Aerobasics – An Introduction to Aeronautics

1. Historical Perspective

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Modern aircraft are designed for the utmost in performance and safety as the penalty for any shortfalls in these areas is very heavy. Thus they incorporate many complex systems and subsystems, each developed using advanced scientific concepts and manufacturing methods. Aircraft design is undertaken by a group of design engineers, each with a specialized knowledge about a few subsystems but only a rough understanding of the whole aircraft. This rough overall understanding of the concepts and principles based on which an aircraft is organized is a vital element of a design engineer's toolbox. It helps him perform his own specialized task such that it fits in the complete design seamlessly. This comprehensive knowledge is not easily acquired from modern technical literature which is voluminous and primarily caters to special interest groups. An attempt has been made here to gather this knowledge and present it concisely as a series of articles, so that it will serve as a broad general introduction to aircraft engineering. This material should be useful not only to fresh engineers entering the aeronautical industry but also to students in all relevant branches of engineering. It is also likely to be of general interest to any scientifically inclined reader as a source of basic information in a number of aeronautical disciplines. The general philosophy adopted here is best summarized by the following quote from the *Panchatantra*: *"Knowledge indeed is unlimited, but life is short and there are many obstacles to the acquisition of knowledge. Therefore one must grasp the essential knowledge leaving out much detail ... ."*

Keywords
Balloons and airships, fighter aircraft, bombers, mini and micro air vehicles, vertical take-off and landing, vectored thrust, tilt rotor.

The science of aeronautics as we know now is about a hundred years old. However, speculations about and possible applications

of flight vehicles have excited the imagination of human beings from the dawn of history. This article highlights this background from early fantasies to modern times.

1. Ancient Myths and Legends

A strong urge to fly appears to have been a part of human nature from at least early historic times. Ancient Egyptians endowed their Sun God Osiris with wings as did the Greeks their Goddess of Victory, Nike. Ancient Indian gods as well as other semi-divine beings like *Kinnaras*, *Gandharvas*, *Vidyadharas*, *Siddhas*, *Charanas* as well as some *Rakshasas* could fly leaving only the poor humans without the facility of air travel! The existence of flight vehicles of excellent capacity, speed and range is referred to in the ancient epics, the *Ramayana* and the *Mahabharata*. Flight vehicles are also referred to in later Sanskrit literature like the *Kathasaritsagara* and the *Panchatantra*. Two samples are given in *Box* 1 to illustrate the concept and potential use of flight vehicles as depicted in this literature.

Box 1.

From the *Ramayana*

In the course of his quest for Sita, Hanuman entered the palace of the *Rakshasa* king Ravana. In the center of the palace Hanuman saw the aerial vehicle, Pushpaka, which had been beautifully constructed by Vishwakarma, the architect of the gods, for Brahma, the self born. The vehicle was gifted by Brahma to Kubera, the half brother of Ravana. Ravana had taken it away by force from Kubera.

The Pushpaka was ablaze with well-made pillars of gold and silver and embellished with images of wolves. It had many balconies and pleasure chambers, brilliant as the Sun and it appeared to scrape the heavens like Meru and Mandara mountains. The Pushpaka had stairways of gold and excellent platforms radiant with sapphires and emeralds. It had lattice windows embellished with gold and crystal, and floors constructed with coral, gold and sandalwood.

Hanuman leapt up the heavenly car, Pushpaka, and could smell the odor of fine food and drinks. The odor impinged on him as if it were solid air and appeared to invite Hanuman like an esteemed relative saying 'come hither'.

From the *Kathasaritsagara*

In the city of Ujjayini, during the reign of king Punyasena, there lived his minister Hariswamy and his family – his wife, their son and their beautiful daughter Somaprabha. Somaprabha made it known that she would

Box 1. continued...

