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Innovation for the Air: A Brief History of Worldwide Aviation

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INNOVATION FOR THE AIR:
A BRIEF HISTORY OF WORLDWIDE AVIATION

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Abstract

The purpose of this report is to present a brief but comprehensive overview of the variety of innovations related to aviation, and to discuss their impact on scientific progress over the course of human history. Relevant discoveries from the fields of physics and aerodynamics, and the numerous technologies built based upon these discoveries, are discussed over a period ranging from ancient times to the twenty-first century. The scope of this report is an overview of the development of powered and unpowered aircraft, including lighter-than-air, heavier-than-air, and aerospace technologies. Aviation developments were generally not limited to one specific country or person, but often came from a combination of research and testing from many engineers and enthusiasts from a variety of locations and backgrounds. Races to meet milestones would inspire competition between individuals, scientific institutions, and countries. It is hoped that this report will be instructive to readers who may not have extensive familiarity with aviation-related history, and will promote personal research and interest.

Key Words: aviation history, aerospace history, engineering, aerodynamics

Innovation for the Air: A Brief History of Worldwide Aviation

Introduction

The purpose of this report is to present a brief but comprehensive overview of the variety of innovations related to aviation, and to discuss their impact on scientific progress over the course of human history. The human race (in its modern form) has lived on the surface of the Earth for about two hundred thousand years. For almost three thousand of those years, the human race has been trying to leave that surface in some capacity. From ancient times onwards, flight has been a measure of scientific progress, a symbol of wealth and status, and a catalyst for interpersonal and international competition. It is a field that has, for the majority of its history, been pioneered largely by the dedication of individuals rather than corporations or governments. The history of aviation is incredibly broad and complicated, so much so that its entirety couldn't be easily contained in any single written source. Therefore, this report will serve as merely an overview of the variety of discoveries that allowed aviation to become the wide-ranging feature in our modern society it is today.

Due to the wide variety of innovations associated with aviation, this report has been divided into five sections. Each of these sections discusses either a specific time period or a specific category of aviation, and information about milestones progresses in a mostly chronological fashion. Each section may cover developments that occurred earlier than the latest developments in the previous section. Sources are also organized by section appearance, not by alphabetical author order or chronological date. The five sections are: Initial Leaps; Floating Upwards; Understanding Airpower; From Theory to Practicality; and Beyond Gravity.

Initial Leaps: Early Flight

The beginnings of human experimentation into flight are not known to begin with any one person, nor with any particular event. However, it is evident that the possibility of human flight or flying objects were manifest in human interest thousands of years before the first practical flying objects were ever developed. Ancient mythical and religious sources are full of references to flight machines, such as the Vimana referenced in the *Vedas* and *Ramayana*, numerous flying carpets, eagle-driven craft, and the flaming chariot used to deliver the prophet Ezekiel to heaven in the Hebrew Bible.[1, 2, 3] The most widely known example of flight-related mythology, particularly in modern times, is the Greek myth describing the flight of Daedalus and Icarus using wings constructed from feathers and wax.[4] While presenting a possible method of human flight, the tale also centers around Icarus's fall from the sky, foreshadowing the difficulties and dangers that early aviators would have to overcome as they pursued their ideas.

The specifics of gravity were not entirely understood by ancient scientists, but observation of the world around them obviously demonstrated that things which were sent up into the air tended to come back down. The first known theory related to gravity was posited by Aristotle, who believed that objects tended to move towards their "natural place," or the center of the earth.[5] Other Greek and Roman mathematicians and architects expanded on this theory to develop the first descriptions of what would come to be known as specific gravity and the center of gravity. Expanding further, the Indian astronomer Brahmagupta would be the first to describe gravity (which he called gurutvakarsanam) as an attractive force produced by the earth's tendency to draw things to itself.[6] The exact definitions of why this attractive force existed were still unknown, however the force itself presented the single greatest obstacle to flight.

To early aviation engineers, the only things which appeared to truly be able to defy the attractive force of the earth (whatever its cause) were birds, insects, and the smoke produced by fire. Out of all of these options, it was birds that provided most of the initial inspiration. The ability of birds to fly was attributed to their wings, and the ability to control their flight in midair attributed to their tails. With these facts in mind, early aviators attempted to recreate birdlike anatomy, particularly the wings, in the earliest flying machine designs. This idea was not entirely without merit. The shape of bird wings follows the physical description of an airfoil, a shape designed to maximize lifting force in relation to the drag force as it passes through a fluid such as air.[7] Lift, the force provided by the change in air pressure differentials underneath the wing, is vital for allowing birds to keep themselves in the air and to glide over long distances.[7, 8] To produce lift and thrust forces and to overcome both the gravitational force holding a bird to the ground and the drag forces associated with air hitting their wings, birds have developed the ability to flap their wings, which are generally flexible and which birds can control to generate appropriate velocities.[7, 8]

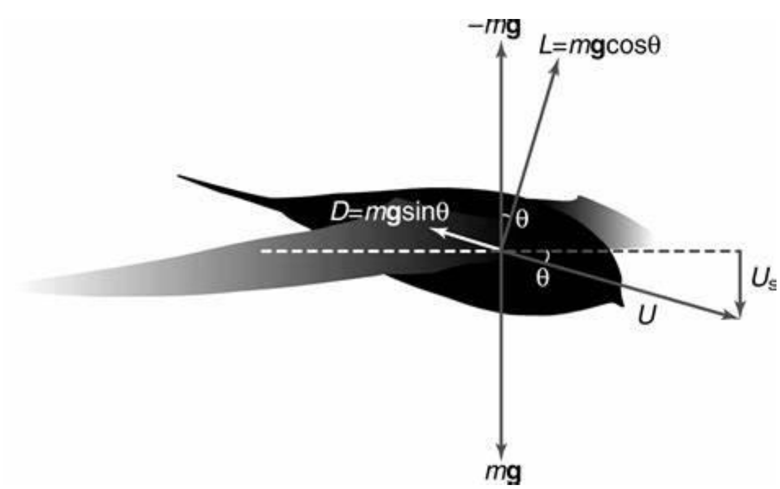


Fig. 1: A simplified diagram of the lift, drag, and gravitational forces imposed on a bird during flight. The gravitational force acts towards Earth's surface, while the directions of the lift and drag forces is dependent on the angle of the bird's progress through the air. If all of the forces are at equilibrium, the bird is able to glide through the air.[9]

