
航空航天工程类专业规划教材

# INTRODUCTION TO AERONAUTICS

# 航空概论

薛彩军　主编

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National Defense Industry Press

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# ABSTRACT

This textbook is designed to meet the learning needs of international students in China who take a selective, introductory course about flight. It provides a comprehensive and overall introduction to flight vehicle history, basic aerodynamics, flight mechanics, aircraft control and stability, propulsion system, aircraft structure and so on. Considering that international students from different countries may have different knowledge background, we organized the contents of this textbook from the basic principles to advanced technologies. This will be useful for the readers on different levels as possible.

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# Preface

This textbook is designed to meet the learning needs of international students in China who take a selective, introductory course about flight. It provides a comprehensive and overall introduction to flight vehicle history, basic aerodynamics, flight mechanics, aircraft control and stability, propulsion system, aircraft structure and so on. Considering that international students from different countries may have different knowledge background, we organized the contents of this textbook from the basic principles to advanced technologies. This will be useful for the readers on different levels as possible.

Prof. Caijun Xue and Dr. Hongshuang Li have jointly compiled this textbook. Dr. Xiangming Zheng and Dr. Tianhang Xiao and Dr. Feng Deng also participated in the compiling and discussion of certain chapters and sections. We are grateful for their critical reviews and recommended improvements. This textbook has referred to lots of great textbooks and information on websites about flight both at home and abroad. Here, we especially wish to acknowledge Prof. John D. Anderson and Prof. Dava Newman for quoting some legends and wonderful statements in their books. We also extend our thanks to our students: Yuan Xu, Xingyu Gong, Yuanyuan Fang, Zibo Jin, Guifen Xia and Rong Zhao for their efforts and assistance with collecting materials, typing manuscripts and drawing figures.

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# Chapter 1

# Rich History

## 1.1 From Wheels to Stars

Many people today take the very means of travel available to them for granted. Few stop to think of how life would be different if man had never tamed the first wild horse, or shaped the first wheel. How did ancient man hit on these life - altering ideas? Where did the thought first originate? How have the advances of time led humanity from the ground to the stars?

Archaeologists believe that the first step toward man - made transportation began in either Mesopotamia or Asia, sometime around 4000 - 3500 BC, with the invention of the wheel. By this point, man had domesticated the horse a long time ago, and was using it to help him till the soil and plant crops. But the invention of the wheel would eventually make man's ability to transport his crops from one place to another less awkward, and then people generated the idea of trade and exchange. The invention of the wheel would lead to the development of mass transportation, as man put his new invention to practical uses.

The next logical evolutionary step from the wheel was the invention of the cart and chariot. The two - wheel chariot found its birthplace in Sumeria (Fig. 1 - 1), and is believed to be the world's first form of wheeled transportation. Built around 3500 BC, this chariot increased the speed of travel over land, and later it developed into the four - wheeled cart, which took the burden of carrying supplies and equipment off of the shoulders of the common man.

As man overcame the boundaries of land travel, his curiosity about the world increased. To his aid, man had developed a means of traveling on water even before he had domesticated the horse. The origin of the dugout boat is one of history's great mysteries. Historians are unable to pinpoint when or where the first water vessel was set afloat, and even speculate that it might have been purely an accident for the first time. However, it happened, the addition of the boat changed the face of transportation. Boats allowed man to, for the first time ever, sail on the water without getting wet.

Figure 1 - 1 An Example of Two - wheeled Cart

Over time, the simple boat evolved to include a large square of cloth mounted on a central pole. This cloth, called a sail, would turn the boat into a sail - propelled ship. This new addition gave man the ability to use waterways as a means of swift travel from one place to another, and even to travel against the current of rivers. However, the evolution of water travel didn't stop with the sail. Ships would eventually take on sleekness as they increased in size. Before long, they would add oars and rudders, and then deck covers. By Greek and Roman times, ships had grown clunky shipboard towers, as well, which developed, over time, into the medieval stern - and forecastles. By the late medieval era, these castles were built solid, as a part of the ship's basic structure. Then, by the Renaissance and the Age of Exploration which followed, ships became sleek and speedy with tires of rigging and sails gained.