Box 1. continued...

marry only a scientist, an engineer or a hero. Very soon, three suitors, a scientist, an engineer and a hero sought her hand in marriage and the family decided to meet all of them on a certain day. On the appointed day, the suitors arrived at the house of Hariswamy, but Somaprabha could not be found anywhere even after a search. Hariswamy got scared and confused and asked the scientist to help. The scientist after due calculations declared that Dhumrashika, a Rakshasa living in the Vindhya forest had abducted her. The engineer immediately built an aerial chariot fully equipped with weapons and they all flew to the abode of the Rakshasa. There ensued a terrible battle between the hero and the Rakshasa for the sake of Somaprabha, like the famous battle of *Ramayana*. In the end the hero killed the Rakshasa and they all flew back to Ujjayini along with Somaprabha.

2. Balloons and Airships

The earliest recorded demonstration of flight was in Portugal in 1709 using a hot air balloon – a large envelope filled with heated air. The Montgolfier brothers of France demonstrated a successful manned ascent and safe descent in a hot air balloon in 1783. Balloons filled with hydrogen (and later a safer noncombustible gas, helium) were successfully attempted during the 19th century which also saw the development of the airship – a cigar-shaped balloon driven by a propeller and powered by an internal combustion engine (*Box* 2). By the end of the 19th century, airships had developed sufficiently to perform useful duties like aerial observation and passenger transport. At the peak of airship development, the airship Hindenburg, built by Zeppelin of Germany operated across the Atlantic with a passenger capacity of about one hundred. Following a major fire accident to Hindenburg at New Jersey in USA in 1937 (attributed to a lightning strike as the craft was preparing to land in stormy weather), the popularity of airships dwindled and now only relatively small airships are in service. The major role of air transport is now performed by airplanes.

3. Airplanes

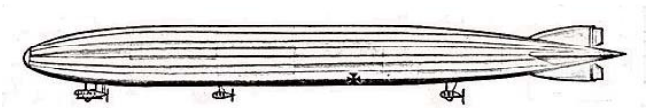
Compared to the balloon, the development of a heavier-than-air flying machine has been beset with many failures due to its higher level of complexity. Natural fliers, like the birds and insects,

Box 2. Performance of Airships

Balloons and airships derive their lift mostly from the buoyancy of the lifting gas. Aerodynamic lift of an airship and vectored thrust from the propeller are generally used for control purposes only. At sea level, the weight of air is about 1.22 kg/m^3 and this sets the upper limit to the lifting capacity of balloons and airships. Hydrogen, being the lightest gas with a weight of only 0.08 kg/m^3 at sea level, provides a net buoyancy of 1.14 kg/m^3. Helium, an expensive but non-combustible gas, is the next lightest with a weight of 0.16 kg/m^3. It provides a slightly lower lift of 1.06 kg/m^3. A non-combustible mixture of helium and hydrogen is a possible economical lifting gas for balloons and airships. With the above gases, loss of the lifting gas by slow diffusion through the envelope of the airship is a problem which affects the economics of airships. Air heated to about 100 ^{o}C solves the above problem, but provides a net lift of only 0.28 kg/m^3 and hence the airships have to be four times the volume for the same lift. A fuel-burning heater is required to sustain the heat loss from the airship envelope.

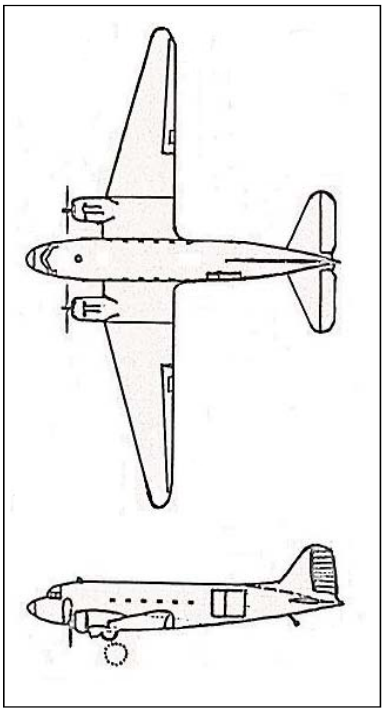
Practical balloons and airships are large-volume structures as the lifting capacity per unit volume is small. The Hindenburg had a gas capacity of about 2,00,000 m^3 (a length of about 250 m and a diameter of about 30 m). As the density of air and hence the lifting capacity of an airship falls off rapidly with height (about 10% for every 1000 m), the Hindenburg flew at a height of only 200 m above the sea in the Atlantic.

