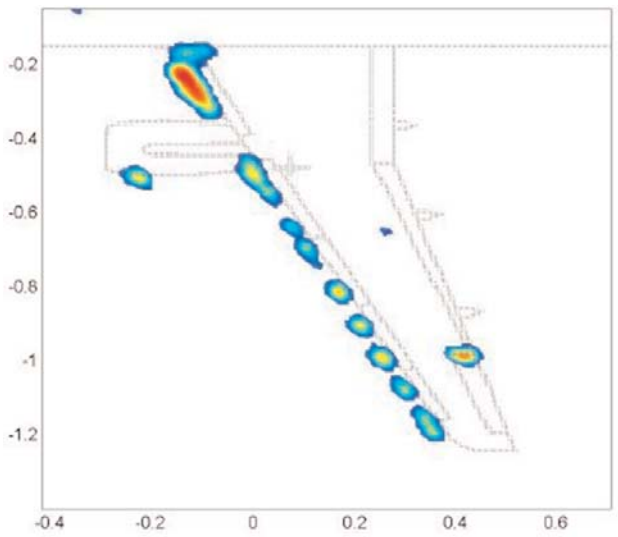
1.6 How to detect noise sources ?

Humans are able to detect the direction from which a sound is coming. This is possible because of a time lag of a sound wave reaching locations a different distances to the sound source. This principle is also used by microphone arrays, also called acoustical cameras, to detect sound sources. A microphone array consists of multiple microphones in well known positions. Knowing the speed of sound and the position of the microphones, for every sound source position the time lag between the sound generation at the source and its arrival at the particular microphones can be determined. The signals of the microphones are shifted by the determined time lag for a particular sound source position, so they coincident on the time axis. Then the signals of all microphones can be added up resulting in a gain of the signal generated by the chosen sound source position, whereas signals generated by other sources are repressed. In further evaluation the frequencies and amplitudes of the signals are analysed. Doing this analysis for a complete observation area, a kind of a sound map can be obtained, visualising the sound source locations and sound level. That is why microphone arrays are also called acoustic camera.

1.7 Noise reduction

The principles of noise generation, sound propagation and wave properties of sound result in different strategies of noise reduction. The optimal approach is noise reduction at the sound source itself. It is easy to make a radio quieter or just switch it off. A minimisation of traffic noise at the sound source, e.g. cars, trains and aircrafts, is much more complicated.

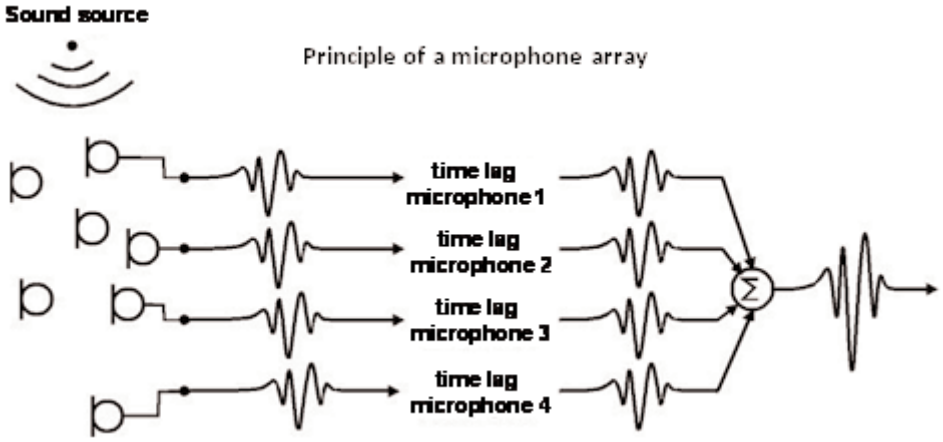
Thus research about noise optimized design of vehicles is an important challenge. But the re-design of cars, trains and especially aircrafts deliver rather long-term improvements, because the development of new vehicle takes a certain time. A quite simple short-term method to reduce traffic noise is speed limitation. Therefore close to towns speed limits are enforced to control the noise of the road traffic. Also for aircrafts a speed reduction will lead to a noise reduction, but one has to take into account, that the aircraft must not go below the minimum air speed to keep it flying.



Aerodynamic sound sources on a half model in a wind tunnel at 70 m/s

The increase of the distance to a sound source is a simple noise reduction method based on sound propagation, because the sound level decreases with increasing distance. The absorption of sound by the air contributes to a noise reduction as well. However, it is not always possible to reduce noise by increasing the distance. Another option for noise reduction is the use of sound insulating walls made of sound absorbing material.

Active noise control or anti-noise uses the interference of two or more sound waves to attenuate the sound. A noise-cancellation speaker emits a sound wave with the same amplitude but with inverted phase (also known as anti-phase) to the original sound, so effectively both waves cancel each other out. Noise-cancelling headsets are an example of active noise control. A microphone at the headphones measures the environmental noise and an inverted signal is generated in the headset to cancel the unwanted sound at the eardrum. Additionally, the headphones can play useful sounds like language. These kinds of headsets are used for helicopter pilots to attenuate the noise of the helicopter blades and enable a communication with the ground control and other passengers. For large areas noise cancellation is more difficult as the three dimensional wave fronts of the unwanted sound and the cancellation signal could match and create alternating zones of constructive and destructive



interference. In small enclosed spaces (e.g. the passenger compartment of a car) a global cancellation can be achieved via multiple speakers and feedback microphones.

Ear protections, like earplugs or sound isolation headphones, are the final possibilities to protect the hearing from damage due to too much noise, if no other method is working. The use of such protection means is mandatory in the environment of loud machinery.

1.8 What causes the airplane noise?

Aircraft noise is noise pollution produced by any aircraft or its components, during various phases of a flight: on the ground while parked such as auxiliary power units, while taxiing, on run-up from propeller and jet exhaust, during take off, underneath and lateral to departure and arrival paths, over-flying while en route, or during landing.

The noise originates from three main sources:
• Aerodynamic noise
• Engine and other mechanical noise
• Noise from aircraft systems
• Aerodynamic noise

Aerodynamic noise arises from the airflow around the aircraft fuselage and control surfaces. This type of noise increases with aircraft speed and also at low altitudes due to the density of the air. Jet-powered aircraft create intense noise from aerodynamics. Low-flying, high-speed military aircraft produce especially loud aerodynamic noise.

The shape of the nose, windshield or canopy of an aircraft affects the sound produced. Much of the noise of a propeller aircraft is of aerodynamic origin due to the flow of air around the blades. The helicopter main and tail rotors also give rise to aerodynamic noise. This type of aerodynamic noise is mostly low frequency determined by the rotor speed.

Typically noise is generated when flow passes an object on the aircraft, for example the wings or landing gear. There are broadly two main types of airframe noise:

Bluff Body Noise (circular cylinder - fuselage) - the alternating vortex shedding from either side of a bluff body, creates low pressure regions (at the core of the shed vortices) which manifest themselves as pressure waves (or sound). The separated flow around the bluff body is quite unstable, and the flow "rolls up" into ring vortices - which later break down into turbulence.

Noise - when turbulent flow passes the end of an object, or gaps in a structure (high lift device clearance gaps) the associated fluctuations in pressure are heard as the sound propagates from the edge of the object. Engine and other mechanical noise.

Much of the noise in propeller aircraft comes equally from the propellers and aerodynamics. Helicopter noise is aerodynamically induced noise from the main and tail rotors and mechanically induced noise from the main gearbox and various transmission chains. The mechanical sources produce narrow band high intensity peaks relating to the rotational speed and movement of the moving parts. Aircraft Gas Turbine engines (Jet Engines) are responsible for much of the aircraft noise during takeoff and climb. With advances in noise reduction technologies - the airframe is typically noisier during landing.

The majority of engine noise is due to Jet Noise - although high bypass-ratio turbofans do have considerable Fan Noise. The high velocity jet leaving the back of the engine has shear layer instability (if not thick enough) and rolls up into ring vortices. This of course later breaks down into turbulence.

Noise from aircraft systems

Cockpit and cabin pressurization and conditioning systems are often a major contributor to noise within cabins of both civilian and military aircraft. One of the most significant sources of cabin noise from commercial jet aircraft other than the engines is the Auxiliary Power Unit (or APU). An Auxiliary Power Unit is an on-board generator used in aircraft to start the main engines, usually with compressed air, and to provide electrical power while the aircraft is on the ground. Other internal aircraft systems can also contribute, such as specialized electronic equipment in some military aircraft.

Particular attention must be paid to structural design and material selection so that vibrations are transmitted less effectively. For reducing the cabin noise, aircraft cabins now incorporate more advanced materials included in sound-absorbent seats, cabin walls, acoustic isolation and electronic noise cancellation systems.

For anyone living next to an airport, constant noise from aircraft can pose serious long-term health problems caused by stress, lack of concentration and loss of sleep. The number of flights is expanding very fast, and we need to be looking for new technologies that reduce noise more efficiently. Airplanes typically land in

"staircase-like" paths, reducing their altitude in a series of steps towards an airport. Each step requires a noisy engine thrust to level out the aircraft after moving to a lower level. Mostof the noise is generated at the lowest step. Some airports are already using an alternative "continuous descent approach," in which the aircraft maintains a cruise altitude until it is relatively close to an airport, at which point it makes an even, continuous descent to the runway. This can more than halve the noise level. It can also reduce fuel emissions and slightly shorten flight time, since the plane operates at lower power settings, maintains higher altitudes and speeds, and takes more direct paths to the runway.

Noise reduction in air transport

To reduce the noise impact in the vicinity of airports aeronautical research also aims for noise reduction at the sound source. Great successes were already achieved in the past, comparing the sound level of old and modern airplanes. Nevertheless experts estimate that the noise level of the engine can be further reduced by nearly 10 dB. So, modern concepts for noise reduction of aircrafts must be investigated, especially taking into account the long design process of new aircraft types. For modern aircrafts the noise generated by the jet of the engines could already be improved a lot compared to older models. Nowadays the fan located in the intake of the aircraft engines comes to the focus of the acoustic research. One possibility investigated is the usage of active noise control to attenuate the quite annoying tonal components of the fan noise. The feasibility of the classical approach of a loudspeaker-microphone combination was already demonstrated by researchers. A new approach is the usage of aerodynamic anti-noise sources, like well-directed air injection by pressurized air, which is more practicable for this application.

