Textbooks for Tomorrow's Scientists

AERONAUTICS

Caijun XUE

Introduction to Aeronautics

History and Fundamental Principles

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Introduction to Aeronautics

History and Fundamental Principles

Caijun XUE

This book provides a comprehensive introduction to the fundamentals of aeronautical science and technology, guiding readers from the origins of flight to the latest developments in aerospace engineering. Structured in six main parts, it covers the history of aviation, basic aerodynamics, flight principles, aircraft propulsion systems, aircraft structures, and aircraft instruments and navigation, while also presenting selected recent technological advances in the field. Combining historical perspective with engineering fundamentals, the book offers clear explanations, practical insights, and numerous illustrations to help readers understand the principles that underpin modern aviation and aerospace systems.

Designed primarily for undergraduate students in aeronautical and aerospace engineering, this textbook is particularly well suited to introductory courses in flight and aviation science. It provides a solid foundation in key subjects such as aerodynamics, flight mechanics, stability and control, propulsion, aircraft structures, helicopter fundamentals, and astronautics. The accessible presentation also makes it a valuable resource for aviation enthusiasts and readers seeking a structured introduction to the field.

Caijun XUE is Professor and Doctoral Supervisor at Nanjing University of Aeronautics and Astronautics (NUAA). He has extensive experience in teaching and research in aeronautical engineering, with expertise in aircraft landing gear design, structural optimization, and computer-aided engineering (CAE).

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Preface

The objective of designing this research textbook Introduction to Aeronautics originally stems from the passion to cater to the needs and meet the learning requirements of aeronautical engineering students. I have jointly collaborated with Dinagara Aroulen Vencatasawmy (M. Eng. Postgraduate) to build this textbook while referring to many fundamental books on aeronautics and gathering information from local and international accredited websites.

We highly recommend this textbook, which suits both Chinese and foreign students studying the selective introductory course on flight. Considering the different backgrounds and cultural approaches of foreign students regarding aeronautics, this book provides an overview of some fundamental concepts in this interesting field.

The simplicity and modernity of this textbook ensures that students get a clear and in-depth understanding of this complex subject while learning about the technical differences between various fields of the aeronautical domain. Despite the use of complicated mathematical formulas for the analysis of abstract aeronautical concepts, the explanation is clear and lucid, supported by specific diagrams, graphics, and pictures.

This book also intends to aim at aviation enthusiasts and aeronautics lovers, giving them a head start to dive into the challenging world of aerospace, deepening their passion and increasing their knowledge in this fascinating field of study. Covering the latest updates and facts, it is an inspiring book to get your hands on.

I wish to extend special acknowledgment to Mr. Dinagara Aroulen Vencatasawmy, who served as a Supporting Contributor/Advisor. Mr. Vencatasawmy was one of the main contributors to the previous edition as co-author, and he continues to provide valuable supporting input for future versions of this textbook.

I wish to express my gratitude to all those who brought their contribution and support without whom, this book would not have been possible. High tribute

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College of Aerospace, NUAA
Prof. Caijun Xue
May 2026

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Chapter 1

History of Aeronautic

1.1 Evolution from Wheel to Space

Most people today have a very little understanding of how traveling was challenging in ancient times and take for granted the very means of travel available to them. One could imagine how different life would be if man had never tamed that first wild horse, or shaped that very first wheel. How did our ancestors think about these life-altering ideas? Where did those instincts come from? How time led humanity from the ground to the stars? The history of aviation has extended over more than two thousand years, from the earliest forms of aviation, kites, and attempts at tower jumping, to supersonic and hypersonic flight by powered heavier-than-air jets. Kite flying in China dates back to several hundred years BC and slowly spread around the world. It is thought to be the earliest example of man-made flight. Some kites in China were capable of carrying a man into the air. The ancient Chinese also invented hot-air lanterns and bamboo-copter toys with spinning rotors.