Then, in the 1800s, ships began to shed their sails on the rivers once again. The advent of automationchanged transportation forever. The first automation in ships was the cumbersome paddlewheel. Due to their bulky form and inability to turn easily, paddlewheel boats were confined to river travel, where they would experience calmer currents and need less maneverability.

Zheng He was a Chinese mariner, explorer, diplomat and fleet admiral, who made the voyages collectivelyknown as "Zheng He to the Western Ocean" (Fig. 1 - 2), from 1405 to 1433.

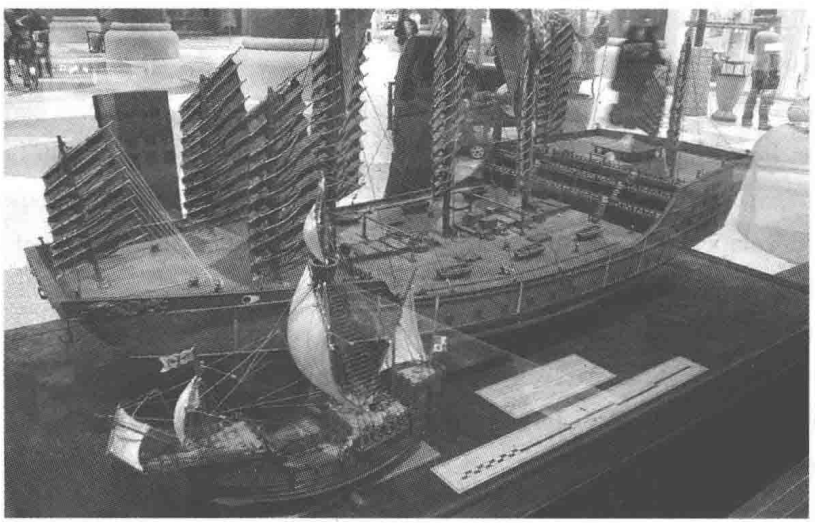

Figure 1 - 2 A Model of the Zheng He Treasure Ship

After the paddlewheel came the steamship, burned coal or wood to heat water, which in turn created the steam pressure used to work the pistons which moved the ship. The steamship was to enjoy a long and trusted run on both rivers and seas. Then, in 1912, the first diesel - powered ship, the Danish Selandia, was launched. That diesel engine design was not to become the industrial and military standard until the end of World War Ⅱ. Then, in 1958, the first nuclear powered ship was launched. However, nuclear power was soon discarded by industry as too expensive and risky, though it would continue to use in the military community.

Automation also improved travel by land. Mass transit became a standard, originally through the steam engine of the eighteenth century. But these earlytrains were slow and often very dangerous (Fig. 1 - 3). Then, the locomotives came into use in 1804, which used steam to power a series of pistons (much like a steamship). These locomotives were powerful enough that one engine could pull several cars, a feat hopelessly beyond the capacity of the earlier steam engines.

Over the next one hundred years, various improvements would be made to the locomotives, speeding up transit and attempting to make trains travel safer. Then, during World War Ⅱ, the diesel engine came into widespread use, and steam was almost completely forgotten. Even electricity had been experimented with in the running of trains, as early as 1895, but was considered too expensive and unreliable to run until the advent of the subway, when electricity became the easiest and cleanest means of underground motion.


Figure 1 - 3 A Train

Automation was not, however, reserved exclusively for mass transit. As early as 800 BC, therewas some evidence that vehicles powered by steam were used in the Orient. And these were not used for mass transit, but rather for individual travel. However, the first actual surviving record of a powered vehicle was in AD 1670, when a Jesuit missionary in China built a cart driven by a steam turbine. By 1840, this concept had developed into the "road locomotive", a contraption bit like the modern - day bus.