In keeping with the ideas presented in the myth of Icarus, the earliest experiments involving human flight consisted mainly of people jumping from high cliffs or buildings, using "wings" composed of feathers, fabric, and other materials. Not only were many of these machines lacking proper tails, but they also did not properly account for the forces involved in keeping a human being off of the ground. The forces previously discussed (thrust, lift, drag, and weight/gravitational force), were not to be formally identified for centuries, so the vast differences between bird flight and human flight were not apparent to early engineers. Birds are generally very light in terms of mass, which ensures that the gravitational force (which is equal to mass times the acceleration of Earth's gravity) holding a bird to the ground is not as large as the gravitational force that holds a human to the ground. This ensures that the amount of force that a bird has to produce is significantly smaller than a human would have to produce by flapping, even with human-sized wings.

Consequently, the early experiments of aviation exploration were plagued by injuries, many of them fatal. As early engineers were unaware of the particulars of the bird flight they were inspired by, most of the problems associated with tower jumping were believed to be the fault of not choosing a high enough jumping point, or of choosing feathers that were not strong enough. Despite this, there are many accounts of "successful" flight attempts: the chronicles of the Chinese emperor Wang Mang report a successful tower jump by one of his scouts around 100 BCE, although it's unclear what type of "wings" were used.[10] Jumps by the Muslim inventor Abbas ibn Firnas and the English monk Eilmer of Malmesbury were also reported later, although the jumpers were injured upon landing due to an inability to steer and control their machines.[11] Even when more sophisticated methods of getting people into the air were being proposed and implemented, tower jumping experiments involving feathered wings continued to be documented until the early sixteenth century. These accounts of early flights could probably be characterized as gliding at best, and details of the flights would not be reported until centuries after the claimed attempts were made and any primary sources were lost. However, it is likely that they did provide some of the groundwork for the understanding that achieving flight was going to be a far more complicated process than simply imitating bird flight.

Although early flight experiments relying on human power were often unsuccessful, there was far better success when it came to unmanned flying objects. Rather than attempting to recreate the "flapping" motions associated with bird wings, most of these objects relied on the gliding aspects instead. Probably the most well-known of these objects was the kite, which was reportedly invented in China in the fifth century BCE, likely for decorative or entertainment purposes.[12, 13] Very quickly, the Chinese began to utilize kites for a variety of other purposes, including in military operations and in ceremonies.[12, 13] These uses also spread to, or were invented in tandem by, India, the Polynesian Islands, and other groups in the Asian South Pacific, who used them for ceremonial purposes, analysis of local meteorological conditions, and even sports in the form of kite-fighting.[13] There are even reports of the use of kites large enough to carry people, which were reportedly used as punishments for convicted criminals.[14] These man-carrying kites were widespread enough that they even appeared in Marco Polo's reports of his travels to China in the thirteenth century.[14] Despite this account, descriptions of kites would not appear in European literature until the seventeenth century.[15] Although kite-flying would not become a widespread phenomenon in Europe beyond occasional use for later flight experiments, it is likely that the idea of these man-carrying kites inspired the future exploration of the unpowered gliders that would be developed in later centuries.


80 *The ſecond Booke*

thereof; then hang the wings on in ſuch wiſe, that they may ſhake as the Dragon runnes along the line; you may diſpoſe divers ſmall ſerpents in the wings; marke the figure.

How to make fire Drakes.

YOu muſt take a peece of linnen cloth of a yard or more in length; it muſt bee cut after the forme of a pane of glaſſe; faſten two light ſtickes croſſe the ſame, to make it ſtand at breadth; then ſmeare it over with linſeed oyle, and liquid varniſh tempered together, or elſe wet it with oyle of peter, and unto the longeſt corner faſten a match

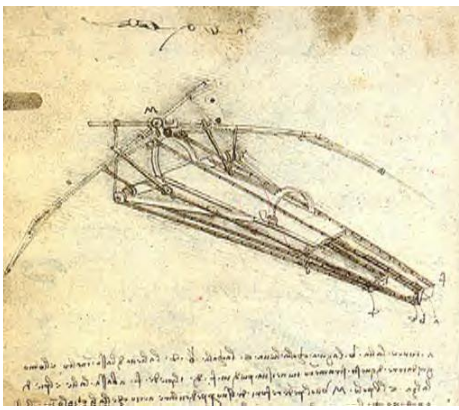
Fig. 2: A depiction of a kite from the seventeenth century English text Mysteryes of Nature and Art, which details instructions for making a kite under the title: "How to Make Fire Drakes."[15] This is one of the first depictions of a kite in print.

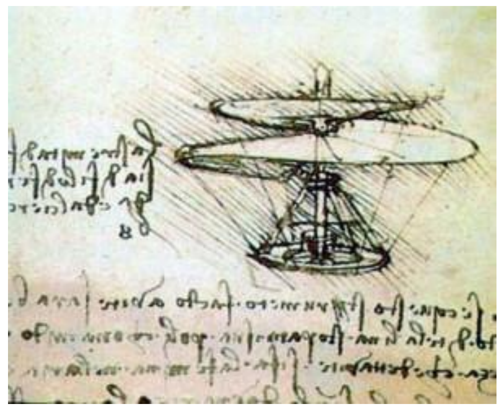
The Chinese also developed the first gunpowder rockets, which may not have necessarily been developed for extended flight or aviation innovation, but nevertheless likely planted the seeds that would inspire future rocket development.[16] Other Chinese developments include the bamboo-copter, a toy utilizing a rotor that was attached to a stick.[17] Although not designed for anything other than play, it demonstrated that rotor-type technology could be a feasible way of generating lift if applied correctly, and more advanced models of rotor-type flight machines would eventually appear.