Airships derive their lift statically due to the buoyancy and hence they need power only for overcoming the aerodynamic resistance of the hull during the cruise. As the power required for this is proportional to the cube of the flight speed, the economical cruise speed is low – the Hindenburg cruised at about 35 m/s. Airships can however have a large endurance – several days or more if required. Airships do pose difficult ground handling problems in gusty winds due to their large size. However, airships, while comparing unfavorably with airplanes in terms of speed and capacity, still find some special applications for tourist sight-seeing, aerial surveillance, communication relays and for advertisement purposes.



Zeppelin L59: This airship was built by the Zeppelin Company in Germany in 1917. It was about 24 m in diameter and 226 m long with a normal weight of about 52 tons. It was powered by five 180 kW piston engines and had a maximum speed of 108 km/hr and a range of about 8000 km.

employ complex motions of their wings to generate the forces for lift, propulsion and control, and cannot be easily imitated. Early attempts to build a glider carrying a man based on scientific studies were made by Sir George Cayley in 1843. The German pioneer, Otto Lillenthal, made many successful flights using gliders he built during 1891–96. Samuel Langley, the secretary of



Douglas DC-3: This aircraft was by far the most successful pre-war transport aircraft. Designed around the year 1930 by the Douglas Aircraft Co., USA, it found extensive use during World War II and a few are in flying condition even today.

the Smithsonian Institution in USA, built a steam-powered airplane which was launched from a houseboat on the Potomac river in 1903, but his invention crashed into the river. Finally, success came to Orville and Wilbur Wright of USA on 17th Dec 1903 when their Flyer made a historic flight covering a distance of 37 m. The success of the Flyer was in good measure due to advances made by the Wright brothers in the science and art of aircraft control. (See *Resonance*, Vol.8, No.12, 2003.)

Following the successful flight of the Flyer, airplanes[1] developed rapidly. They were much smaller and more agile than airships and their military potential came to the forefront during the First World War of 1914. Initially, they were used for aerial observations and for directing artillery fire. Later, they were fitted with machine guns for attacking airships and other aircraft[2]. These were the forerunners of fighter aircraft of the Second World War. Simultaneously larger aircraft were developed for air raids on cities using bombs and this line of development led to bombers. These two lines of development converged after the Second World War. We now have multi-role combat aircraft which combine the functions of fighters and bombers. True bombers are now in service only with the erstwhile super powers – USA and Russia.

In the early days, civilian applications of airplanes were for joyrides and carrying mail, particularly in USA. As the speed and range of aircraft improved, air travel became a reality in the early 1920s. Innovations like all-metal construction and high-powered radial engines led to the development of the Douglas DC-3 nicknamed the Dakota, in 1935. This airplane was so successful that over ten thousand of these were built and a few of them are in service even today.

The aircraft industry has always been highly innovative as improved performance directly translates into military superiority which is highly prized by all nations. The Second World War provided a strong incentive to innovations. The swept wing which

[1]Airplane is a conventional fixed-wing type flying vehicle.

[2]Aircraft: all types of flight vehicles including helicopters.