In 1860, a Frenchman named Jean Joseph Etienne Lenoir devised an internal combustion engine

which ran on illuminating gas. The first actual automobile, however, wasn't patented until the 1890s. Advancements have continued to be made since then. The automobile was the most important development in the history of transportation since the invention of the wheel. Automobiles increased personal mobility and permitted people to live far away from their work, which led to the formation of suburbs.

**The next stride in transportation looked not to the land, or even to the seas, but to the sky. Although many people have toyed with flight over the millennia, the first sustained, controlled flight didn't take place until December 17, 1903, at Kitty Hawk, North Carolina. The inventors of this new flying machine (Fig. 1 - 4) were brothers, Orville and Wilbur Wright, two bicycle makers. Their invention would eventually grow from a bicycle - propelled contraption to, after World War Ⅱ, jet - propelled aircraft capable of world - wide mass transit. The aeroplane allowed people to cover great distances in less time, cutting transatlantic travel time in half.**

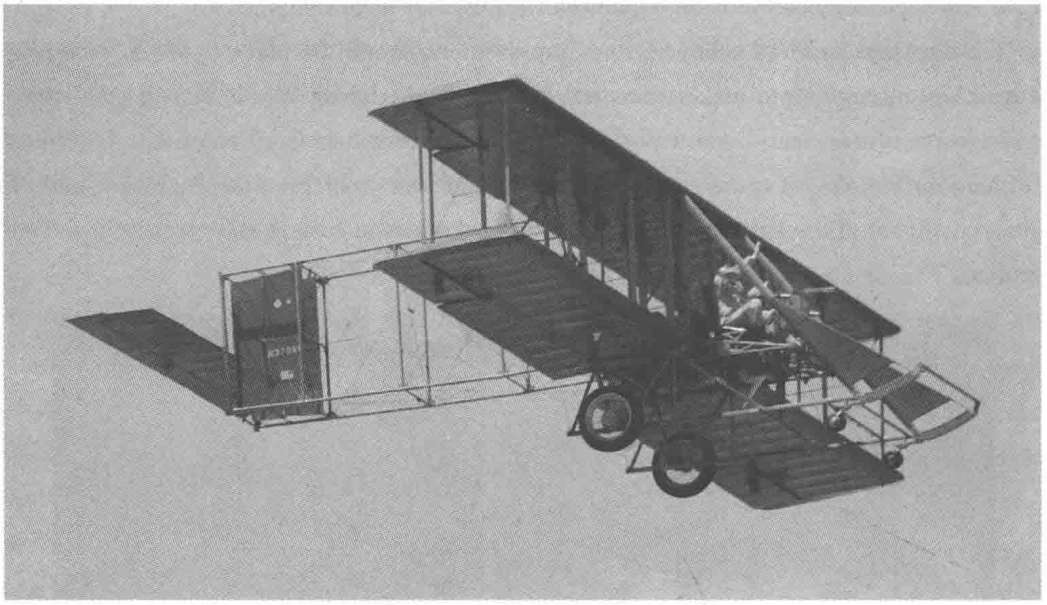

Figure 1 - 4 A Picture of the Wright Flyer Ⅰ

Having conquered flight, man's gaze turned toward the night sky, and the stars. After experiencing centuries of rockets unable to pierce the atmosphere and escape the gravitational pull of the earth, the United States announced the formation of the Vanguard Satellite Program (VSP) in 1955, and began exploring what it would take to break away from the earth. On October 4, 1957, however, the USSR succeeded in launching the first earth - orbiting satellite, Sputnik Ⅰ (Fig. 1 - 5). The first manned space -flight, however, did not take place until April 12, 1961, when the Russian Cosmonaut Yuri Gagarin orbited the earth in the Vostok Ⅰ. Then, on July 16, 1969, American astronaut Neil Armstrong became the first man to set foot on the moon. In July of 1975, a joint American - Russian venture began, docking spacecraft together in space. Then, on February 18, 1977, space - flight took another stride with the test flight of the first reusable space shuttle, the US craft Enterprise.