Aircraft noise is dominated by the noise of the engines, so the airframe noise due to air flow is only relevant for the approach at low thrust of the engines. The base for the reduction of the airframe noise is a detailed analysis of the mechanisms of aerodynamic sound generation. Wind tunnel tests showed for example that a main component of the airframe noise is generated by the slat of the high lift system of the wing. Such wind tunnel tests use microphone arrays to detect and visualize sound sources which enable the investigation of the effectiveness of several approaches of noise reduction. The measured acoustic data are also used to validate numerical methods to predict aerodynamic sound sources. Those prediction tools can be used in an early stage of the design process to

optimize an aircraft acoustically. A further approach is the investigation of noise-optimised take-off and landing procedures. It is mainly based on an optimisation of the flight altitude, the engine performance, speed and the aerodynamic configuration of the aircraft. At the enlarged airport area a reduction of the noise level by nearly 3 dB is possible. There are mainly two possibilities to reduce the aircraft noise. Firstly, there is the reduction of the thrust of the engine, because the engines have a large sound emission. Secondly, the distance between aircraft and ground can be enlarged, because the atmosphere attenuates the noise. To optimize the take-off and landing procedures a lot of criteria must be taken into account. Beside the noise reduction also economic and safety aspects must be considered. New procedures must not lead to additional stress for the pilots. To avoid a loss of the airport capacity they must not be more time consuming. For economical and environmental reasons a reduction of fuel consumption is desired. Finally noise reduction is an inter-disciplinary challenge, for which the overall system of an aircraft and many different requirements must all be considered to find the best compromise.

2

2. Drag

2.1 What is friction ?

Friction is the force that holds objects in motion back — or so it may seem.

Friction is the rubbing between solid objects. For instance, when you rub your hands together you will feel friction, the force that resists motion and creates heat. Friction can be used for positive purposes: athletes wear sneakers on a gym floor so that they don't fall down while running.

Actually, friction is essential for everyday living.

Imagine a world without friction:
NO WAY to drive a car on the road,
NO WAY to walk on pavement,
NO WAY to pick up the ham sandwich or your phone.

Friction may seem like an enemy to the hearty physics follower, but it's also your friend.

Friction comes from the interaction of surface irregularities. If you put together and press two surfaces that have plenty of microscopic pits and projections, you produce friction. And the harder you press thos two surfaces, the more friction you create as the irregularities interlock more and more.

2.2 What is drag

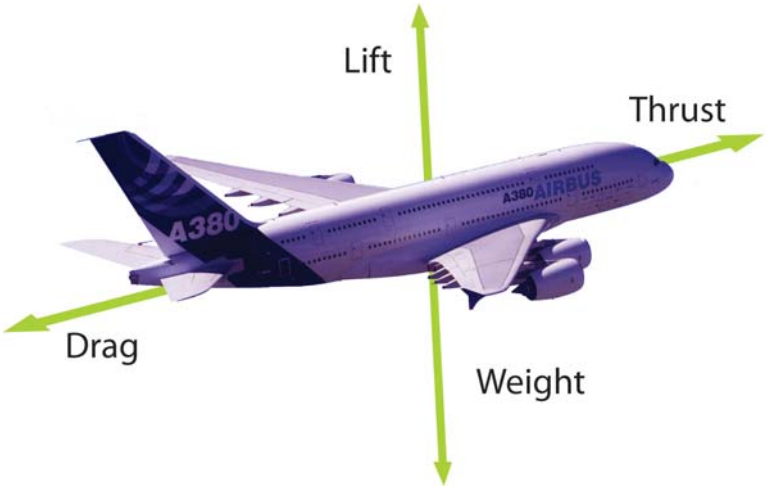
Drag is the friction between a solid object and fluid (liquid or gas). For instance, when you sail a boat across a lake, the force that resists the movement of the boat through the water is drag. Heat is generated by drag just as heat is generated by friction.

When you ride a bicycle at high speed, drag makes the bike harder to pedal and increase speed. Racing cyclists crouch over their handlebars to decrease drag and increase speed.

Which are the factors influencing drag?

As with aircraft lift, there are many factors that affect drag. We can group these factors into those associated with the object, those associated with the motion of the object through the air, and those associated with the air itself.

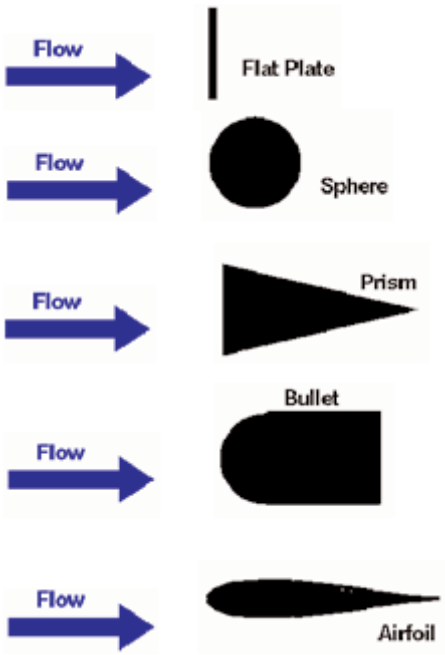
a) The Object: Shape and Size
b) The Motion: Velocity and Inclination to Flow
c) The Air: Mass, Viscosity, Compressibility



You can experience drag at home in your bath tub or at school in a tank filled with water. Try to move your hand through the water, first with your fingers put together and facing the water and then with your palm facing the water. In which way the movement is easier?

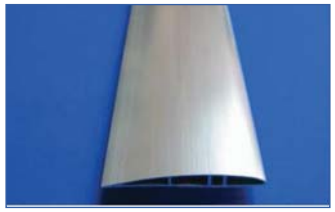
When a solid body is moved through a fluid (gas or liquid), the fluid resist the motion. The object is subjected to an aerodynamic force in a direction opposed to the motion which we call drag. This is the force that opposes movement of a boat through the water.

This is the force that opposes movement of a plane through the air.



2.3 The Object

Geometry has a large effect on the amount of drag generated by an object. As with lift, the drag depends linearly on the size of the object moving through the air. The cross-sectional shape of an object determines the form drag created by the pressure variation around the object. The three dimensional plan form shape affects the induced drag of a lifting wing. If we think of drag as aerodynamic friction, the amount of drag depends on the surface roughness of the object; a smooth, waxed surface produces less drag than a roughened surface. This effect is called skin friction and is usually included in the measured drag coefficient of the object.



Rough surface: produces a big amount of drag.

Smooth surface: the surface of a plane is very smooth and polished, producing a small amount of drag.

Between all the shapes in the next picture, the smallest amount of drag is produced by the aerodynamic profile (airfoil).

2.4 Motion of the Air

Drag is associated with the movement of the aircraft through the air, so drag depends on the velocity of the air. Like lift, drag actually varies with the square of the relative velocity between the object and the air. The inclination of the object to the flow also affects the amount of drag generated by a given shaped object. If the object moves through the air at speeds near the speed of sound, shock waves are formed on the object which create an additional drag component called wave drag. The motion of the object through the air also causes boundary layers to form on the object. A boundary layer is a region of very low speed flow near the surface which contributes to the skin friction.

2.5 Properties of the Air

Drag depends directly on the mass of the flow going past the aircraft. The drag also depends in a complex way on two other properties of the air: its viscosity and its compressibility. These factors affect the wave drag and skin friction, which are described above. We can gather all of this information on the factors that affect drag into a single mathematical equation called the Drag Equation. With the drag equation we can predict how much drag force is generated by a given body moving at a given speed through a

given fluid.

2.6The Drag Equation

Drag depends on the density of the air, the square of the velocity, the air's viscosity and compressibility, the size and shape of the body, and the body's inclination to the flow. In general, the dependence on body shape, inclination, air viscosity, and compressibility is very complex.

One way to deal with complex dependencies is to characterize the dependence by a single variable. For drag, this variable is called the drag coefficient, designated "Cd."

This allows us to collect all the effects, simple and complex, into a single equation.

Reducing drag

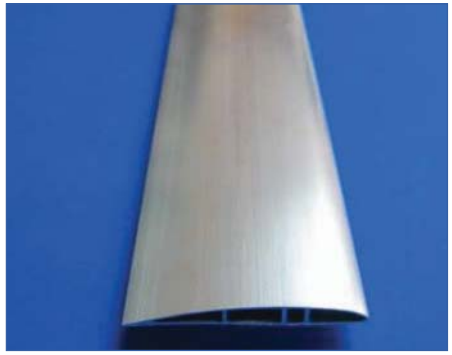
To decrease friction, low-friction materials such as Teflon and other plastics are used. Contact surfaces are designed to be smooth as possible. Lubricants are introduced to reduce friction.

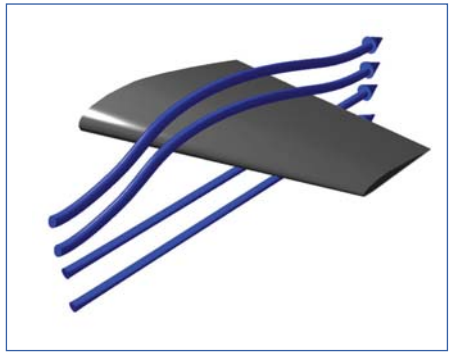
To decrease drag on an airplane, smooth surfaces and a streamlined design are used. In addition, high aspect ratio wings are used as well as an optimum camber.

How can drag be reduced?

1. Using smooth surfaces: the surface of a plane is very smooth and polished, producing a small amount of drag.

2. Streamlined design hat is a flow? A flow is the continuous movement of a fluid, either a liquid or a gas, from one





The drag coefficient Cd contains all the complex dependencies, like the dependence on body shapes, inclination, air viscosity, and compressibility and is usually determined experimentally.

The drag equation states that drag D is equal to the drag coefficient, cd, times the density,ρ, times half of the velocity, V, squared, times the reference area A.

$$D = Cd.\ (\rho.V^2/2).A$$

3

3. Turbulence

3.1 Turbulence in nature

What is a flow? A flow is the continuous movement of a fluid, either a liquid or a gas, from one place to another. Basically there exist two types of flows, namely laminar flows and turbulent flows. Roughly speaking we can say that a laminar flow is a 'simple' flow while a turbulent flow is a 'complicated' flow. We will illustrate what we mean by 'simple' and 'complicated' using the following, simple experiments.

This is a simple experiment to demonstrate the laminar flow:

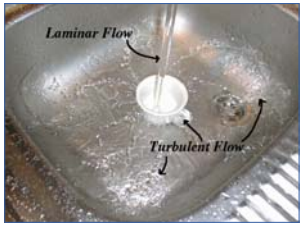
Go to your kitchen sink and open the faucet. The stream of water that emerges from your faucet is very smooth and very regular. The flow of water is smooth because all the water molecules move, at more or less the same speed, in the same direction. This is called a laminar flow. Furthermore, if you did not open the faucet too much, the water will also flow down the drain in a laminar flow.