Although there are few sources detailing other unmanned flying machines, there are some exceptions. Around 400 BCE, there are reports of a flying machine called the “dove” or “pigeon” developed by the Greek philosopher Archytas, which was able to fly for about two hundred meters before it came to rest.[18, 19] Although exact reports of the machines’ function vary, the fundamental machine likely consisted of a hollow wooden object resembling a bird, which was attached to a bulb containing water.[18] The bulb was heated by fire, and the steam generated inside would eventually propel the wooden “bird” off of the bulb and allow it to glide for considerable distances.[18] The most notable feature of this machine is that it incorporated heated steam in its design to help generate thrust, which makes it the first documented use of some sort of self-sustaining power other than wind or human power to produce flight.

Fig. 3: A modern recreation of Archytas’ “Pigeon”

Attempts at making flying machines capable of supporting humans would continue as the centuries went on, and the focus of experimentation moved towards Europe. The modern public is likely familiar with the variety of designs for flying machines proposed by Leonardo da Vinci in the late fourteenth century. Da Vinci had devoted a great deal of study into bird flight and its aerodynamic properties, and had made a number of statements theorizing about the nature of lift, drag, and the fluid properties of air in his work *Codex on the Flight of Birds.*[20] Most of his initial designs, which included ornithopters and rotorcraft, were man-powered, designed to be propelled by human arms or legs.





Figs. 4 and 5: Some sketches from da Vinci's work of theoretical aircraft

Although some of these designs did pose some merit or have improvements on earlier designs, da Vinci's work did not have a substantial effect on future aviation developments for a number of reasons. Firstly, his designs were limited by the understanding of the time, and the few flightworthy pieces of his designs were undermined by flaws that would have caused the designs to fail in practice. In addition, what survives of his work was left mostly in his notes and there is only minimal evidence that there were any successful attempts to construct or fly his machines. Most importantly, the bulk of da Vinci's work on flying machines (mostly contained in *Codex on the Flight of Birds* and *Codex Atlanticus)* wasn't discovered until the eighteenth century, well after his death, and significant progress in aviation theory and the building of flying machines had either rediscovered or negated what had appeared in da Vinci's designs. Despite this lack of meaningful progress, da Vinci's designs did affirm what would eventually be posited by other scientists: human power alone was not enough to power a flying machine, and external power from some source would be necessary. This understanding led to an overall shift in the type of machines being studied as time and experimentation went on.

Floating Upwards: Lighter-Than-Air Flight

Around the same time that the initial flight experiments were taking place, innovations were being achieved in another form of flight. Rather than relying upon mechanical means to generate lift, these technologies made use of what would become known as "lighter-than-air" theory Machines that operate under these principles rely on the difference in densities between fluids (in this case, gases) to generate lift.[21] When an object of low density is surrounded by a fluid of higher density, the object "floats" in the fluid due to the distribution of buoyancy forces acting on the object.[21] These buoyancy forces are equivalent to the weight of the fluid that is displaced by the low-density object, and push upwards (or more exactly, in whatever direction is opposite to the force of gravity acting on both objects).[21] For the flight machines discussed in this section, the low density objects are the machines themselves, which encase either heated air (which has a lower density than cool air) or gases which have a lower density than atmospheric air, which serves as the high density fluid.

Exact mathematical explanations of buoyancy and how gases such as air respond to temperature changes may not have been finalized at the time of the earliest flight experiments, but there was substantial understanding that heated byproducts of materials such as smoke and steam rose into the air. This understanding would eventually be accompanied by the knowledge that if enough of such materials were contained within an enclosed (and preferably light) object, the object could rise into the air.

Some of the earliest uses of lighter-than-air technology were developed by the Chinese, who reportedly used lanterns for a variety of uses as early as the 3rd century.[12] These lanterns were generally made out of paper and encased a flame, the heated air and smoke produced from this flame providing the lift. Most of these uses were either ceremonial or decorative, but similarly to the kites, it would not be long before lanterns were used for military purposes as well in the form of signaling.[12] Through trade along the Silk Road, and continuing through the Mongol conquests, a variety of Chinese-invented technologies were brought to Europe, lanterns included. In at least one account of the Battle of Legnica, a city located in what is now Poland, the Mongols used what are reported to be either lanterns or lighted kites to signal various commands over the course of the battle.[12]

Robert Boyle's work with confined gases in 1662 would define the tendency of hot gases to rise, it wasn't long before European engineers began to attempt to develop balloons using heated materials.[22] The first documented balloon flight was a small paper craft developed by a Portuguese priest named Bartolomeu de Gusmão, who demonstrated it in front of the Portuguese royal court in 1709.[23] In the years that followed this demonstration, significant scientific advances were made in the field of ballooning, with a multitude of projects being funded by progress-minded sponsors and even the public, who were beginning to see the first demonstrations that human flight may indeed be possible.

The year 1783 in particular was filled with "firsts." A variety of inventors were racing to demonstrate and capitalize on ballooning technology, but the most successful of these were the French Montgolfier brothers. They had invented their own version of a hot-air balloon made from paper and sackcloth and filled by wood smoke from a fire they suspended underneath the balloon.[24] Despite the danger of fire, these balloons were very successful, and the brothers launched their first public unmanned balloon flight in June of 1783.[24] This would very quickly be followed by another flight in September of 1783, this time with non-human passengers in the form of a sheep, a rooster, and a duck.[24] These animals were not chosen randomly: rather, they were chosen because they either served as controls for effects of the balloon (in the case of the birds), or provided a look at how flight could affect a "human-like" physiology (in the case of the sheep). These balloon launches had a great deal of publicity, but many more advances would take place before the year was over.