Archaeologists believe that the very first step toward man-made carriage began in either Mesopotamia or Asia, sometime around 4000–3500 BC, with the invention of the wheel. Man had already learned how to train horses by this period, and they were used to till the soil and plant crops. The invention of the wheel eventually created man's ability to transport his crops from one place to another, where it gave birth to the idea of trade and exchange, and thus leading to the development of bulk transportation. The next evolutionary step of humankind was the invention of the cart. The two-wheeled cart was invented by the Sumerians around 3500 BC and it is believed to be the world's first form of wheeled carriage. With time, this chariot evolved to the four-wheeled cart, which resolved the issues of carrying supplies and equipment.

As man overcame the boundaries of land travel, his curiosity about exploring the world's frontier became imminent. Even before the taming of the horse, man had already developed a way to travel on water. The dugout boat is one of history's great mysteries due to its unknown origin. Historians are unable to identify when or where the very first water vessel was set afloat, and even speculate that it might have been purely an accidental creation. Fortunately, the development of the boat led to a change to the phase of transportation due to its ability to allow man to cross continents for the first time ever without the thought of dying.

Over time, simple boat also known as a sail consisted of a large piece of cloth mounted

on a central pole, transforming the boat into a sail-propelled ship. This new invention contributed to the ability to use rivers and oceans as a means of instant travel from one place to another against the current. Man kept expanding this horizon due to its vast exploitation possibilities and its potential in the future. Ships would eventually take on sleekness as they increased in size. Not long after, ship increased in size where oars, rudders, and deck covers were added. By Greek and Roman times, ships had grown clunky shipboard towers as well, which developed, over time, into the medieval 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 had gained tiers of rigging and sails, becoming sleek and speedy.

In the 1800s, ships began to shed their sails on the rivers once again. The advent of automation was changing transportation forever. The very first automation in ships was the cumbersome paddlewheel. Due to their bulky form and inability to turn easily, paddlewheel boats were limited to river travel, where they would experience smoother currents and need less maneuverability. Zheng He was a Chinese mariner, explorer, diplomat, and fleet admiral, who made the voyages collectively referred to as the travels of "Zheng He's Voyages to the Western Ocean" from 1405 to 1433.

The invention of steamship came just after the paddlewheel that these vessels used burning coal or wood to boil water to create steam. This pressure created due to the boiling water was used in turn to move the pistons of the engine to enable sailing of the ship. The steamship was utilized to enjoy a long and safe ride on both rivers and seas. Then, in 1912, the first diesel-powered ship, the Danish Selandia, was launched. That diesel engine design was made to fulfill the industrial and military standards until after World War II. Then, in 1958, the first nuclear-powered ship was conceived. However, nuclear power was soon cast-off by industry as being too expensive and risky, though it would continue to find its use in the military community.

The steam engine was a significant creation that became an automotive standard and a landmark for mass transit by land during the eighteenth century. However, these early trains were slow and often very dangerous. Then, the locomotives came into use in 1804, which used steam to power a series of pistons (much like a steamship). These locomotives were so powerful that one engine was enough to pull several cars, which was way beyond the efficiency and capacity of the earlier steam engines.

Over the next hundred years, various ideas were implemented to improve the locomotive in order to speed up transit and make trains travel safer. Then, during World War II, the diesel engine was widely utilized and steam was almost completely forgotten. Even in early 1895, the idea of using electricity as a mean of energy for trains was already on track with experiments. Unfortunately, it was considered too expensive and unreliable to run until the advent of the subway, when electricity became the cleanest means of underground motion.

As mankind always looks up to the next frontier, 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 and controlled flight wouldn't take place until

December 17, 1903. The inventors of this new flying machine were two bicycle makers, brothers Orville Wright and Wilbur Wright. Their invention would eventually grow from a bicycle-propelled concept to, after World War II, jet-propelled aircraft capable of world wide mass transit. The airplane allowed people to cover great distances in less time, cutting transatlantic travel time in half.