Now we can define the laminar flow:

Laminar flow is that state of fluid motion which is characterized by same direction, same speed, the move being more or less smoothly.

After you have done the previous experiment, try this simple experiment to demonstrate the turbulent flow:

Place a cup under the stream of water emerging from the faucet. Although the stream is still laminar, the flow pattern of the water in the sink has become very complicated. This is due to the fact that now the water molecules tend to move in different directions at different speeds. Such a flow is called turbulent.



Another example of turbulence you can easily observe at home is in a cup of hot water when you put the tea bag or the flow of water in a boiling pot of water. Put water in a pot and heat it up on your electric cooker. If you wait for a short while, the water will start to move in a laminar way, in a very regular way. If you wait a bit longer bubbles will start to rise from the bottom to the surface and the motions of the water become very complicated or turbulent. In this particular case the turbulence is due to convection.

Convection refers to the movement of molecules within fluids (liquids and gases). Convection is one of the major modes of heat transfer and mass transfer.

Now we can define the turbulent flow:

Turbulence is that state of fluid motion which is characterized by apparently random and chaotic three-dimensional velocity. When turbulence is present, it usually dominates all other flow phenomena and results in increased energy dissipation, mixing, heat transfer, and drag. If there is no three-dimensional velocity, there is no real turbulence. The reasons for this will become clear later; but briefly, it is ability to generate new velocity from old velocity that is essential to turbulence.

Try this simple experiment to visualize the turbulent flow of the smoke generated by a perfumed stick. For the first few centimeters, the flow remains laminar, and then becomes unstable and turbulent as the rising hot air accelerates upwards. After that you can place a pen or an eraser in the smoke (in the first few centimeters when the flow is still laminar) and observe what is happening. The smoke will avoid the obstacle and will start to flow in very different directions and different speeds, it will be very unstable and turbulent.

Where does turbulence occur?

Turbulent motions are very common in nature. Turbulence occurs nearly everywhere: in the oceans, in the atmosphere, in rivers, even the flow of blood in arteries, oil transport in pipelines, lava flow, flow through pumps and turbines, and the flow in boat wakes and around aircraft wing tips, even in stars and galaxies.

In fact it is easier to find a turbulent flow than a flow that is really laminar.

Here are a few examples of turbulent flows: smoke rising from a perfumed stick; similarly, the car exhaust fumes and the dispersion of pollutants in the atmosphere are governed by turbulent processes; the wake of a ship or submarine is turbulent; the rain water on the road; the swirls and eddies in a fast flowing river are turbulent.

How is turbulence generated?

How easily a fluid becomes turbulent depends to a large extend on its viscosity. Simply speaking, viscosity is the resistance of a fluid (either a liquid or a gas) to movement. The more viscous a fluid is the less likely it is to become turbulent. Thus, water and air which have a low viscosity can become turbulent relative easily, while honey or syrup, which are very viscous, tend not to become turbulent.

There are many ways in which a fluid can become turbulent.

1. Heating: If you heat a fluid at the bottom and cool it at the top the fluid becomes turbulent due to convection. This is what happens in a boiling pot of water.

2. Pressure: The water stream that emerges from the faucet in the picture above is laminar. This is because the faucet is not fully open and the pressure in the pipe is fairly low. If you open the faucet to its full extend the water will shoot out in a very wild manner. When the faucet is fully open the pressure in the pipe is very large.

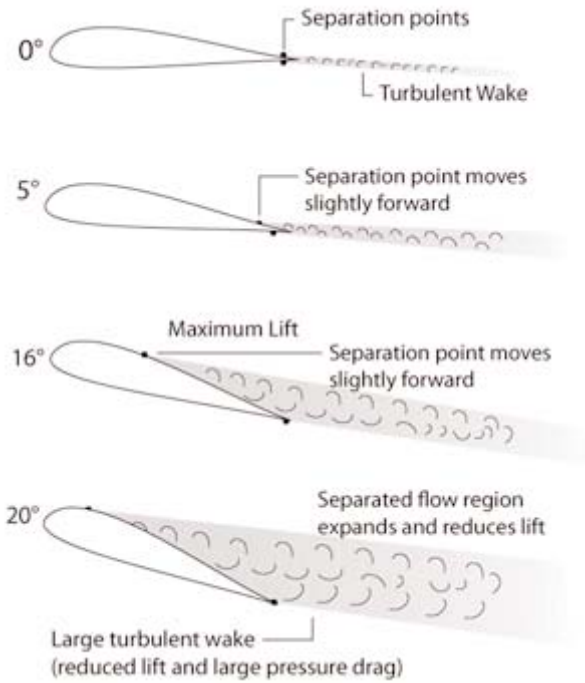
3. An obstacle introduced in the flow.

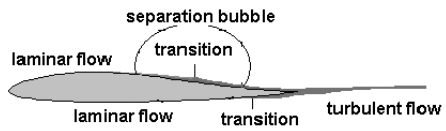
For example, a river may flow smoothly until it hits a boulder, at which point the water around the obstacle will become turbulent as it moves around or over it. In the air, turbulence can be caused by things such as the collision of two weather fronts, or by the formation of a storm. Air turbulence can also be caused by obstacles on the ground, ranging from mountains to buildings.

The agitated, irregular motion usually involves movement at various rates of speed, and a number of factors can influence the movements of liquids and gases. This is why turbulence on an aircraft can be difficult to predict.

3.2 Turbulent flow around aircraft

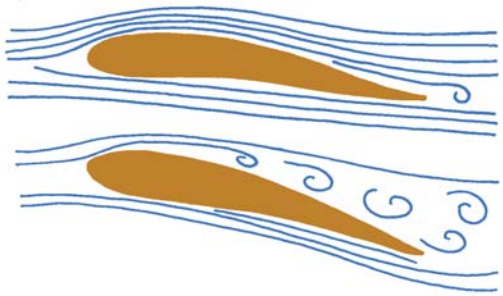
All solid objects traveling through a fluid (or alternatively a stationary object exposed to a moving fluid) acquire a boundary layer of fluid around them where viscous forces occur in the layer of fluid close to the solid surface. Boundary layers can be either laminar or turbulent. A reasonable assessment of whether the boundary layer will be laminar or turbulent can be made by calculating the Reynolds number of the local flow conditions. The flow can become unstable, and it can experience transition to a turbulent state where large variations in the velocity field can be maintained. If the disturbances are very small, as in the case where the surface is very smooth, or if the wavelength of the disturbance is not near the point of resonance, the transition to turbulence will occur at a higher Reynolds number than the critical value. So the point of transition does not correspond to a single Reynolds number, and it is possible to delay transition to relatively large values by controlling the disturbance environment. At very high Reynolds numbers, however, it is not possible to maintain laminar flow since under these conditions even minute disturbances will be amplified into turbulence. The area of separation is called separation bubble.

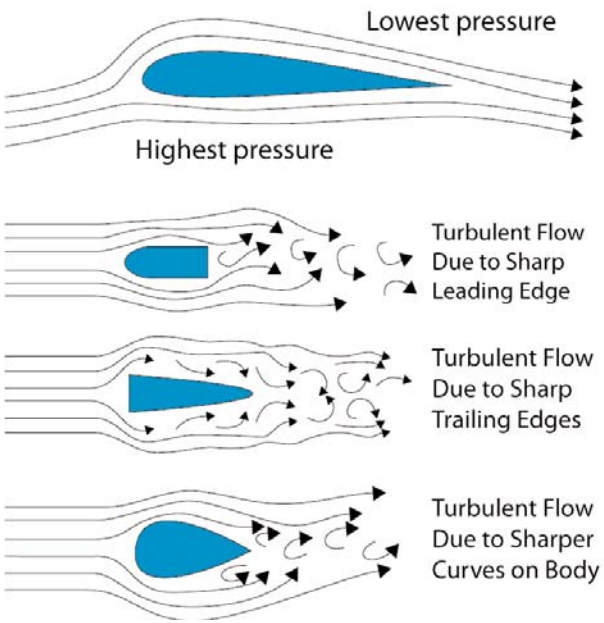




The boundary layer is that layer of fluid in the immediate vicinity of a boundaing surface.

The Reynolds number, Re is a dimensionless number that gives a measure of the ratio of inertial forces to viscous forces.





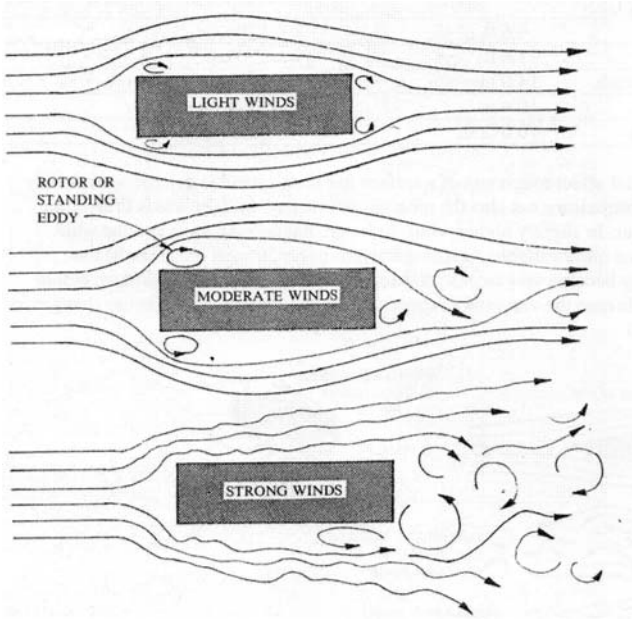
3.3 What is the turbulence wake?

Turbulence wake is the turbulence that forms behind an aircraft as it passes through the air.

All aircraft produce wake turbulence, which consists of wake vortices formed any time an aerofoil is producing lift.Lift is generated by the difference in pressure over the wing surfaces. The lowest pressure occurs over the upper surface and the highest pressure under the wing.

Air will want to move towards the area of lower pressure. This causes the air to move outwards under the wing and curl up and over the upper surface of the wing. This starts the wake vortex. The pressure differential also causes the air to move inwards over the wing. Small trailing edge vortices, formed by outward and inward moving streams of air meeting at the trailing edge, move outwards to the wingtip and join the large wingtip vortex.

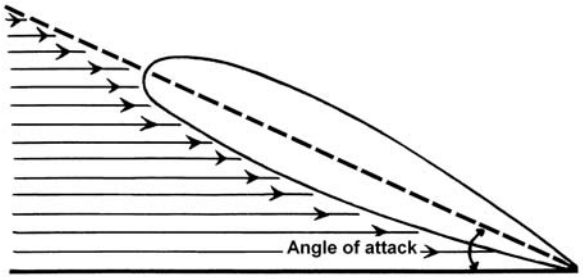
When a solid body is placed in the wind, the air will start flowing differently, creating turbulence.