Fig. 6: A publication depicting one of the Montgolfier brothers' balloons

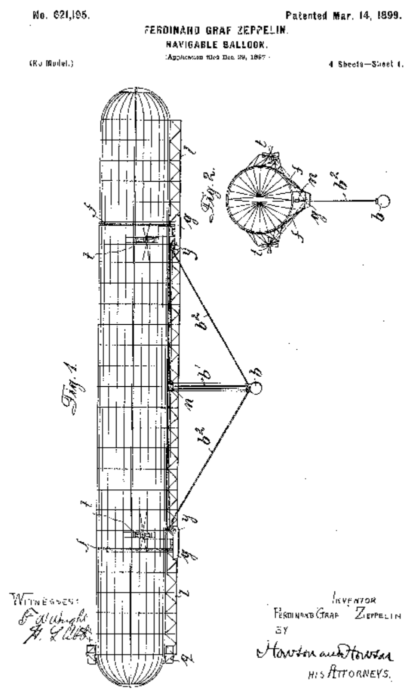
At the same time as the Montgolfier brothers, developments were being made with balloons that were lifted by gases other than air. The most promising among these was hydrogen, which had been formally identified as an element in the 1760's. Physicists including Robert Boyle and Henry Cavendish conducted several experiments with hydrogen. After engaging in some small-scale soap bubble experiments, a French inventor by the name of Jacques Charles believed it was possible to fly a balloon lifted by the element.[24] Charles teamed up with a pair of engineers known as the Robert brothers, and they set out to construct, fill, and fly the world's first hydrogen balloon. Unlike the paper design of the Montgolfier brothers, this balloon was constructed of fabric strips sewn together and primed with a mixture of rubber and turpentine.[24] It was filled by pouring sulfuric acid on iron and collecting the hydrogen gas produced by the reaction, which was the most well-known means of producing hydrogen at the time.[24] They successfully filled and launched this balloon on August 27th, 1783. It flew untethered for a distance of twenty-one kilometers before it landed.[24, 25] Unfortunately, the balloon was then attacked by frightened locals in the area of the landing and was destroyed, but it would only be the beginning of Charles' and the Robert brothers' hydrogen balloon launches.[25] Their introduction into the ballooning field represented direct competition for the Montgolfier brothers, which continued to speed the testing of more complicated flights.[24]

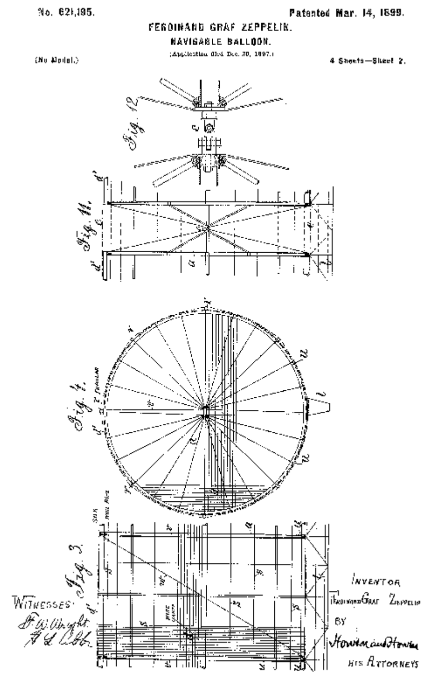
By the end of the year, ballooning technology had advanced to the point of lifting humans into the air. The Montgolfier brothers launched the first public manned, tethered balloon flight on October 15th, 1783, which carried three passengers up into the air over a French estate.[24, 26] In November, the first manned, free balloon flight was conducted, carrying a passenger from the October flight and a local Marquis for around five miles.[24] Ballooning as a scientific endeavor and as a hobby was spreading, mostly among the French nobility or scientists who could secure crowdfunding. Hot air manned flight was soon followed by the first manned flight in a hydrogen balloon developed by Charles and the Robert brothers in December of 1783.[24, 27]

These ballooning advancements led to a number of other milestones. These included the first ever crossing of the English Channel by air (1785), the first manned balloon flight in America (1793), and the first balloon flight by a female pilot (Sophie Blanchard, 1804) The first aviation disasters were also recorded, with the earliest known occurring in May of 1785 when a balloon crashed in the Irish town of Tullamore and set fire to multiple houses.[28] By the late eighteenth century, hydrogen was the most frequently used lifting gas.

Balloons were also quickly utilized for military purposes, mostly for gathering intelligence rather than engaging in combat. The high vantage point offered by balloons offered good opportunities to report on troop movements, leading to balloon use in a variety of battles. Military balloons were used during the American Civil War in the 1860's, in which the Union Army Balloon Corps utilized several civilian-piloted balloons for reconnaissance with varying degrees of success.[29] Due to the need for storage and transport of the balloons, a refurbished coal barge named the *George Washington Parke Custis* was used to house them, making the vessel the world's first aircraft carrier.[30] Despite the benefits military balloons offered to armed forces, they had their limitations: many balloons had to be tethered to safe territory to prevent them from floating behind enemy lines and being shot down, so their range was limited.

Attempts to construct more controlled, steerable balloons, which would eventually be referred to as airships or dirigibles, began for military use as the nineteenth century brought turmoil in the form of the French Revolutionary Wars, the conquests of Napoleon, and the Franco-Austrian and Franco-Prussian Wars. Although there were several failed attempts to produce airships for military combat (including an extensive series of attempts made by Franz Leppich to produce one first for France, then for Russia), the first successful flight of an airship was eventually achieved by Henri Giffard in 1852.[31, 32] This airship was powered by a steam engine, an increasingly more influential power source at the time.[32] The invention of the internal combustion engine, and its eventual integration into airships, made the technology even more feasible, and a flight using an internal combustion engine was completed in 1872.[33] Further improvements to the frames of airships to make them rigid rather than flexible, a technology pioneered by the German Ferdinand von Zeppelin, allowed the airships to travel farther distances and to better withstand variable weather conditions.[32, 33] This led to the first completely controlled flights of practical airships starting in the beginning of the twentieth century.