**From the wheel to the stars, man's travel has only ever been limited by the scope of his imagination. As each new challenge is conquered, humans ready to meet the next challenge. The annals of history are evidence that humans will continue to stride forward, particularly when**

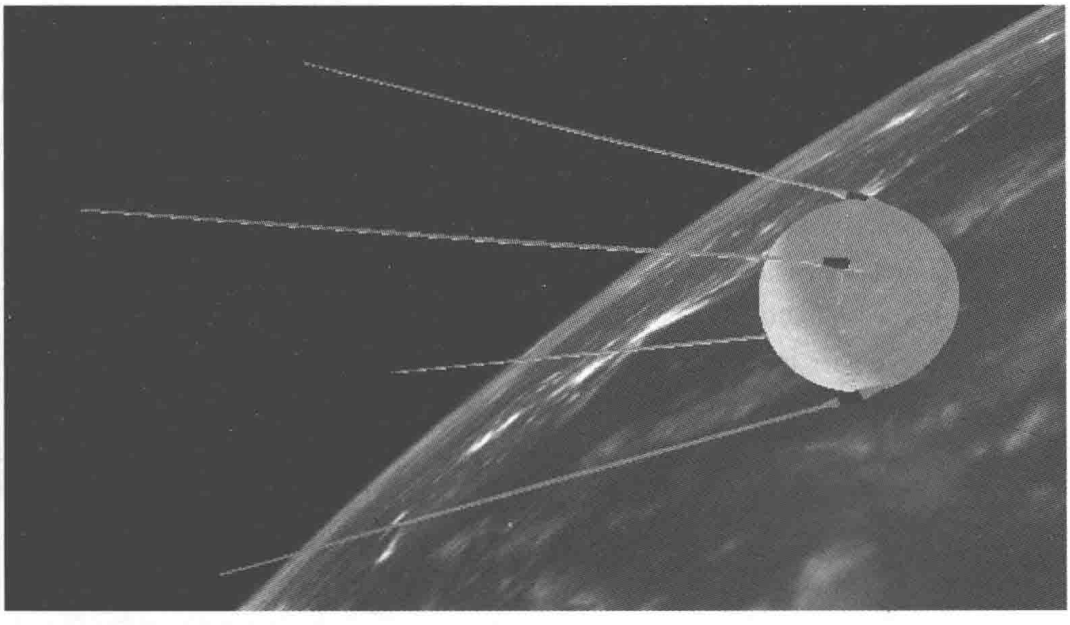

Figure 1 – 5 A Picture of First Earth – orbiting Satellite, Sputnik I

**faced with challenges in transportation.**

The ability to move people, cargo and information quickly through air and space is unmatched. For example, what if you want to deliver medicine to a place across the ocean? Would it be faster to take a ship across the ocean, than to fly? What if you have to get to a town hundreds of miles away? Would it be faster to take a car than to take a plane? The answer to these questions, of course, is to fly or to take a plane. Another aspect of air and space power that makes it unique is elevation. You can not only fly over an obstacle that is on your way, but also see over it. Elevation gives you the ability to see objects that are far away.

However, our ability to use air and space was not so easy. Many lessons were learned the hard way, and many people lost their lives along the way. Mistakes were made while we experimented with new engines, wings and life support systems. We don't want to repeat costly mistakes. We want to build on what we learned from them so we can get even better. The following part introduces many major developments in the history of air and space power. Additionally, the part points out why these are important to the continuing development of our air and space power.

## 1.2 Myths and Legends

### How Did We Learn to Fly Like the Birds?

Long before people appeared on this planet, other forms of life, including birds, mammals (bats) and reptiles (pterodactyls) learned to travel through the air. Some imaginative people even believe that, many centuries ago, life from other planets may have traveled through space.