The degree of turbulence is influenced by fluid viscosity, fluid speed, geometrical obstacles that the fluid encounters in its path. To observe how each influence the turbulences, these variables will be modified one at the time: the speed at which the fluid is flowing, the geometrical shape of the obstacle that the flow encounters in its path and fluid viscosity (using different types of smokes for demonstrations).

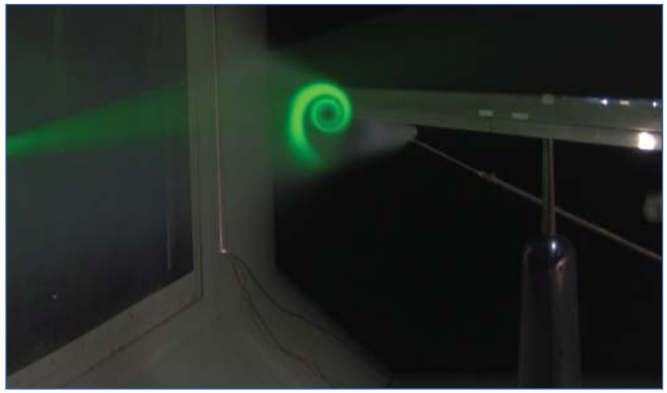
Angle of attack (α) is a term used in fluid dynamics to describe the angle bewteen a reference line on a lifting body (often the chord line of an airfoil) and the vector representing the relative motion between the lifting body and the fluid through which it is moving.

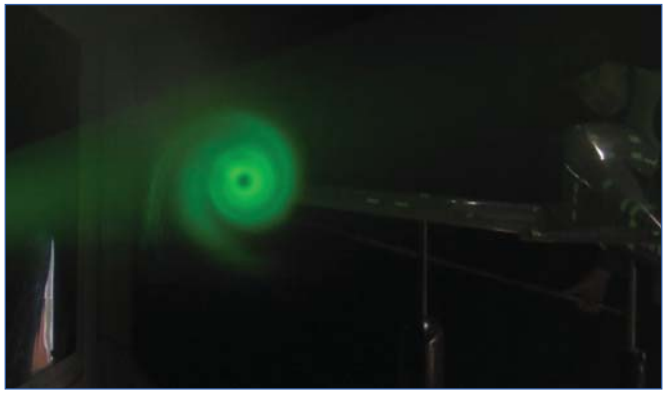
The degree of turbulence is also influenced by the angle of attack. Angle of attack is the angle between the lifting body's reference line and the oncoming flow.



The air flow from the wing of this agricultural plane is made visible by a technique that uses colored smoke rising from the ground. The swirl at the wingtip traces the aircraft's wake vortex (the turbulence that forms behind an aircraft as it passes through the air), which exerts a powerful influence on the flow field behind the plane.

The turbulence generated by plane's wings can be made visible in the wind tunnels, using laser visualizations. (See the laser visualization in INCAS wind tunnel).





Part III

III. How a plane can fly assuring safety ?

1

1. What is security?

1.1 Mission of a transport airplane

The mission of an airplane in the Air Transportation is to transfer passengers and/or goods from one point to another of the Earth safely and comfortably, that is without any danger to them and without any discomfort for passengers.

1.2 Air transportation system

The Air Transportation System consists of all organizations/entities involved in air transportation, that is: Airliners, Airplane Manufactures, Airport Management Companies, Air Traffic Controllers Organizations, Certification Organizations, Aeronautical Information Organizations.

Typical air transport mission profile

Airliner, transport, flight control room

1.3 Security

Security is the technology devoted to avoid any danger to passengers, crew, goods and property from abnormal behaviour of people like for examples in the case of terrorism or hijacking.

Some terroristic actions in air transportation

Air transportation Security is dependent on procedures, applied in the Airport and on the Aircraft.

Control at the Airoport area: passport control, body scanner, baggage control

2. What is safety?

Safety is the technology devoted to avoid any airplane accident, that is without fatalities (deaths) or severe injuries to passengers and crew or to external people or properties, due to some technical failure or to errors in the procedures (human factor).

Active safety has the goal to avoid accidents.

Passive safety (or crashworthiness) has the goal to save people or avoid severe injuries even in the case of an accident, when the airplane is severely damaged.

Safety pays a role in all Air Transportation System and it is involved
- in the design, the manufacture of an aircraft, £
- in its operational utilization and maintenance

The design and manufacture requirements involving safety are fixed by Certification Organizations and compliance to them has to be demonstrated by calculation and/or testing.

Some airplanes accidents

Airplane crash research at NASA

Aircraft crash research at CIRA

2

The safety technology has gradually improved in aeronautical history, but applied research continues to decrease the number of accident and fatalities or severe injuries in the air transportation.

Parameters to analyse the safety level are :
-the number of accidents for the total number of flights;
-the number of accident for number of km of flight multiplied the global number of passengers (active safety);
-the number of fatalities or severe injuries for number of km of flight multiplied the number of global passengers (active and passive safety);

Today the safety measure of air transport is 0,05 deaths per billion passengers * km; 6 times saver thanCar Transportation.

A lot can be the sources of accidents in Air Transportation: structural failures, stability and control problems, navigations and guidance problems, meteorological problems (extreme turbulence, lighting, etc.), and so on.

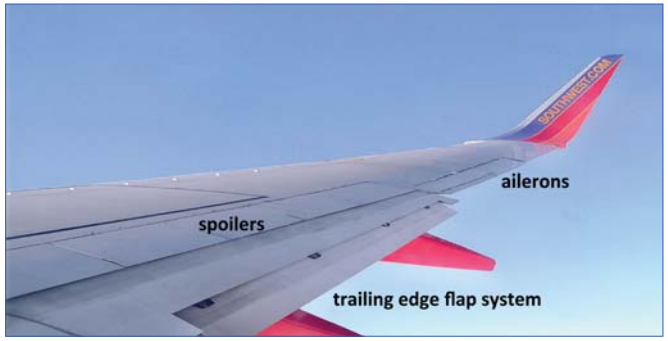
Just some of them are discussed in this cycle of lessons.

3. Which material for a transport airplane structures?

3.1 Which forces act on a flying airplane?

Wing

The main function of an airplane wing is to develop lift. The lift is the result of elementary forces due to pressure change on the wing generated in its motion through the air. Lift has to be adequate for all flight conditions. For the take off and landing phase an aircraft utilizes leading and trailing edge flaps (camber and surface effect). In many airplanes the wing often stores fuel. Moreover the wing develops a large part of drag. So the wing has to withstand to global and local forces: aerodynamic forces, weight and inertial forces in accelerated motion.



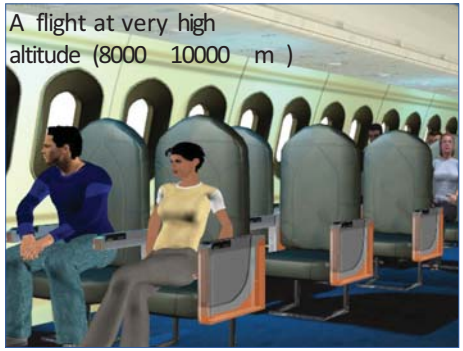
Airplane wing and some of its components

Fuselage

The fuselage contains people and/or goods in the cabin and pilots in the cockpit. For pressurized fuselage, structures have to withstand the external and internal pressure difference (at 10000m altitude the atmospheric pressure is about 1/3 of the pressure at see level). Moreover the fuselage has to withstand global and local forces as aerodynamic forces, weight and inertial forces, impact on the ground forces, generated by itself or transferred by other parts of the aircraft. The fuselage has to assure the liveability and the comfort of passengers and crew.

External pressure

1/3 the value of sea level



A draft view of an airplane cabin

40°C

The tail of a very famous airplane

Empannage

At the back of an airplane there is the horizontal tail, with a fixed part (stabilizer: 2) and a mobile part (elevator: 1) and a vertical tail, with a fixed part (fin: 3) and a mobile part (rudder: 4). The fixed part with the mobile part, in fixed condition) are utilized for motion stability. The mobile parts (elevator and rudder) together with aileron on the wing are utilized to control, to maintain or change airplane angular position about its centre of gravity.


A today airplane turbofan engine

Propulsion system

The propulsion system (propulsion devices: propeller or nozzle and engines) transforms energy and generates the thrust or traction to maintain the adequate speed or accelerate to necessary speed of the airplane in any phase of the flight.

An airplane flying in a straight line motion are acting (for simplification we assume an horizontal flight) are:

• pressure forces (Lift and Drag due to pressure), for which each elementary force is perpendicular to the external airplane surface.

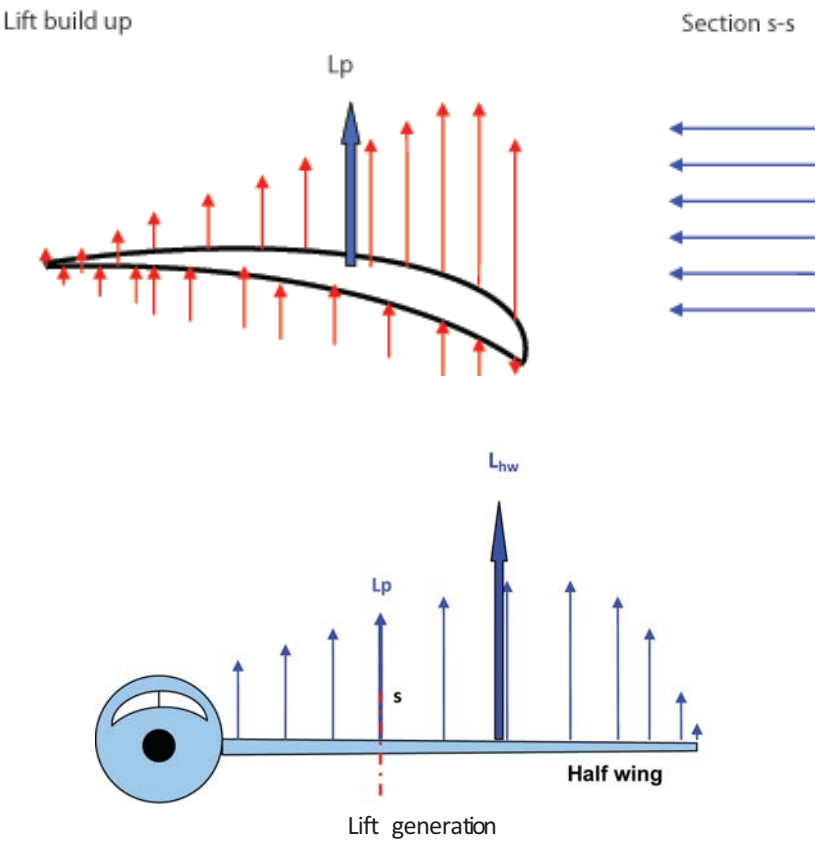
• tangential forces (friction Drag), for which each element is parallel to the external airplane surface