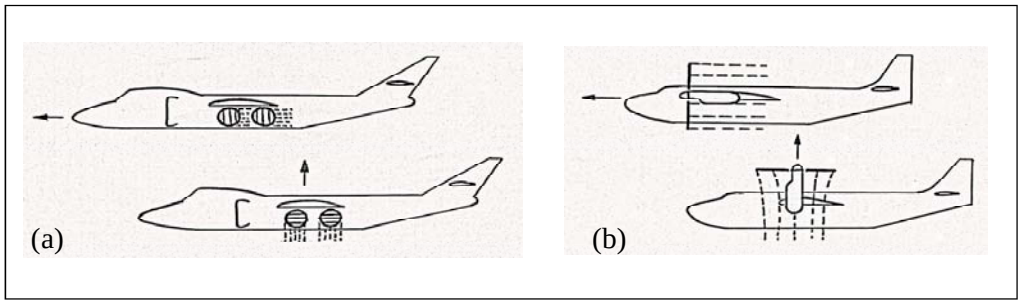
overcomes the speed limitation of the straight wing and the jet engine which makes possible flight at speeds up to three times the speed of sound were introduced during this period. More recent innovations in the field of advanced structural materials and computer-based control systems, initially introduced on combat aircraft, have found their way into civil aircraft as well. Enhanced use of computer control of flight vehicles has already led to long-range unmanned surveillance aircraft and extensive research is underway to develop unmanned combat aircraft also. Advances in computers and control hardware (sensors and actuators) have been such that the human pilot can be eliminated and the airplane size dramatically reduced. Mini and micro air vehicles, as small as 15 cm in span, have been developed and are already finding applications.

4. Helicopters and VTOL Aircraft

An important limitation of fixed-wing aircraft discussed above is their inability to take off or land vertically. These aircraft need a minimum forward speed to generate lift sufficient for airborne flight and thus need a runway on which they can accelerate to or slowdown from the minimum flight speed. The possibility of generating lift by a powered rotor which overcomes this limitation was suggested by Leonardo Da Vinci in the 15th century.

The modern helicopter using a powered rotor with two or more blades of airfoil section evolved from the work of Ivan Sikorsky who built the first practical helicopter in 1939. Helicopters are less fuel efficient and more expensive than fixed-wing aircrafts and are limited to a forward speed of less than about 100 m/s due to compressibility effects of the blade tips. They find military applications in anti-tank warfare, for search and rescue missions and as heavy lift transports. Civil applications include missions for supporting offshore oil-drilling platforms, etc. In these applications, the vertical take-off and landing capability of the helicopter plays a major role.

Other concepts for vertical take-off and landing aircraft (VTOL) include the use of vectored thrust jet engine as in the Harrier and



(a) Tilt rotor: Vertical take off and landing is achieved in this airplane by tilting the engines such that the propeller thrust is vertical. During normal operation, the propeller provides forward thrust as in a conventional airplane.
(b) Vectored thrust airplane: In this design, the nozzles of the jet engine which powers the airplane are rotated so that the jet thrust is vertical during take off and landing. The nozzles are turned towards the rear of the aircraft to provide thrust for normal operation.

the tilt rotor concept as used on the Ospray. In these aircraft, thrust of the power plant is deflected into the vertical direction during take-off so as to overcome the weight of the airplane. During cruise, the thrust is directed in the flight direction while the wing lift overcomes weight as in a normal airplane. These concepts overcome the high speed limitation of the conventional helicopter and achieve a performance comparable to that of a fixed-wing aircraft.

From the above discussion, it is clear that advancement of aeronautics in the last century has been spectacular and the aeronautical sciences are very mature today. A broad understanding of the current status of these sciences forms the subject matter for the following articles.

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Suggested Reading

[1] ***Srimad Valmiki Rama-yana*, Part II, (in Sanskrit with English translation) pp.38–39, Gita Press, Gorakhpur, India, 1998.**

[2] ***Kathasaritsagara*, (in Sanskrit) pp.418–419, Motilal Banarasidas, Delhi 7, India, 1970.**

[3] ***Panchatantram*, (in Sanskrit with Hindi translation), pp.99–113, Motilal Banarasidas, Delhi 7, India, 1977.**