For people here on Earth, however, air and space travel is a recent occurrence. Only within the

last century have we been able to fly. In another sense, however, people have probably traveled through air and space for as long as they have been on Earth—at least, in their imagination they have.

**Among the earliest recorded stories of man in flight was the Chinese legend of Emperor Shun (Fig. 1 - 6). According to this legend, nearly 4,000 years ago, Emperor Shun escaped from prison by "donning the work clothes of a bird."**

Shun's birth mother died when Shun was very young. His father was blind and re - married soon after Shun's mother's death. Shun's stepmother then gave birth to Shun's stepbrother Xiang and stepsister. Shun's step mother and stepbrother treated Shun terribly, often forcing Shun to do all the hard work in the family and only giving him the worst food and clothes. Shun's father being blind and elderly, was often ignorant of Shun's good deeds and always blamed Shun. Yet, despite these conditions, Shun never complained and always treated his father, his stepmother, and his stepbrother with kindness and respect.

Figure 1 - 6 Emperor Shun

When he turned barely adult, his stepmother threw him out of the house. Shun was forced to live on his own. Yet, because of his kindness and innate leadership, everywhere he went, a lot of people would follow him. Under Shun's leadership, these people were kind to each other and tried their best to work for Shun. When Shun first went to a village that produced pottery, with the help of Shun, the potteries in the village were produced more beautiful than before just within one year. When Shun went to a fishing village, people there at first always thought amongst themselves over the fishing grounds, and many people were injured or killed in the fights. Shun taught them how to share and allocate the fishing resources, and soon the village became prospering and all hostilities ceased.

When Emperor Yao became old, he was in distress that his 9 sons were all useless, who only knew how to spend their days enjoying themselves with wines and songs. Yao asked his administers to propose a suitable successor. Yao then heard of Shun's tales. Wise Yao did not want to simply believe in the tales about Shun, so Yao decided to test Shun. Yao gave a district to Shun to govern and married his two daughters to him, with a small dowry of a new house and some money.

Though given a district and money, Shun still lived humbly. He continued to work in the fields every day. Shun even managed to convince his two brides, the two princesses who are used to good living, to live humbly and work along the people. But Shun's stepmother and stepbrother were extremely jealous of Shun and conspired to kill him. Once, Shun's stepbrother Xiang lit a barn on fire, and convinced Shun to climb onto the roof to put the fire out. But after Shun climbed onto the roof, Xiang took away the ladder, and therefore Shun was trapped on the burning roof. Luckily, Shun skillfully made a parachute out of his hat and clothes and jump down in safety.

The Chinese have always been particularly enchanted by flight. Legends tell us that Kei Kung, the Chinese god of thunder and lightning, can fly by using the wings of a bat. Also, about 1,800 years before Christ, it is said that Ki - Kung - Shi built a flying chariot that had no visible means of support.

Although we don't know whether those legends are true or not, we do know that the Chinese built the first device that can enable us to fly. About 100 BC, the Chinese invented the kite (Fig. 1 - 7).

Some of the kites were very large and may have carried man aloft. We are fairly certain the Chinese used man - carrying kites to watch enemy troops in the seventeenth century.

About 900 AD, the Chinese invented gunpowder, and by 1100 AD, they began to use gunpowder to build simple rockets. These early rockets were used for celebrations and in warfare. There is at least one Chinese legend of manned flight using rocket power. According to this legend, a Chinese official named Wan Hoo (Fig. 1 - 8) attempted a flight to the Moon using a large wicker chair to which 47 large rockets were fastened. When the rockets were ignited, Wan Hoo disappeared in a large ball of smoke and fire and never to be seen again. The Chinese deduced that maybe Wan Hoo is the man in the Moon.