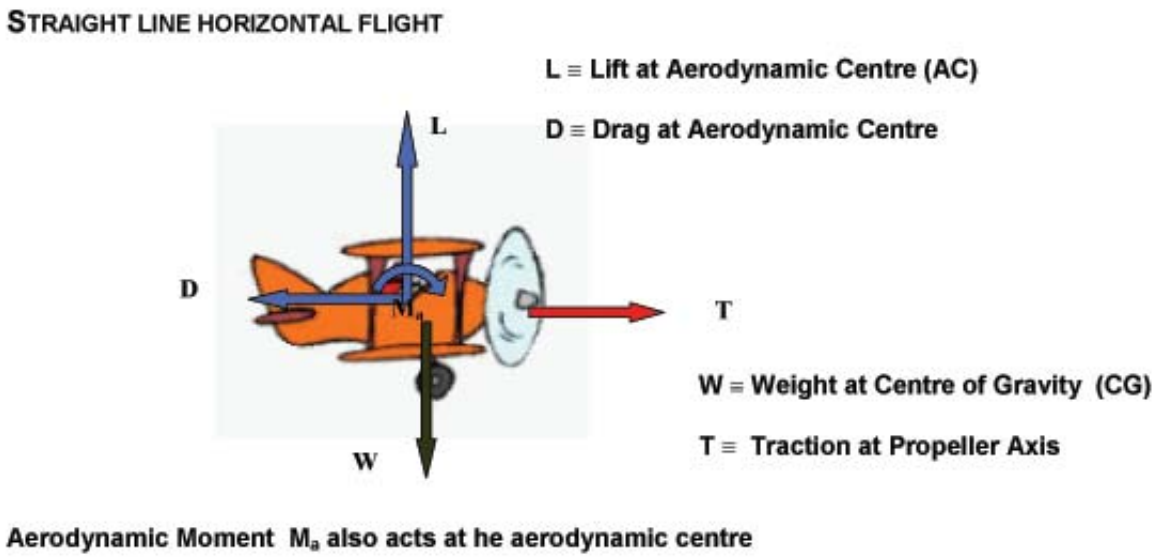
• Force proportional to mass (Weight and Inertial Force)

• Propulsive forces

An airplane flying in curved line motion are acting, besides the above forces also: inertial forces (centrifugal forces).

The forces proportional to the external surface (pressure and tangential forces, that is the aerodynamics forces have as resultant a global force applied at a point called Aerodynamic Centre (AC) and a force moment a straight like passing through that point. The forces proportional to the mass have a resultant at the Centre of Gravity (CG) and a force moment-about a straight line passing through that point.





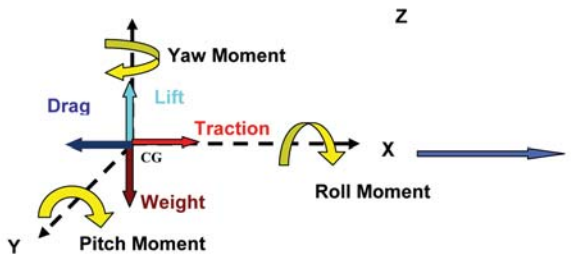
The propulsion system produces the propulsion force (traction or thrust): propeller or nozzle for the airplanes; the engine transforms energy to generates the propulsive forces.

On the upper airfoil surface we have less air pressure than on the lower airfoil surface.

The air pressure difference between upper and lower surfaces generates a local aerodynamic force Lp perpendicular to airflow velocity.

The Lift on a half wing is the resultant of local aerodynamic wing spanwise forces.

If we consider tri-rectangular axis system XYZ with the origin at Center of Gravity, the axis XZ in the symmetry plane of the aircraft, assumed as a rigid body, all the above forces can be broken up in Lift (along Z axis), Aerodynamic Lateral Force (along Y axis), Drag (along X axis), Weight + Inertial Forces (along Z axis, but opposite to Lift,...), Propulsion Force (along X axis but opposite to Drag) and three force moments: Pitch Moment (above Y axis),



Airplane speed in stationary atmosphere

Roll Moment (above X axis) and Yaw Moment (above Z axis). In a correct straight flight all Force Moment are equal to zero, and this is gotten by mobile surfaces (elevator, rudder and ailerons). If we want to change flight parameters the mobile surfaces (called control l surfaces) have to be deflected.

All forces and moment acting on a rigid airplane are reduced to three forces and three force-moments applied at Centre of Gravity.

How solid, liquid and gases withstand loads?

The set of all forces acting considered from the point of view of structural resistance are called < Loads >.

If we consider part of all these forces and moments acting on a single structural element (for simplicity we consider a beam like element), this element can be pulled up (traction), pushed down (compression), sheared (shear force), bended (bending moment) and twisted (torque moment). The structural element will deform itself until the elastic reaction (internal forces) balance the loads.

There is however a limit to structural capability of withstanding loads. This limit depends on the material properties, the geometry and the way loads are applied. So you can have limits for maximum static loads, for structural instability, for aero-elastic problems and for cyclic application of loads (fatigue)

The arch is bended and sheared first by the bowstring and even more by the muscular force of the man.

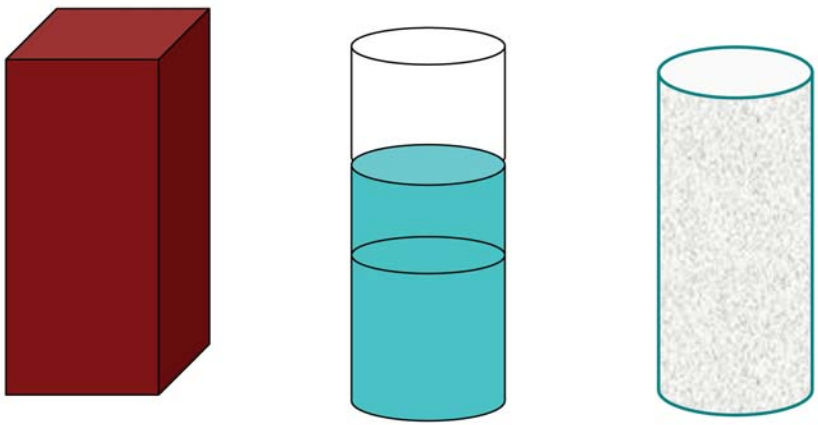
The bowstring is subjected to traction load. On the arrow the bowstring exercise a compression load and the arm of the man is subjected to traction load and soon.

By experience we know that liquids and gases can withstand only compression loads, solids instead can withstand any kind of loads. This is because the differences internal constitution of solid, liquid and gas materials. So an airplane structure must have the characteristics of a solid.

Solids

The general behaviour of solids depends on the internal structures of the material: the particles(atoms/ molecules)/ molecules are in fixed positions. The particles can vibrate around the fixed position.

Solid , Liquid and gas status of matter



Global behaviour of solids, liquids and gases

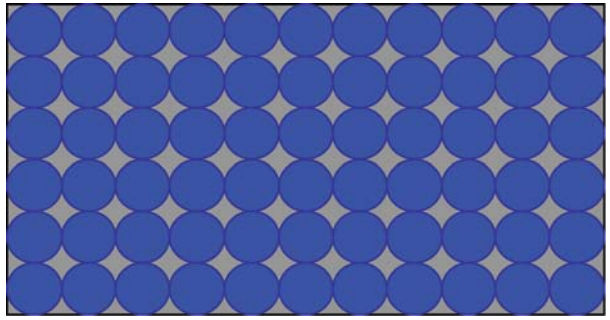
The amount of kinetic energy of all particles is the heat, the mean kinetic energy is just the temperature. (Simple Kinetic Theory of Heat and temperature).

Liquids

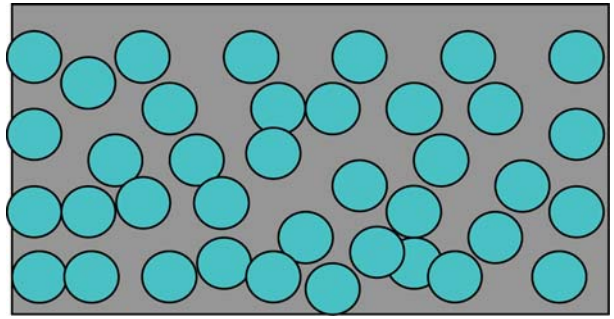
The particles of a liquid (atoms or molecules) have a mean distance of the magnitude of the same diameter of particle diameter. The Particles translate each to respect the others and rotate about a generic axis. Heat and temperatures have the same definition as for gas in the simple Kinetic Theory of Heat and temperature). Because of its mobility their weight tends to push them to full up the lower free space.

Gases

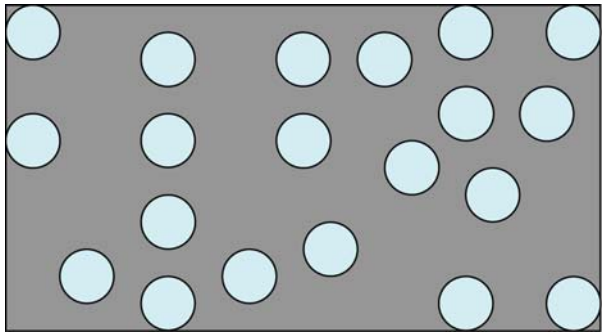
The mean distance between particles is much greater than a particle diameter. The particle free path is very great and velocity is very high. The particle collisions push the gas to fill up the container and so the gas assumes the same form of the container. The particle collisions against the container walls is the <thermodynamic pressure>. Note: The is a physical difference between static pressure and thermodynamic pressure for gases!