Figs. 7 and 8: Drawings submitted by Ferdinand van Zeppelin as part of his 1899 patent for a rigid-frame "navigable balloon"

Completely controllable airplanes would not be developed for a few more years. The planes that were developed were limited to small craft that wouldn't find extended use until WWI, and weren't yet reliable over long distances. When it came to large-scale commercial transport, passenger transport, and military power, airships were believed to be the future. They were initially used by a variety of world powers at the beginning of WWI in the hopes that they could serve as reconnaissance or bombing devices, but issues with navigation and the invention of incendiary and explosive ammunition (which seriously compromised the hydrogen gas-filled airships) proved that they were impractical for long-range missions behind enemy lines.[34] Some airships were utilized in naval operations, but the focus of world powers after WWI shifted to making airships a means for passenger or commercial transport.

Multiple countries developed airship programs after WWI, and attempts were made to establish passenger transportation across the Atlantic via airship. This was achieved by the British-made airship R34 in July of 1919, which managed to successfully travel to Long Island and back.[35] Other airships were constructed or purchased by the United States of America, including two which were suspended using helium instead of hydrogen.[36, 37] Helium was scarce enough at the time that almost the entire world's available supply was located within one of these balloons, which allowed only one of the airships to operate at a time.[36, 37] Nevertheless, the United States attempted to conduct research into the use of airships as aircraft carriers, although this eventually proved to be inefficient.[36]

Airships proved to be a reliable transport when they were maintained, and it was the German airships which provided the best reliability, highest degree of safety, and the most energy efficiency. Post-war reparations and restrictions limited the ability of the famous German-owned Zeppelin company to construct anything but small-scale passenger craft, but when the restrictions were lifted in the 1920's, the company was able to produce a variety of airships that could compete with the traditional ocean liners of the time. Despite this success, multiple airship-related disasters over the course of almost a single decade would halt progress. Three out of the four United States-owned airships were wrecked in accidents between the years of 1925 and 1935, while the British-developed R101 crashed on its maiden flight in 1930.[37, 38] Even the safer German-owned airships were not spared: in one of the most well-known aviation disasters in history, the Zeppelin *Hindenburg* caught fire and crashed on May 6th, 1937.[39] Unlike other airship disasters, this one was caught on film, allowing the tragedy to be brought firsthand to the general public around the world.[39] This destroyed public support for airship transportation, and airship travel was eventually almost completely replaced by the rapidly advancing airplane.

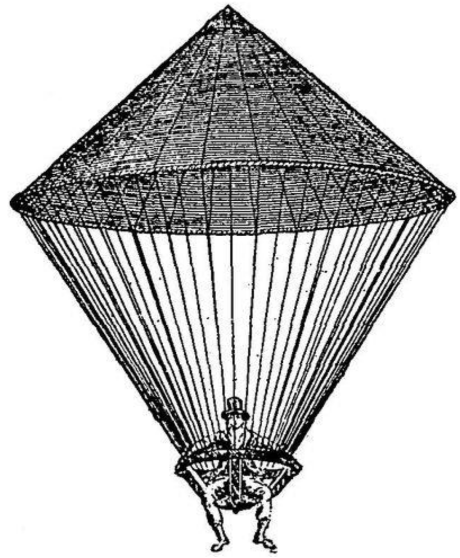
Fig. 9: Photograph of the destruction of the Hindenburg in 1937, one of the most publicized aviation disasters in history

Despite the end of ballooning as humanity's most widely studied exploration of flight, balloons and a few airships still exist for a variety of purposes. The great majority of these are owned by private organizations, and are used either for recreation or for advertising. Balloons are still used for meteorological data collection and the occasional military research project, although planes remain the most popular for most aviation uses. There have still been opportunities for adventurous balloonists to achieve feats. In 2002, the first nonstop circumnavigation of the world by any kind of aircraft was achieved by Steven Fossett in a hot air balloon named *Spirit of Freedom.*[40]

Understanding Airpower: Heavier-Than-Air Flight Developments

Some of the more successful attempts at making early flight machines involved elements that supported gliding motion rather than recreating the mechanical motion of bird flight. As lighter-than-air technologies were progressing, unpowered machines such as gliders and parachutes were also being developed. Before these aircraft could transition to the powered, controlled devices that are so common in the modern world, numerous scientific breakthroughs would have to take place.

Centuries of jumping from high places with varying degrees of success had refined the design of the devices used in jumping, which moved away from the winged designs. The first published design for what would seriously resemble a modern parachute (with the exception of da Vinci's as-yet undiscovered, pyramidal design) was presented in 1615 by the Croatian Fausto Veranzio, and was titled *Homo Volans* (flying man).[41] There is no evidence that this design was constructed or tested, but the design features a piece of material supported by a frame and attached to the user by ropes, which isn't far removed from what is known today as a modern parachute. Despite further publishing and testing of similar devices by many around the world, it would be some time before a successful documented parachute jump would be completed by Louis-Sebastien Lenormand in 1783, when he jumped from the Montpelier observatory tower in France.[42]



Figs. 10 and 11: A portion of the published sketch of Veranzo's Homo Volans (left) compared to a sketch of Lenormand's parachute (right)

The advances made with parachute development were accompanied by the development and display of several glider-type aircraft. These were mostly developed for spectacle's sake rather than serious research, but some were able to successfully make it off the ground. Among the better-documented early gliders was the "Dragon Volant" built by Tito Livio Burattini.[43] The glider was reportedly able to lift a cat, but there are no records of any human flight supported by the glider.[43]

Only a few decades later, the physicist and physiologist Giovanni Borelli would publish in his treatise *De Motu Animalium* ("On the Movement of Animals") what many had already theorized: the human arm was not able to produce the proper forces by flapping to generate lift.[44] In 1687, Isaac Newton published *Philosophiae Naturalis Principia Mathematica*, which revolutionized the world's understanding of physics. A variety of vital theories were contained in this work, some of the most relevant for aviation including the law of universal gravitation, Newton's laws of motion, and theoretical derivations of multiple equations including what would eventually become the drag equation.