Having conquered flight, man's gaze and curiosity turned towards the night sky and the stars. After 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. History changed on October 4, 1957, when the Soviet Union successfully launched Sputnik I. The world's first artificial satellite was about the size of a beach ball (58 cm or 22.8 inches in diameter), weighed only 83.6 kg, and took about 98 minutes to orbit the Earth on its elliptical path.

The first manned space-flight, however, did not take place until April 12, 1961, when the Soviet cosmonaut Yuri Gagarin orbited the Earth in Vostok I. Then, on July 16, 1969, American astronaut Neil Armstrong became the first man to set foot on the moon. In July 1975, a joint American-Soviet venture began, docking spacecraft together in space. Then, on February 18, 1977, space-flight took another stride with the test flight of the very first reusable space shuttle, the U.S. craft Enterprise. That launch ushered in new political, military, technological, and scientific developments. While the Sputnik launch was a single event, it marked the start of the space age and the U.S.-USSR space race. Sputnik II was the second spacecraft launched into Earth orbit, on November 3, 1957, and was the first to carry a living animal, a Soviet space dog named Laika. It survived for several orbits but died a few hours after the launch.

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, humanity looks beyond it, to the next challenge. The annals of history are evidence that humanity will continue to stride forward, particularly when faced with challenges in the transport mechanism. The ability to move people, cargo, and information quickly through air and space is unmatched. Another aspect of air and space power that makes it unique is altitude. Not only can you fly over an obstacle that is in your way, but you can also see over it. Elevation in height gives you the ability to see objects that are far away. Lessons were learned the hard way, which cost many lives along the way, enhancing our ability to conquer space. Mistakes were made while expanding our horizon through experiments of engines, wings, and life support systems. We should learn from the experiences of our ancestors to ensure the future of mankind in a better way. Let us have a look at different major developments in the history of air and space power, in which addition points outlined their importance to keep up researches in these fields.

1.2 Legends and Chinese Kites

Long before people appeared on this planet, other forms of life, which included birds, mammals (bats), and reptiles (pterodactyls), learned to travel through the air. Some even believe that, many centuries ago, life from other planets may have traveled through space. However, space travel is a very recent occurrence for the human species, and it took a century for humankind to gain the ability and concept of flying. Human beings have always dreamed of flight. It is the flight to which humans traditionally aspired was that of the birds. To this, the myths and legends of many cultures testify through history.

Among the earliest recorded stories of man in flight is the Chinese legend of Emperor Shun. According to this legend, nearly 4000 years ago, Emperor Shun escaped from prison by stitching cloth in the form of a bird. Shun's birth father was blind and re-married after Shun's mother's death. Shun's stepmother then gave birth to Shun's stepbrother Xiang and a stepsister. Shun was treated awfully by the stepfamily that forced him to do all the hard work and gave him the worst food and torn clothes. Shun's good deeds were often ignored due to his father's blindness and age. Yet, despite being blamed for everything, Shun never complained and always treated his family with kindness and respect. His stepmother threw him out of the house when he turned barely adult and he was forced to live on his own. Due to his compassionate nature and his natural leadership skills, people followed him and praised him everywhere he went, and he was able to preach kindness around him and encourage people to do their best.

When Emperor Yao became old, he was concerned over the fact that his nine sons were useless and only knew how to spend their days enjoying themselves with wines and songs. Yao then heard of Shun's tales while asking him administers to propose a suitable successor. The wise emperor decided to test Shun's skills. Shun was given a whole district to govern and turned out to be fruitful. Eventually, he married the two daughters of the emperor, with a new house and money. However, the inventor still lived humbly though given his new lifestyle. He somehow managed to convince his two brides, the two princesses who were used to good living, to live humbly and work with the people. But Shun's stepfamily became extremely jealous and conspired to kill him. Once, Shun's stepbrother lit their barn on fire and tried to trap him on the roof of the burning barn. The legend of Emperor Shun ascended when he made a parachute out of his hat and cloth. Then, he jumped down safely due to the resistance of the air and the shape of the cloth.