Solids



Liquids



Gases

4

4. A flight at high altitude

4.1 Life inside the airplane cabin and cock-pit

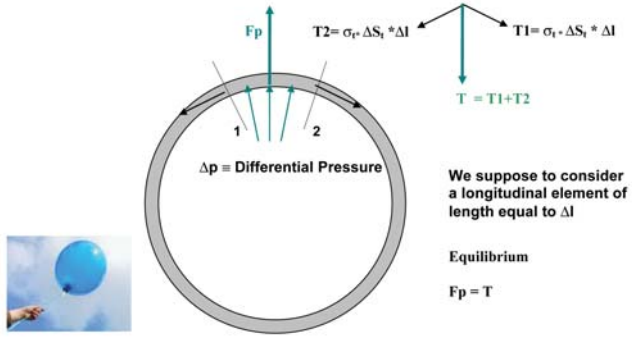
Modern airplane with jet propulsion flies at a cruise altitude between 8000 and 11000 m. At that altitude the pressure is about 1/3 than at sea level and the temperature is about – 40 °C. These conditions inside the cabin and cockpit the life for passengers and crew not possible. To solve that problem air is spilled out from engine and conditioned to allow living.

4.2 How works a pressurized fuselage structure?

To allow life inside the cabin/cockpit there is a very high pressure difference between the internal and external skin of the fuselage when flying at high altitude. So the skin has to be designed to withstand this differential pressure.

4.3 How the fuslage skin withstands forces dur to differential pressure

The resultant pressure force Fp is acting on fuselage skin element 1-2, with a thickness? This pressure force is balanced by the resultant



of internal traction force that the skin external to that element does exert on it. It works as an inflated balloon. When a balloon flows up away the internal thermodynamic pressure is more and more greater than the atmosphere static pressure (decreasing with altitude), and at the end the balloon explodes.

4.4 Ice problem

We are used to think that water turn to ice at 0 °C, but this is only true at sea level and inside the freezer. If the atmosphere pressure is less than at sea level, the water is very clean it is still liquid even at temperatures very lower than zero.

The clouds are made either of little ice crystal or (more often) of very small water droplets. In this case they are not transformed in ice because the two above explanations.

If an airplane meets a water cloud, the water freeze on the wing surfaces instantly, or on some other parts of the airplane (both acting as condensation nuclei) .

The ice on the wing produces a degradation of aerodynamic characteristics of the wing and can cause a critical stall condition or a loss of control capability. The ice on engine inlets can cause a flame out of the engine or even an engine explosion.

The ice accretion is also dangerous for some important probe instrumentation as anemometer, altimeterter, etc.

The solve the problem, modern aeronautic technology utilises de-icing systems : the ice does form but the deicing system breaks it down; in other cases heat sources are utilized anti-icing system, in this case the ice does not form at all. The anti-icing system is normally used for engine inlet or for probe instrumentation.

Applied Researches are going all over the world to improve the ice accretion knowledge and protection on Air Accretion and Protection.

That research involves:
- Ice Wind Tunnel Simulating the flight at actual ice accretion condition;
- improving on design of anti-icing and de-acing systems;
- better knowledge of meteorological condition related to the occurrence;
- improvement of the procedures in ice condition flight ;

Cube ice at sea level

Cirrus clouds are made of ice crystals

Water clouds

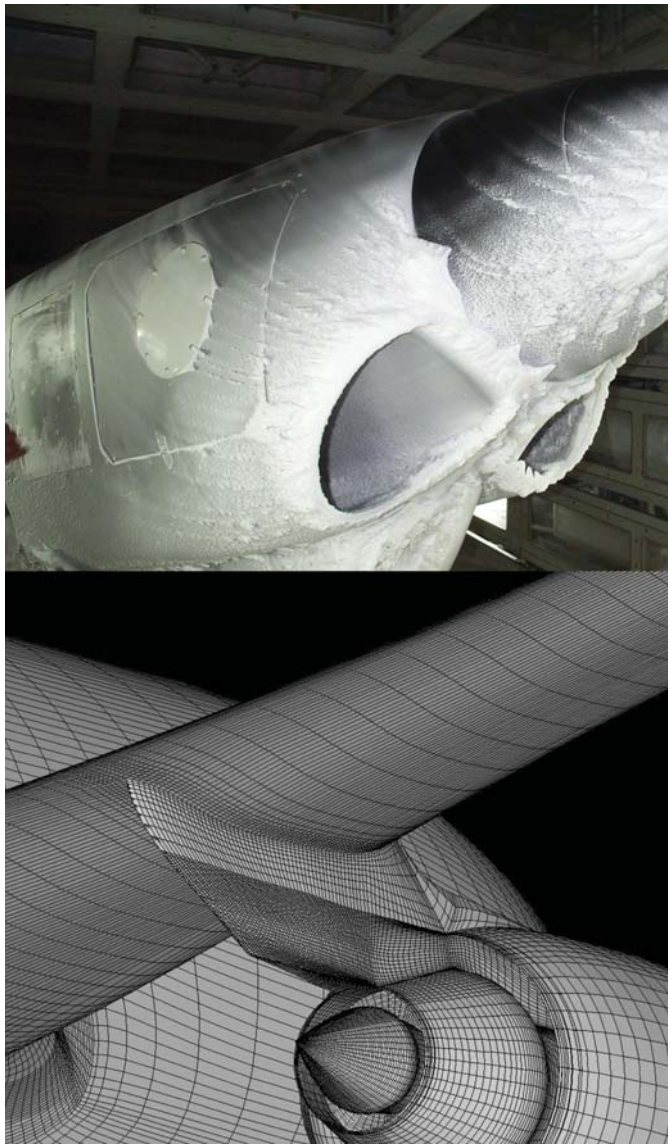


Fig 4.3 Experimental and numerical applied research on ice problems in Air Transport Airplane

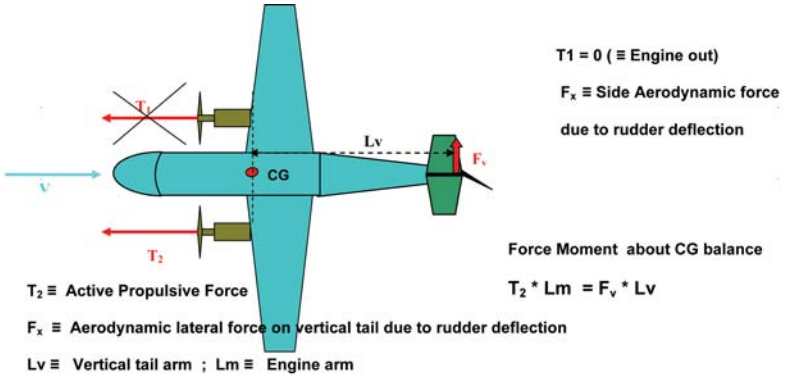
5. Critical situations in take off or landing flight phase

- Improvement on numerical tools to understanding ice accretion on an airplanes;

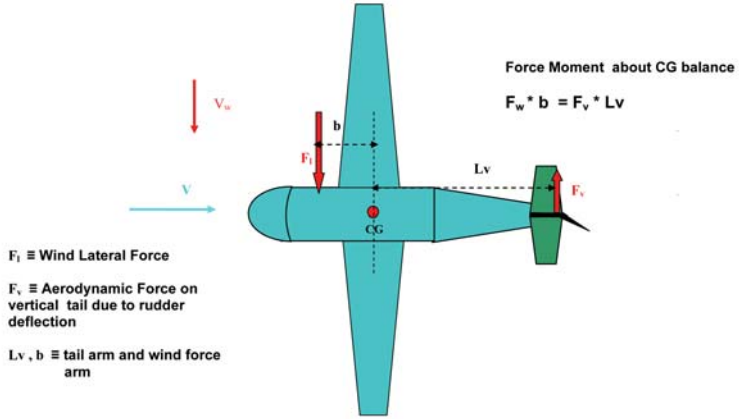
In Take Off or Landing Phases to maintaining the axis runway is mandatory !!!

5.1 One engine out control

A critical situation during the take off phase or a landing phase could be an engine out condition. In this case, the operative engine will create a force moment that has to be balanced by a side aerodynamic force created by the rudder deflection.



5.2 Wind side control



5.3 Carshworthiness

In a normal airplane landing the vertical speed towards the ground is about 2 ? 4 m/s. If the vertical speed is between 6 m/s and 8 m/s, we speak of hard landing, and the problem just a matter of a control maintenance of the landing gear. If the landing vertical speed is higher than 8m/s, we speak of a crash problem: the fuselage could structurally fail and fatalities or severe injuries can occur.

This situation can happen because pilot error in landing procedures (vertical speed too high or not the correct position of the plane with rapport to the ground), special meteorological phenomena, as turbulence (vertical speed towards the ground) or wind shear (wind velocities parallel to the ground, that decrease suddenly the relative on the speed of the airplane wind reference to the air).

So far no certifications requirements are requested on the whole airplane; requirements do exist just on seats.

6. How confortable has been your flight?

6

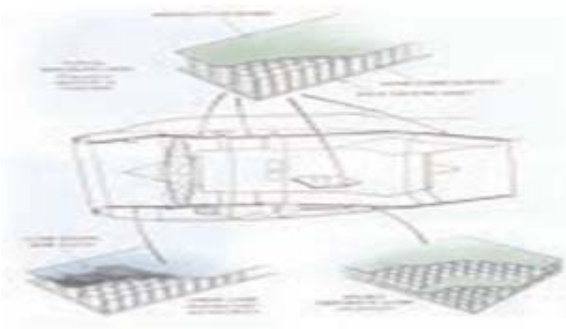
However some research are going on to improve the passive safety of the aircraft, both in material and structures either in experimental and numerical methods

6.1 Noise and vibration

Who has already flown have experienced some difficulty to talk with other people or he has been bored from vibrations. Noise and vibrations inside the airplane cabin and cockpit have two principal sources:

- engine (direct noise or local turbulence induced by propeller or nozzle flow)
- airflow on the external surface of the fuselage (boundary layer)

The direct and induced engine noise and vibration can be reduced by a well designed engine system and its transmission can be reduced by special material inside the engine nacelles and special materials inside the internal wall of cabin and cockpit (passive devises).



Noise reduction material on a jet engine

Noise insulation material between fuselage skin and cabin wall

Research on noise and vibration reduction on transportation

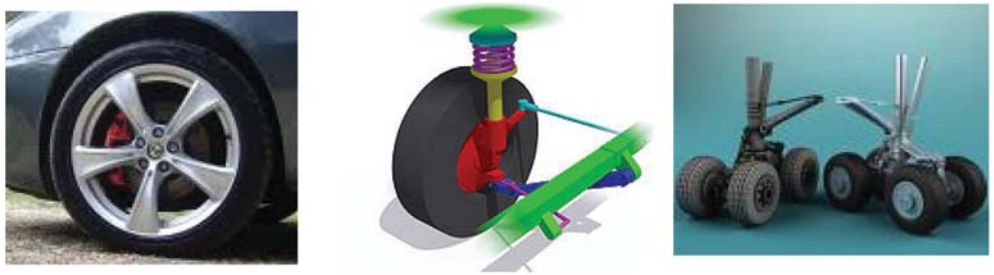
Applied research is going on for possible application of active reduction of noise and vibration, that is with mechanical and/or acoustics devises that work in counter phase with the original noise and vibrations.