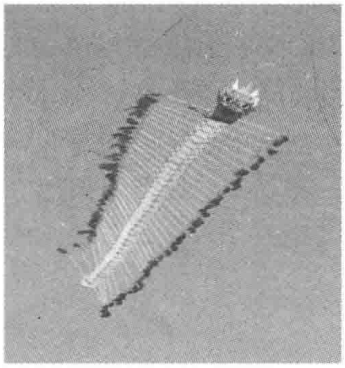

Figure 1 - 7 A Kite

Figure 1 - 8 Wan Hoo

It is from ancient Greece and Rome (800 BC—527 AD), however, that we get our most familiar legends and art showing flight. The most famous myth of all is that of Icarus and Daedalus (Fig. 1 - 9). According to this myth, Daedalus (an architect and mechanic) and his son, Icarus, were imprisoned by King Minos of Crete. Having determined to escape, Daedalus made wings for himself and his son. The wings were made of feathers. Daedalus and Icarus attached the wings to their bodies with wax. With these wings, they glided away from the island prison. Despite his father's warning, Icarus flew too close to the sun. The wax melted, and Icarus fell down into the ocean.

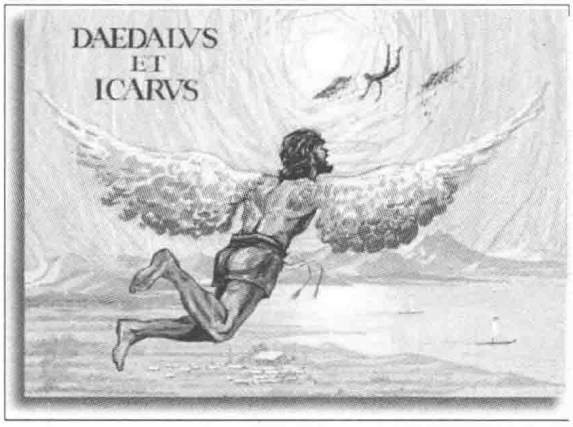


Figure 1 - 9 Daedalus and Icarus

## 1.3 Early Scientific Research

Leonardo da Vinci (Fig. 1 - 10), (1452—1519), a great Italian artist, architect and scientist made the first scientific experiment in the field of aviation. He devoted many years of his life to understanding the mysteries of flight and left the world 160 pages of descriptions and sketches of flying machines. Among these descriptions and pictures are the world's first known designs of the parachute and

the helicopter.

He understood and wrote about the importance of the center of gravity, center of pressure and streamlining. These principles are vital in designing and building modern aircraft and spacecraft. He described, sketched (Fig. 1 – 11) and built models of many types of *ornithopters* (flying machines that are kept aloft and propelled by flapping wings) (Fig. 1 – 12). He left detailed sketches of wing mechanisms that used levers and pulleys to allow human muscle power to flap the artificial wings.

It is important to note that Leonardo da Vinci is a brilliant scientist whose work could have changed the entire history of flight—except for one tragic fact. It was 300 years after his death when his manuscripts were published and made known to the world. Perhaps because his manuscripts were not known to the world in time, it's likely that the progress of manned flight was delayed.