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. According to this myth, Daedalus (an architect and mechanic) and his son, Icarus, were imprisoned by King Minos of Crete. Determined to escape, Daedalus made a large set of wings for himself and his son. The wings were made of feathers. They attached them to their bodies with wax. They glided away from the island prison. Despite his father's warning, the wax melted, and Icarus fell to his death into the sea.

Although we don't know how truthful these legends are, we do know that the Chinese

built the first devices that enabled us to fly. It is thought to be the earliest example of man-made flight. Some kites in China were capable to carry a man into the air. It was invented in China possibly as far back as the 5th century BC by Mozi (Mo Di) and Luban (Gongshu Ban). Later designs often emulated flying insects, birds, and other beasts, both real and mythical. Some were fltted with strings and whistles to make musical sounds while flying. Ancient and medieval Chinese sources describe kites being used to measure distances, test the wind, lift men, signal, and communicate and send messages.

About 900 AD, the Chinese invented gunpowder, and by 1100 AD, they were using 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 Hu attempted a flight to the moon using a large wicker chair to which were fastened 47 large rockets. When the rockets were ignited, Wan Hu disappeared in a large ball of smoke and fire—never to be seen again. The Chinese legend concludes that maybe Wan Hu is the man in the moon.

1.3 Early History

1.3.1 Scientific Research

Leonardo da Vinci (1452–1519), is well known around the world as an Italian artist. Millions of people every year flock to the Louvre Museum in Paris, France, to get a glimpse of his painting the "Mona Lisa". His sketch of the "Vitruvian Man" changed the way people use proportion in art. But Leonardo isn't called the ultimate Renaissance man without reason. He was a painter, a sculptor, an anatomy expert, an engineer, and an architect. He made the first scientific experiments in the field of aviation and he managed to predict the steam engine, the tank, and the submarine. During the late 15th century, he wrote about and sketched many designs for flying machines and mechanisms, including ornithopters, fixed-wing gliders, rotorcraft and parachutes.

Leonardo understood and wrote about the importance of the center of gravity, the center of pressure, and the streamlined system. These principles are vital for designing and building modern aircraft. Leonardo studied flight by analyzing birds and anticipated many principles of aerodynamics. He already understood that an object offers as much resistance to the air as the air does to the object, bearing in mind that Newton would not publish the third law of motion until 1687.

Leonardo also took a great interest in flight during his 30's and by the year 1505, and he had collected around 20 years of theory on flights. It is around this time that some people thought that Leonardo built a complex ornithopter, a machine with flapping wings that closely mimicked the anatomy of birds and allow humans to fly. He 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. No one really knows if Leonardo actually built a model and tested his ornithopter. Many of his designs remained

on paper during his lifetime and weren't built until much later. Eventually, some men of science began to discover and define some of the basics of rational aircraft design. It was 300 years after his death before his manuscripts were published and made known to the world. As his work remained unknown until 1797, it had no influence on developments over the next three hundred years.

Evangelista Torricelli (1608–1647) from Italy, **von Guericke** (1602–1686) from Germany, and a Frenchman named **Blaise Pascal** (1623–1662) were three famous European scientists who dedicated their life to studies of the atmosphere. They learned that the atmosphere is fluid and that atmospheric pressure decreases the higher the altitude increases. Torricelli invented the barometer, which measures the pressure of the atmosphere, and Guericke created the air pump, which allowed them to study vacuums. The definite proof of the fall in barometric pressure with altitude is usually ascribed to Blaise Pascal. He was an infant prodigy, particularly in the area of mathematics, but he also did extensive work on the pressure in fluids. One of the best-known subsequent experiments was carried out in 1654 by Otto von Guericke, who had the distinction of making the first air pump. The three scientists' knowledge eventually led to successful lighter-than-air flight.