As the sixteenth century became the seventeenth, more designs for flying machines traveled from models and personal theories to formally published papers. Among the first of these publications was “Sketch of a Machine for Flying in the Air” by the Swedish scientist Emanuel Swedenborg, which was published in 1716 without Swedenborg’s actual sketch of the machine, and only a description of its function.[45] The machine depicted in this sketch did not present any innovation on top of what was already understood at the time and wasn’t flightworthy, which Swedenborg admitted himself.[45] The real purpose of the paper was to present a theoretical combination of probable theories, and Swedenborg would posit that some source of external power beyond human power would have to be used in order for such a machine to be able to fly at all.[45] Up until this point, the only power source which appeared to be available was spring power, but a feasible design utilizing a spring had yet to be proposed. Despite the continued lack of power, there would be several successful glides made over the next several decades, and it would not be long before more serious breakthroughs were made.

It was only a matter of time before someone would be able to take all of the progress and specifically devote themselves to the study of flight alone, and from the beginning to the middle of the nineteenth century, that someone was Sir George Cayley. Cayley contributed so many advances to the field of aviation that many consider him the “father of the aeroplane,” and his designs would inspire many of the projects that would become the first successful unpowered and powered aircraft.

Like many before him, Cayley began his research into flight by studying the mechanics of lift. Where previous designers would generally start by building a full model of their machines and attempting to fly it, Cayley adopted a different approach. He constructed an apparatus that could spin objects around at various speeds, which allowed him to study the effects of drag on small-scale, fixed-wing models.[46] These models would evolve into proper airfoils, capable of generating lift. His experiments also allowed him to determine a variety of ways in which these airfoils could be utilized in aircraft to maximize stability. These included the proper selection of the dihedral angle (the angle between the right and left wings of the aircraft) and the movement of the center of gravity below the wings.[47] Cayley also believed that a modern aircraft would need to have separate systems for lift generation, control, and propulsion, and that it would have to be as light as possible.[47]

The first of many models utilizing these developments was built by Cayley in 1804, and between the years 1809 and 1810, he would publish *On Aerial Navigation*, a compilation of everything he had learned through his research. Not only did he discuss the previously mentioned topics, he also formally identified the vector forces which affect an aircraft's flight. These forces, as previously discussed, were thrust, lift, drag, and weight. These forces are easily recognizable by those with a modern understanding of flight physics and had been theoretically understood before the publication of *On Aerial Navigation,* but Cayley had been the first to present them all in a cohesive manner that provided a blueprint which allowed him to produce successful gliders. He continued his flight research for the rest of his life, and produced at least two successful gliders: the first, built in 1848, was able to lift a young boy into the air for an unspecified distance, and the second was piloted successfully across Brompton Dale in 1853 by the first adult glider pilot, whose identity is unknown but believed to be someone related to Cayley.[46]

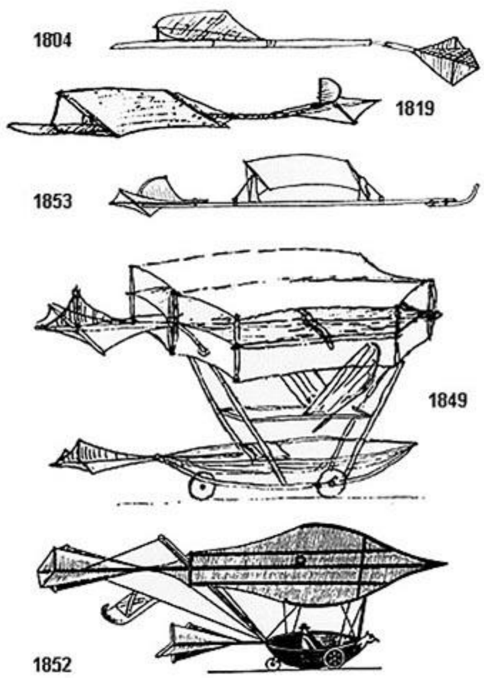


Fig. 12: A compilation of several of Cayley's glider sketches

Inspired by Cayley's work, others would make further advances, especially when the invention of the steam engine provided the possibility of powered flight as recommended by Swedenborg and others. The first design for a propeller-driven aircraft was published in 1842, and the first successful powered (but unmanned) flight of a flight machine using a steam engine was achieved in 1848.[48] The aircraft was developed by John Stringfellow and William Henson, who had diligently applied Cayley's work in their own designs and had gone further. Stringfellow and Henson updated Cayley's cambered airfoil designs, and demonstrated that it would be better for an aircraft to have long and thin wings rather than thick square-shaped wings.[49] This benefit was due to the ratio of the leading edge of the wing to the wing's area was larger for the thin wings, a concept which is now referred to as aspect ratio.[49] Although Stringfellows' later work with "steam carriages" would not achieve much further success, the interest generated by this flight and other developments would lead to the founding of the Royal Aeronautical Society in England.[49] This society hosted some of the world's first exhibitions on aircraft, which not only brought heavier-than-air flight closer to the general public but also developed prize incentives to develop more efficient engines.[49] A 1864 paper titled *On Aerial Locomotion,* further discussed the development of suitable engines, presenting recommendations for either improving existing steam engines or for developing a combustion engine.[50] The only further steam-powered flight of any significance occurred when the French-made *Éole* became the first manned aircraft to take off under its own power, even though it only rose a few inches off of the ground.[51, 52] Further developments with steam engines as power for aircraft did not prove to be successful, so unpowered gliders remained the focus of patents and model-making until internal combustion engines became more widely available.

Glider technology continued to improve, and more designers were jumping into research in an attempt to achieve the coveted first truly powered and controlled flight. A French engineer by the name of Jean-Marie le Bris constructed a few gliders inspired by albatross wings and incorporating adjustable wing elements, which were reportedly able to achieve some short flights in the 1850's.[51] This was soon followed in 1871 by the flight of the "Planophore," a glider heavily inspired by Cayley but including a further innovation: the adjustment of the angle of incidence on the tailplane to be smaller than the angle of incidence on the wings.[52] This additional stability led many to consider the Planophore to be the first stable fixed-wing airplane, although it was still unpowered and unpiloted. A German aviator named Otto Lilienthal produced numerous manned gliders, inspired by his extensive research into the work of other glider developers and his research on birds, which was published in an important treatise titled "Birdflight as the Basis of Aviation."[53] Lilienthal not only constructed these biplane gliders, but to also flew them himself. Lilienthal made frequent test flights, and in a move that differed from many of his predecessors, photographed many of his flights to document them.[53] This foresight resulted in the first photo ever taken of someone successfully operating a heavier-than-air craft; it also inspired worldwide curiosity into flight.[53] Although others had reportedly made small flights, many aviation historians consider Lilienthal to be the first man to truly achieve practical flight with an unpowered glider.