Figure 1 – 10 Leonardo da Vinci

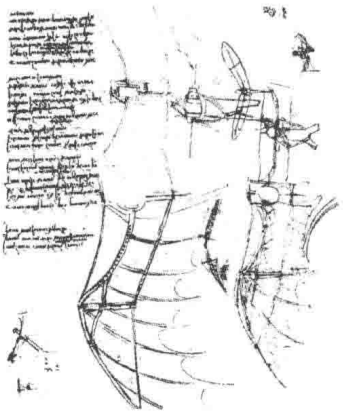

Figure 1 – 11 His Sketches of Flying Machines

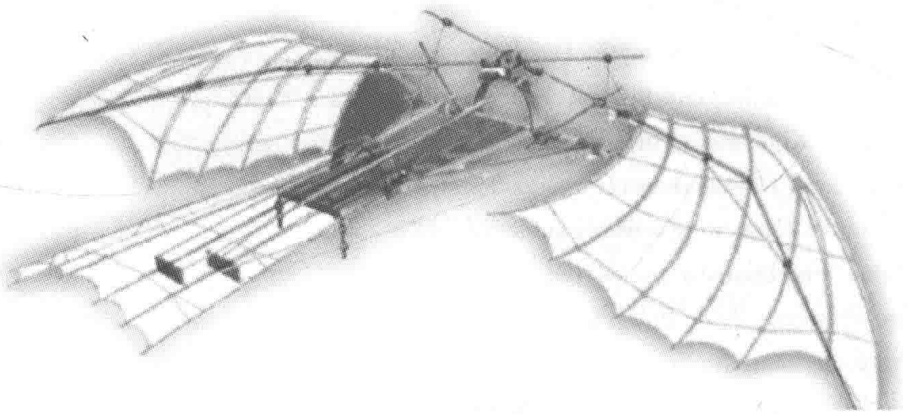

Figure 1 – 12 A Model of da Vinci's Ornithopter

Three European scientists (Torricelli from Italy, Von Guericke from Germany and a Frenchman named Pascal) performed scientific studies of the atmosphere. They learned that the atmosphere is a fluid and that atmospheric pressure decreases when you climb high. They invented the barometer, which measures the pressure of the atmosphere, and the air pump, which allowed them to study vacuums. This knowledge eventually led to successful lighter – than – air flight.

In 1670, a Jesuit priest, Francesco de Lana, a professor of mathematics, wrote about an "aerial

ship" (Fig. 1 - 13). This airship would be carried aloft by four large spheres from which all air had been removed to make them lighter than the surrounding air. He proposed to make the spheres out of very thin copper. The principle was sound but the spheres would have been immediately crushed by the pressure of the surrounding air. Francesco de Lana's writings are the first scientific record of a "vacuum balloon." He also discussed the need for ballast (a heavy substance) to control ascent and the need to let air enter the spheres gradually to control descent. Francesco de Lana also wrote about military uses for balloons.

In June 1783, the **Montgolfier brothers** were ready for a public demonstration using a paper - lined linen bag with 38 feet in diameter. On June 5, in the marketplace, they lit the straw and wood under their balloon (Fig. 1 - 14). The balloon rose to an altitude of 6,000 feet and traveled over a mile before landing. The Montgolfiers had no idea that their balloon rose because it contained heated air that was lighter than the surrounding air. They thought a lighter - than - air gas that was created by the burning fuel caused the balloon's ascent. They called this gas "Montgolfier gas."

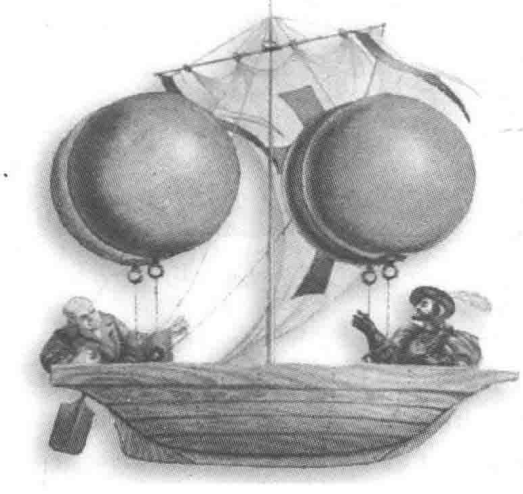

Figure 1 - 13 Francesco de Lana's Aerial Ship

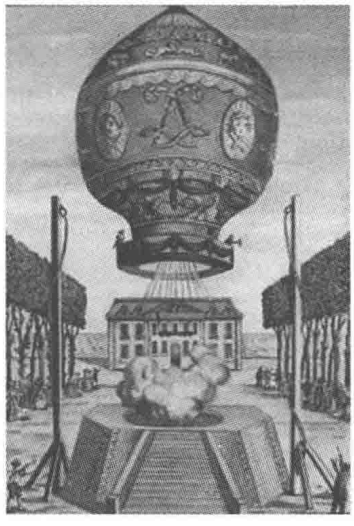

Figure 1 - 14 Montgolfier's Hot Air Balloon

An account of this demonstration was sent to the Academy of Science in Paris. This led to an invitation for the Montgolfiers to demonstrate their balloon. Once again, the demonstration was a success. They were then asked to demonstrate their balloon before King Louis XVI and Marie Antoinette on September 19, 1783. For this demonstration, the Montgolfiers attached a cage to their balloon in which the first living passengers—a sheep, a rooster and a duck—were carried aloft and returned safely to earth.