6.2 Uncomfortable and oscillations

By a cabin window in an air transport airplane, wing oscillations can be seen some times in a flight. Passengers can experiment oscillation of the whole airplane up and down because of gust effects. Usually pilots make some little change to the route to avoid severe gusts. Besides that, oscillations about the airplane CG could occurs because of gust effect or because the so called pilot induced oscillation during a change in flight parameters.

Pitch, yaw or coupled oscillations can occurs that could cause discomfort to passengers or in some case even accidents (undamped pitch oscillations for examples). It is already said that fixed parts of the airplane tails tend to stabilize the motion.

The tendency to return or not to the initial equilibrium is called **static equilibrium problem**. The way the airplane return to the initial equilibrium conditions is called **dynamic equilibrium problem**.The oscillation about Center of



Some examples of devices utilized to damp an oscillation in transportation

Gravity can be damped or not: if oscillation with decreasing amplitude occurs, we speak of **airplane dynamically stable**; if oscillation is maintained, we speak of **airplane dynamically neutral;** if oscillation with increasing amplitude, we speak of **airplane dynamically unstable.**

There are many applications in the today transport technology devoted to reduce uncomfortable or even dangerous oscillations.

6.3 Customer statisfaction

The quality that companies can assure in supplying their products or services is evaluated by means of a set of rules (as for examples ISO 9000 families) and the organization, which have issued those rules, give on demand to the companies, which are in compliance with those rules, an official acknowledgment (Accreditation/ Certification). What is important to remark is that the request of this

acknowledgement is on voluntary basis and looking at the < Market > opportunities. In many Call for tender, participants are more and more often requested to have an Official Quality y Acknowledgment. In these last years great importance is given to the so called **Customer Satisfaction criterion**.

In the Air Transportation System Quality System is involving each relationship between two organizations, for examples between Airliners and Passengers, or between Manufacture Companies and Airliners.

A close up looking at a <customers satisfaction> evaluation in the case of Airliners and Passengers, is evident that the passengers satisfaction of their flight is not only a matter of technical problems as noise and vibration inside the cabin, but and above all, of the behaviour of hostess and stewards or of the comfort/discomfort because of the narrow or the wide body fuselage, or the capability to respect the scheduled flight time. Moreover the passenger unsatisfaction could be amplified by psychological aspects as the fear of flying or health problems.

Compliance to safety requirements is mandatory for an airplane certification! Safety is not a problem of Customer Satisfaction, unlike cabin comfort.

7. The risk of travel

An aircraft accident is defined as an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage.

Transport is a classic case of the public perception of risk being at variance with the actual numbers. The statistics range up and down, particularly in mass transport, where one incident can cause a large number of fatalities.

Another feature of transport risk is that the impact of the numbers is very dependent on how you represent them. Basically, there are three possible ways of quoting transport risk; in terms of distance travelled, number of journeys or time of travel. Interested parties tend to choose the form of presentation that suits their own purposes.

The air transport industry, for example, will almost always choose a per km basis, which is optimum for them, as most fatalities occur on landing and take-off, while the distances are large. Land based transport organisations, in contrast, will tend to select fatalities per number of journeys or hours of travel, since the risks are uniformly spread. Thus both are able to demonstrate that theirs is the safest form of transport. The actual statistics are given below (taken from an article by Roger Ford in Modern Railways, Oct 2000 and based on a DETR survey). They record the number of fatalities per billion km, journeys or hours of travel.

The one thing that stands out is that, whichever way you look at it, motorcycles are disastrously the most dangerous form of transport.

Bus and rail are the safest form of transport by any measure, while road traffic injuries represent the leading cause in worldwide injury-related deaths, their popularity undermines this statistic.

Airplane accident causes:
air traffic control error
bird strike
cargo hold/cabin fire
design flaw
sabotage/explosive device

km	journeys	hours
Air 0.05	Bus 4.3	Bus 11.1
Bus 0.4	Rail 20	Rail 30
Rail 0.6	Van 20	**Air 30.8**
Van 1.2	Car 40	Water 50
Water 2.6	Foot 40	Van 60
Car 3.1	Water 90	Car 130
Pedal cycle 44.6	**Air 117**	Foot 220
Foot 54.2	Pedal cycle 170	Pedal cycle 550
Motorcycle 108.9	Motorcycle 1,640	Motorcycle 4,840

fuel starvation
hijacking (resulting in fatalities)
lightning
pilot incapacitation
pilots shot by passengers

The number of accidents per flight decreases with time. But the number of fatalities per year is changing and does not decrease.

Nowadays, aircraft accidents are less likely than 20 years ago. Nevertheless, the growing number of flying aircraft and their increasing capacity cannot result in a reduction of onboard fatalities.

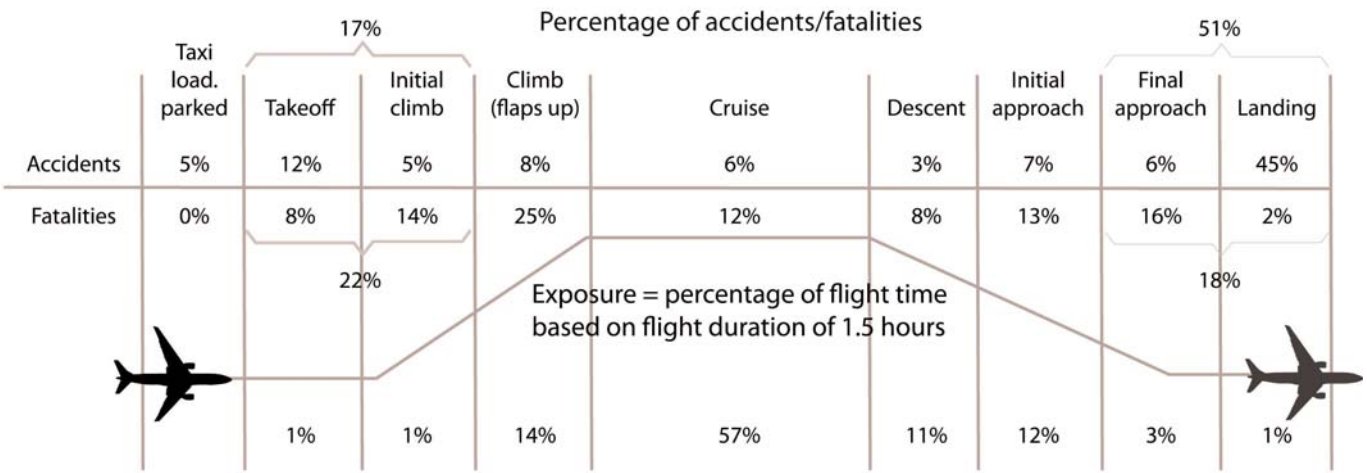
Cause	1950s	1960s	1970s	1980s	1990s	2000s	All
Pilot Error	40	32	24	25	27	25	29
Pilot Error (weather related)	11	18	14	17	21	17	16
Pilot Error (mechanical related)	7	5	4	2	4	3	4
Total Pilot Error	58	57	42	44	53	45	50
Other Human Error	0	8	9	6	8	9	7
Weather	16	10	13	15	9	8	12
Mechanical Failure	21	20	23	21	21	28	22
Sabotage	5	5	11	13	10	9	9
Other Cause	0	2	2	1	0	1	1

7.1 Statistics

The table above is compiled from the PlaneCrashInfo.com accident database and represents 1,300 fatal accidents involving commercial aircraft, world-wide, from 1950 thru 2008 for which a specific cause is known. Aircraft with 10 or less people aboard, military aircraft, private aircraft and helicopters are not included.

"Pilot error (weather related)" represents accidents in which pilot error was the cause but brought about by weather related phenomena. "Pilot error (mechanical related)" represents accidents in which pilot error was the cause but brought about by some type of mechanical failure. "Other human error" includes air traffic controller errors, improper loading of aircraft, fuel contamination and improper maintenance procedures. Sabotage includes explosive devices, shoot downs and hijackings. "Total pilot error" is the total of all three types of pilot error (in red).

Where there were multiple causes, the most prominent cause was used.
Source: PlaneCrashInfo.com database.



Accidents and Fatalities by Phase of Flight: Source: Statistical Summary of Commercial Jet Airplane Accidents, Boeing.

Which type of flying is safer?

Type of Flight	Fatalities per million flight hours
Airliner (Scheduled and non-scheduled)	4.03
Commuter Airline (Scheduled)	10.74
Commuter Plane (Non-scheduled - Air taxi on demand)	12.24
General Aviation (Private)	22.43

Sources: NTSB Accidents and Accident Rates by NTSB Classification 1998 2007.

Odds of being involved in a fatal accident

Odds of being on an airline flight which results in at least one fatality	Odds of being killed on a single airline flight
Top 25 airlines with the best records 1 in 8.47 million	Top 25 airlines with the best records 1 in 13.57 million
Bottom 25 with the worst records 1 in 830,428	Bottom 25 with the worst records 1 in 1.13 million

Source: OAG Aviation & PlaneCrashInfo.com accident database, 1989 2008.

Survival rate of passengers on aircraft involved in fatal accidents carrying 10+ passengers

% surviving	
1930s	21
1940s	20
1950s	24
1960s	19
1970s	25
1980s	34
1990s	35
2000s	24

Source: PlaneCrashInfo.com accident database.base. 1989 2008.

Survival rate of passengers on aircraft ditching during controlled flight

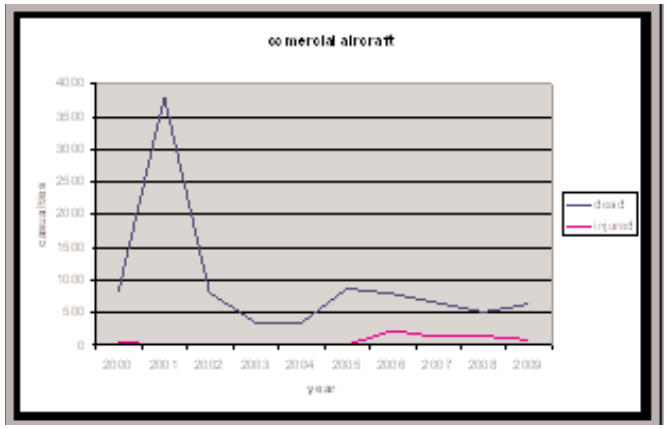
Survival rate of passengers on aircraft ditching during controlled flight = 53%.