Figs. 13 and 14: Otto Lilienthal piloting one of his gliders (left) and a member of a research team piloting a recreation of the same glider design (right). The aim of the research team was to analyze the process of recreating and piloting one of Lilienthal's gliders, and they were able to achieve several successful flights with minor adjustments made to maximize safety.[53]

From Theory to Practicality: Heavier-Than-Air Applications

Glider research in the nineteenth century produced aircraft that were mostly aerodynamically stable that showed the possibility of responding well to powered systems. However, one important aspect of flight that had yet to be perfected was control. The ability to take off, steer, and land an aircraft while keeping both the aircraft and the occupants safe would have to be achieved for aircraft to become a technology capable of competing with the transportation options available at the time.

In the beginning of the twentieth century, multiple designers were working towards the goal of control. Samuel Langley achieved considerable success with his *Aerodrome No. 5,* which was the first large engine-driven aircraft to successfully sustain flight in 1896.[54] Although No. 5 and the *Aerodromes* which followed were supported by the United States government, and were eventually designated by the Smithsonian as the first machines capable of flight, they had several issues.[54] They did not take off under their own power and did not possess proper landing gear, and attempts to find a suitable engine to power the aircraft had reduced the stability and controllability of the aircraft significantly.[54] Other designs for flying machines and engines were built and tested by a German immigrant to the United States, Gustav Whitehead, the New Zealand inventor Richard Pearce, and a number of European designers.

The race to make the first fully controlled and manned flight would eventually be won by *Flier*, the plane constructed by Otto and Wilbur Wright in 1903. The Wright brothers had spent the previous years developing kites, gliders, and eventually powered planes, along with a great deal of testing apparatus to perfect them (including their own wind tunnel).[55] They devoted serious effort to ensuring not only that their aircraft were completely controllable, but also that their aircraft were safe to use. Safety hadn't exactly been a priority for many aviation pioneers, but the Wright brothers were teaching themselves to fly at the same time as they were perfecting their designs, and they therefore devoted significant time to ensuring they would be able to undergo crashes without sustaining serious injuries.[56] They invented the concept of wing warping, or the controlled twisting of an aircrafts' wings in order to achieve lateral control, and put serious care into the design of their rudders, propellers, and wings to maximize their efficiency despite the generally low power generated by their engine.[55, 56] The hard work of the Wrights would pay off on December 17th, 1903, when the first controlled, sustained, powered, and manned heavier-than-air flight was achieved by *Flier* in North Carolina.[55, 56] Continued improvements and even more refined control would soon follow as *Flyer II* and *Flyer III* were released. In 1905, *Flyer III* would become the first aircraft to achieve controlled, powered flight and to return itself and its pilot back to the starting point of the flight without damage, which would lead to its' eventual patent as the world's first practical airplane.[56]

Fig. 15: A photograph taken at the 1903 flight of Flyer, from the National Air and Space Museum's collection[56]

In the years that followed, further advancements were made as individuals, and eventually the first aerospace companies began to develop more aerodynamically stable aircraft, particularly in Europe. These aircraft were mostly of either monoplane or biplane design, and incorporated wheeled undercarriages and improved ailerons for lateral control. Many of these flights were inspired by monetary prizes, which early scientific aviation institutions such as the Aero-Club de France, the Royal Aeronautical Society, and numerous journals and popular magazines offered to increase both public interest and innovation. When Wilbur Wright traveled to Europe in 1908 and gave flight demonstrations in France, many of the engineers in attendance were impressed by the refined control systems of the Wright brothers' aircraft and would go on to adopt some of these designs themselves, or to purchase parts patented by the Wrights.[55] Milestones achieved in this period included the first crossing of the English Channel by plane in 1909 (Louis Blériot), several of the first international aviation meetings, and the development of Europe's first powered flights (Alberto Santos-Dumont's *Demoiselle series*) and the world's first heavier-than-air passenger airline services.[57, 58] There were also numerous accounts of female aviators such as Harriet Quimby and Georgia Broadwick, who respectively were the first female pilot to cross the English Channel and the first woman to parachute from an airplane.[59] In a no less significant advance, the first manned (albeit tethered) helicopter flight took place in France in 1907, with the first free flight to follow that same year.[60]

With the most famous and arguably most successful pilots at the time, the Wright brothers, being American citizens, one would think that the American aviation industry would be flourishing at the same pace as the European industry. Unfortunately, and perhaps unsurprisingly, the Wright's claims to their inaugural flight and to the many patents they had either invented or reinvented were under dispute. Gustav Whitehead, who had been working on powered aircraft at the same time as the brothers, claimed to have made a controlled and powered flight in August of 1901.[61] There were some eyewitness corroborations and a local newspaper article reporting on the flight at the time.[61] However, serious claims that Whitehead had actually flown first would not be brought up until the 1930's, and many of the supposed eyewitness claims either didn't exist or were unreliable.[61] Most importantly, the proposed Whitehead flight lacked the extensive photographic evidence that the Wright brothers' flight had: while no photos exist of any successful manned flight of Whitehead's *No. 21*, there are numerous photos and documents surviving from the Wright brothers' flight in 1903. For these reasons, most aviation historians continue to accredit the first controlled, powered, manned flight to the Wright brothers. What would turn out to be far more damaging to the American industry, however, was what became known as the Wright Brothers Patent War, when the Wright Company first attempted to gain monopolistic control over American aircraft manufacturing and then proceed to litigate against any individual or company involved in manufacturing ailerons or other components of the Wright's flight control system.[55] This didn't halt American production, but it did severely slow it down, and the Wrights' aircraft began to fall behind some of the more freely-improving European models.