## 1.4 Flight in Balloons

**The first men to fly in a lighter - than - air craftrode a Montgolfier balloon into the air over Paris on November 21, 1783.** These two men were Pilatre de Rozier, a young physician, and Marquis d' Arlandes, a young infantry officer. The flight lasted 25 minutes and covered a little more than 5

miles.

After centuries of dreaming, flight became a reality. However, we were still a long way from mastering air and space power. The problem with these hot air balloons was that only if the fire heated the trapped air continually these balloons could stay aloft all the time. This made the balloons very dangerous. It also limited the duration of the flight because a great deal of wood and straw had to be carried as fuel.

Later, the Montgolfiers hired a young scientist, J. A. C. Charles, to further carry out research on balloons. Charles was familiar with the "flammable air" isolated by Cavendish. He also realized that whatever "Montgolfier gas" was, it was not as light as hydrogen. Charles was aware of the difficulties in containing hydrogen; therefore, for his balloon he developed a small globe of rubberized silk.

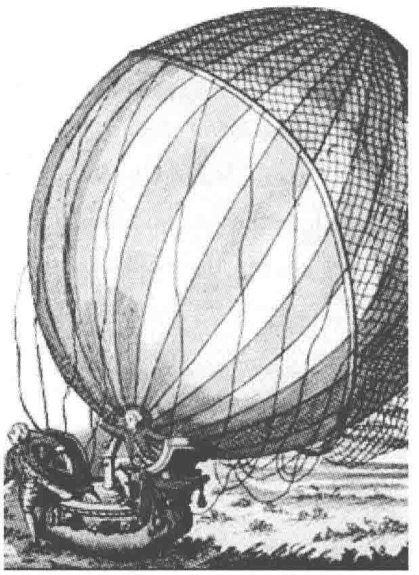

Figure 1 - 15 Flight in a Hydrogen Balloon

On August 23, 1783, the globe was inflated with hydrogen and rose into the air. One of the spectators at this event was Benjamin Franklin. He was so impressed that he immediately wrote to scientists in the United States stressing the military importance of this new invention. **On December 1, 1783, Charles and another passenger made the first manned flight in a hydrogen balloon** (Fig. 1 - 15). This flight lasted over 2 hours and covered more than 27 miles.

Following these early flights, ballooning became very popular in Europe. Between 1783 and 1790, 76 flights were recorded in France alone. During this time period, the hydrogen balloon became much more popular than the hot air balloon. In fact, by the end of the 1700s, the hot air balloon disappeared and its popularity would not return until the advent of modern - day sport balloons.

In 1793, the French government formed an air arm to their Army, and used balloons for reconnaissance during the French Revolution. In 1797, Andre - Jacques Garnerin made the first parachute jump (Fig. 1 - 16) from a balloon flying at an altitude of 3,000 feet.

Figure 1 - 16 First Parachute Jump

On January 7, 1785, a French aeronaut (balloonist), Jean Pierre Blanchard, and an American passenger, Dr. John Jeffries, made **the first balloonflight from one nation to another.** They flew across the English Channel from England to France. The flight covered about 20 miles and required almost two hours to complete.

**The first aircraft disaster occurred in May 1785.** The town of Tullamore, County Offaly, Ireland was seriously damaged because the crash of a balloon resulted in a fire that burned down about 100 houses, making the town home to the world's first aviation disaster.