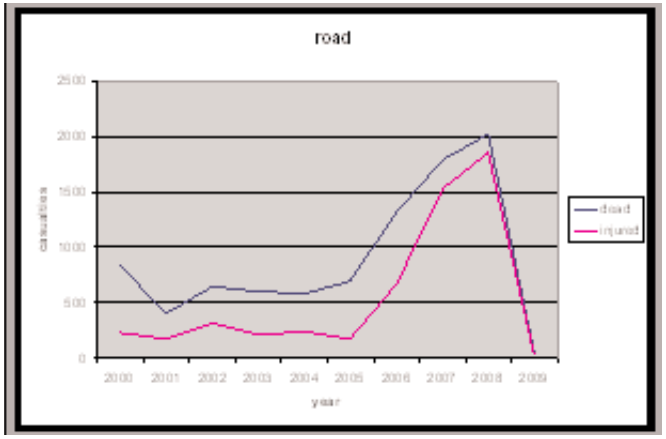
For the following graphs we used lists of accidents and incidents involving commercial air transport accidents, road (bus) accidents and rail accidents, grouped by the years in which the accidents and incidents occurred.

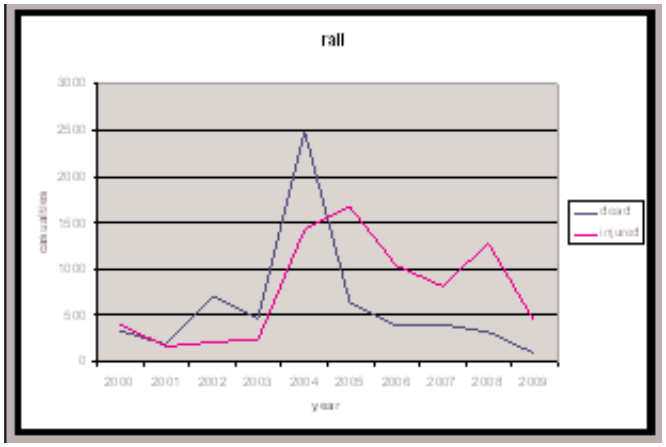
The first graph represents the casualties of commercial air transport accidents (2000–2009) in the world, the second represents the casualties of notable road (bus) accidents (2000–2009) in the world and the third represents the casualties of notable rail accidents (2000–present) in the world.

Regarding the road transportation there are much more variables when dealing with road accidents, as it involves cars, drivers, objects, pedestrians, meteorological changes and lots of other factors.

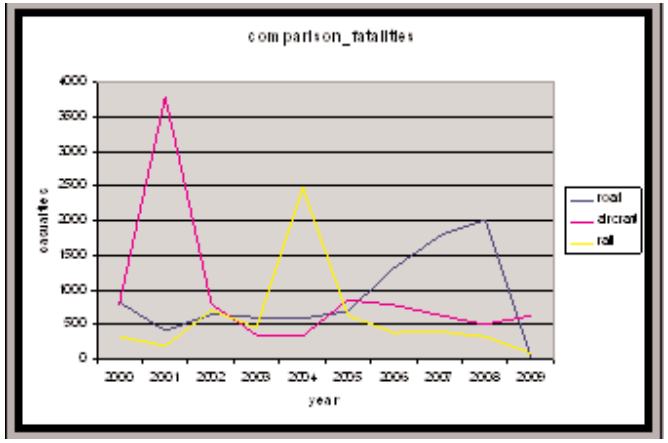
Rail transport is the safest form of land travel. Trains can travel at very high speed, but they are heavy, are unable to deviate from the track and require a great distance to stop. Possible accidents include derailment (jumping the track), a head-on collision with another train and collision with an automobile or other vehicle at a level crossing. The most important safety measures are railway signalling and gates at level crossings. Train whistles warn of the presence of a train, while trackside signals maintain the distances between trains. Vandalism and negligence is responsible for many accidents.

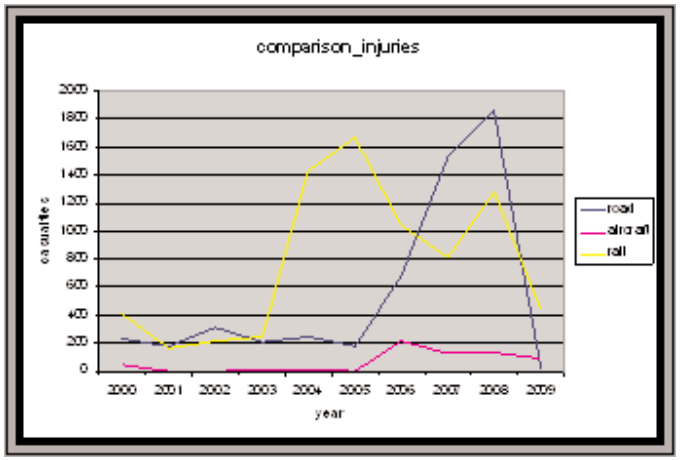






The last two graphs, below represent a comparison between the three means of transportation.





Glossary

Glossary

Accident: an air transportation event, when an aircraft is partially or totally destroyed with fatalities or severe injures on people.

Aircraft: a vehicle able to fly.

Aircraft axis: a three rectangular reference axis XYZ, with the origin at aircraft CG, the plane XZ coincident with the symmetry aircraft plane.

Airplane: a vehicle, heavier than air, able to fly utilizing fixed wings.

Air Transportation System: all organizations involved in the air transportation, considered as a whole.

Aircraft Manufactures: companies that involved in design, manufacturing, certification, partially o totally an aircraft.

Air Traffic Controller: organization that manage the air traffic.

Atoms, Molecules: elementary particles of which the matter is made according atomic or molecular theory.

Anti-icing: a system that avoids the ice accretion on an aircraft parties.

Approach: phase of an aircraft flight during which it descends from cruise altitude to perform landing manoeuvres.

Aerodynamic Centre: the point where is mathematically applied the resultant force of aerodynamic interaction.

Beam: in Construction Sciences is a structural element with the length much more larger than the other two and with regular form.

Bending, Bending Moment: is an elementary load (defined for a beam), that cause the element to be bent.

Cabin: the internal part of an aircraft fuselage devoted to transportation of passengers or goads (for a full cargo).

Certification, Certification Organization: activities devoted to demonstrate compliance of all requirements issued by the related organization. Documentation that allow the airplane to fly.

Climb: is the flight phase during which an airplane, after the take off phase, goes up to the cruise altitude t.

Cockpit: the internal part of an aircraft fuselage devoted to the pilots work and that contents most of devices and instrumentation to manage the aircraft flight.

Compression: is an elementary load (defined for a beam), that cause the element to be shortened.

Control, Control surfaces: the airplane capability to annul the force moment about the aircraft axis or to obtain force moment to change aircraft motion parameters. This capability is possible by means of the control surfaces: elevator, rudder, ailerons (or spoilers).

Cruise: is the flight phase with practically constant altitude and speed. It could be made of several segments with different speed and altitude parameters because of navigations procedures.

De-icing system: a system that breaks down the ice already accreted on an aircraft parties.

Design: the word indicates the activities and/or the documentation (calculation and drawings) that allow an aircraft to be manufactured.

Drag: is the resistance to motion of a body moving through a liquid or a gas (external flow) or the resistance to motion that a liquid or gas meets flowing inside a pipe. It is due to friction and unbalanced pressure.

Empennage: is equivalent to tail surfaces. In a conventional airplane is situated at rear part of the airplane.

Engine System: the aircraft system that transform (usually chemically) the internal energy of a substance (fuel) in thermal and mechanical energy, above all, to obtain the propulsion force.

Elevator: the mobile part of the horizontal tail plane, that allows to annul or change the force moment about the pitch axis.

Elementary Force: is the pressure or the unitary shear multiplied by an element of the external aircraft surface.

Fatality: is equivalent to “dead”, the worth is used in aeronautic accidents.

Fin: the fixed part of the vertical tail plane, that allows motion stability against a side disturb.

Fuselage: the airplane part that contains passengers and goads and connects wing and empennage (conventional airplanes).

Fly, Flying vehicle: we speak of a flying object (on the Earth) if the object weight is prevalently balanced by a force perpendicular to the direction of the relative airspeed (examples of not flying objects: a vertically falling object, a vertically lunched missile, an object moving trough the air with an inertial (about) parabolic trajectory.

Gas: one of the matter status, that assumes the volume and the form of the container.

Gravity Centre: for a extended rigid body is the point where I supposed that the resultant force of gravity (or more in general all mass forces) exercise its action.

Incident: event in aeronautical transport normally managed by procedures, with sometimes little injuries to people or damage to the aircraft.

Landing: flight phase that start at some height from the ground and take the airplane to a speed at which it moves only by the landing gear.

Lift: the force perpendicular to the air speed that is predominant in balance the aircraft weight.

Limit Load: is the maximum value above which some aeronautic structural element failures or loss its functionality.

Liquid: one of the matter status, that maintains its volume and assumes the form of the container.

Loads: are the concentrated or distributed forces acting on an aircraft considered from structural point of view.

Mission, mission profile: in air transport is the task that an aircraft is called to make; the mission profile is a schematic representation of all phases of that task.

Propulsion System: for an airplane is the system that produce propulsion force (propeller or nozzle).

Procedures: in aeronautic field are a set of regulations to accomplish a normal or emergency task.

Pressure: is the ratio between the component of a force perpendicular to a surface and the surface area.

Rudder: the mobile part of the vertical tail plane, that allows to balance a yaw force moment.

Security: is all concerning danger that could come from abnormal people behaviour.

Safety (active, passive): is any serious danger that could come from a technical of procedural failure in the Air Transportation System and technology to prevent it. Active safety technology is devoted to avoid accidents, passive safety technology is devoted to safe life or avoid severe injuries even in the case an accident occurs.

Structural Resistance: is the capability of an aeronautical structure to withstand external forces (loads).

Stabilizer: the fixed part of the horizontal tail plane, that allows motion stability against a pitch disturb.

Stability, stable, neutral, unstable: the concepts are concerning either the aircraft motion or the structural resistance. The terms are associated to the word "equilibrium". The equilibrium is stable, neutral or unstable, if the system tends to return to the original position, or to remain to the new position, or to go away from the original position.

Solid: one of the matter status, that maintains its volume and its form.

Take Off: flight phase during which the airplane accelerates on the runway to the lift off speed.

Tail planes: see empennage.

Wing: the airplane part on which the lift is generated.