In 1670 **Francesco Lana de Terzi** published a work that suggested lighter-than-air flight would be possible by using copper foil spheres that, containing a vacuum, would be lighter than the displaced air to lift an airship. While theoretically sound, his design was not feasible: the pressure of the surrounding air would crush the spheres. The idea of using a vacuum to produce lift is now known as vacuum airship but remains unfeasible with any current. He proposed to make the spheres out of very thin copper. The principle is good in theory, but the pressure of the surrounding air would have immediately crushed the spheres. Francesco de Lana's writings are the first scientific records of a "vacuum balloon". He also discussed the need for ballast (a heavy substance) for controlling ascent and the need to let air enter the spheres gradually to control the descent. Francesco de Lana also wrote about military uses for balloons.

1.3.2 Birth of Lighter-than-Air

On November 21, 1783, the Montgolfiers launched the first free flight with human passengers. The aviators were the scientist Pilâtre de Rozier, and the Marquis d'Arlandes, a young infantry officer. They drifted 8 km (5.0 mi) in a balloon powered by a wood fire and lasted for 25 minutes. **They were the first men to fly in a lighter-than-air craft and rode a Montgolfier balloon into the air over Paris.** Flight became a reality for man after centuries of dreams and thoughts. However, we were still a long way from mastering air flight due to the issue of continuously heating the trapped air in order to keep the mechanism in the sky. It also limited the duration of the flight because a great deal of wood and straw had to be carried as fuel.

Later, a young scientist, J. A. C. Charles, developed a small globe of rubberized silk to carry out further research on balloons. On August 23, 1783, the balloon was inflated with hydrogen and rose into the air, where the flight lasted over 2 hours and covered more than

27 miles. One of the spectators at this event, Benjamin Franklin 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 with a hydrogen balloon.**

Following these early flights, ballooning became very popular in Europe. Between 1783 and 1790, 76 flights were recorded in France alone. During this time, 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 from a balloon, flying at an altitude of 3000 feet.

On January 7, 1785, a French aeronaut (balloonist), Jean Pierre Blanchard, and an American passenger, Dr. John Jeffries, made **the first balloon flight 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 in Ireland**, where the crash caused casualties and 100 houses completely burned. In 1887, a Chinese scientist known as Hua Hengfang made the first Chinese hydrogen balloon, and it took off from Tianjin.

1.3.3 Dawn of the Dirigible (Airship)

The use of hydrogen gas overcame the major disadvantage of the hot air balloon—its inefficiency because carrying fire and fuel airborne to keep the air heated was difficult and dangerous. However, many people were killed due to the fact that hydrogen is highly flammable until helium came into use. In either case, the balloon's concrete major problem was the steering ability. Altering a free balloon into a dirigible (a lighter-than-air craft that can be propelled and steered) would puzzle scientific minds for almost a century, and it was the next frontier during that era.

In 1785, French general, Jean Baptiste Meusnier, made several suggestions that eventually led to successful dirigibles. This would reduce air resistance and also establish a front and rear for the balloon. He also suggested an envelope (container for the gas) made of several compartments and a passenger car shaped like a boat attached to the bottom of the dirigible by a system of ropes. What he did not solve was how to power the dirigible.

Ballooning became a major "Trend" in Europe in the late 18th century, providing the first detailed understanding of the relationship between altitude and the atmosphere. Work on developing a dirigible balloon continued sporadically throughout the 19th century. **The first powered, controlled, sustained lighter-than-air flight is believed to have taken place in 1852, when Henri Giffard flew 15 miles (24 km) in France, with a steam engine driven craft.** He built a cigar-shaped dirigible 114 feet long and 39 feet in diameter. The dirigible was powered by a 3-horsepower steam engine that pushed it at a speed of about 5 mph (mile per hour). This dirigible is generally credited as being the first successful one in the world.