When World War I began in 1914, planes were quickly utilized as a machine of war. Their first military use was during the Italo-Turkish war from 1911 to 1912, but at the time there was no way to attach guns to the structure of the planes.[62] This was remedied when the French fixed machine guns to their aircraft in 1914, and further improved in 1915 when the Germans developed the Fokker E.I., a plane which incorporated a synchronized machine gun.[63] Aerial combat, and the terminology associated with it, became a crucial and almost mythically revered aspect of the World Wars as flight technology continued to accelerate. In 1915, German aircraft designer Hugo Junkers would develop the first all-metal aircraft, which would quickly become adopted by all involved world powers.[64] The war would also serve to bring about the end of the Wright patent wars, which had limited American aircraft production to the point that the Americans had been forced to use French-made aircraft at the start of their involvement.[65]

After World War I, many of the pilots who had served in various armed forces turned their attention to showcasing their skills for the public, supported by the sturdier aluminum planes that had been introduced during the war. Barnstorming, the art of stunt flying, brought aviation directly to audiences all over the world, and supported the announcement of a variety of speed, distance, and skill prizes. Attempts to improve aircraft designs to win these prizes led to more aerodynamically efficient aircraft, which allowed pilots to achieve previously unheard-of feats. These included the first flight using internal instruments in 1922, where Portuguese aviators Gago Coutinho and Sacadura Cabral flew in a plane with an “artificial horizon” they had developed.[66] Other events included the first successful rotorcraft flight of an autogyro in 1919, Charles Lindbergh’s solo flight across the Atlantic Ocean in 1927, Sir Charles Kingsford Smith’s flight across the Pacific Ocean in 1928 and first world circumnavigation in 1929, and Amelia Earhart’s crossings of the Atlantic and Pacific.[67, 68, 69, 70] In 1929, American General Jimmy Doolittle achieved the first flight using only internal instruments such as an improved artificial horizon and gyroscope, a flight type which makes flying in nearly all types of weather conditions possible and which is commonly referred to as “blind” flight.[70]

Much of Germany's flight technology was grounded or surrendered as post-war reparations after WWI. However, this did not stop German aviation advancement. Gliding competitions became increasingly popular in Germany in the inter-war period, and the desire to make cars, planes, and other forms of transportation faster sparked a whole new kind of innovation. Fritz von Opel, along with other German scientists, worked on a variety of solid and liquid-fueled rocket-powered vehicle designs. These designs would set numerous speed records, and would lead to the creation of the first rocket program, Opel-RAK.[71] The first successful rocket-powered flight would be achieved by the *Ente*, which had been designed by Julius Hatry.[71] Other countries would soon jump onto rocket-powered development, and would begin to work on designs for jet-propelled engines as well. Both jet-powered and rocket-powered engines began to be implemented into aircraft on a limited basis.

World War II, similar to WWI, supported significant aviation innovation. The war introduced the first jet-powered fighter airplanes, jet-powered bombers, and the first rocket-powered airplane, along with a variety of cruise and ballistic missiles. Despite the incredible speed demonstrated by these aircraft, fuel shortages limited their use and effectiveness, and piston-engine aircraft remained more commonly used.[73] Helicopter development also greatly improved, with a variety of models being developed and used by both the Axis and Allied powers.

After World War II, aircraft developed for military uses would be repurposed to serve commercial and passenger needs. The British were the first to develop a commercial airliner in the form of the de Havilland Comet, but design issues prevented it from achieving wide use outside of Britain.[74] The USSR would have better success with its' Tupolev Tu-104 and its' related Aeroflot airline.[75] This would be closely accompanied by development of American jet liners such as the Boeing 707. Airliners would grow into an increasingly profitable enterprise, and air travel would become more widespread from the 1950's onward.

Not all post-war development was commercial: after World War II ended, the military and social landscape had been changed by the invention and potential for disaster of the nuclear bomb. The need to mount defenses against nuclear power fueled further development. The first controlled, officially recorded flight which broke the sound barrier was achieved by a rocket-powered Bell-X1, which had been commissioned as a research project by multiple American government and military organizations.[76] This would be followed by the development of both supersonic aircraft and intercontinental ballistic missiles, which would only fuel other Cold War experimentation.

Fig. 16: A photograph of the Bell-X1, the first aircraft to officially break the sound barrier

Despite its mostly military origins, supersonic flight would, at least briefly, become more accessible to the civilian flight world. Jet aircraft had already advanced to larger and more durable aircraft, and many airlines wanted to add supersonic airliners to their fleets. The first of these would be the Aeroflot Tu-144, and the most famous of these would be the British Airways and Air France Concorde.[77] Concorde would go on to achieve flights at incredibly fast speeds, and would provide a luxury experience for its passengers.[78] However, the combination of lethal accidents, rising operating costs, and a significant drop in flights after the September 11, 2001 terrorist attacks, would lead to the retirement of Concorde, and an almost complete abandonment of supersonic aircraft for anything beyond military use.[78]

There is one further development that may not have revolutionized aviation, but proved that the vast expanse of design work had paid off significantly. In 1977, aeronautics engineer Paul MacCready and a team of developers built the *Gossamer Condor,* a small aircraft inspired by aspects of the Wright brothers' *Flyer* and constructed from modern materials.[79] This aircraft was not powered by any engine, but rather by a cyclist named Bryan Allen, who used a pedal system similar to a bicycle to propel a two-bladed propeller.[79] As stated previously in this report, many scientists throughout the centuries had reached a conclusion that completely human-powered flight was not possible, but the combination of multiple advances and the fact that MacCreadys' design used leg power rather than arm power, had made this impossibility a reality. On August 23rd, 1977, Allen flew *Gossamer Condor* around a course in California, and achieved the first human-powered, controlled, sustained flight.[79] MacCreadys' designs would only improve, and in 1979 a NASA-supported *Gossamer Albatross,* once again piloted by Allen, would make a successful crossing of the English Channel.[80]

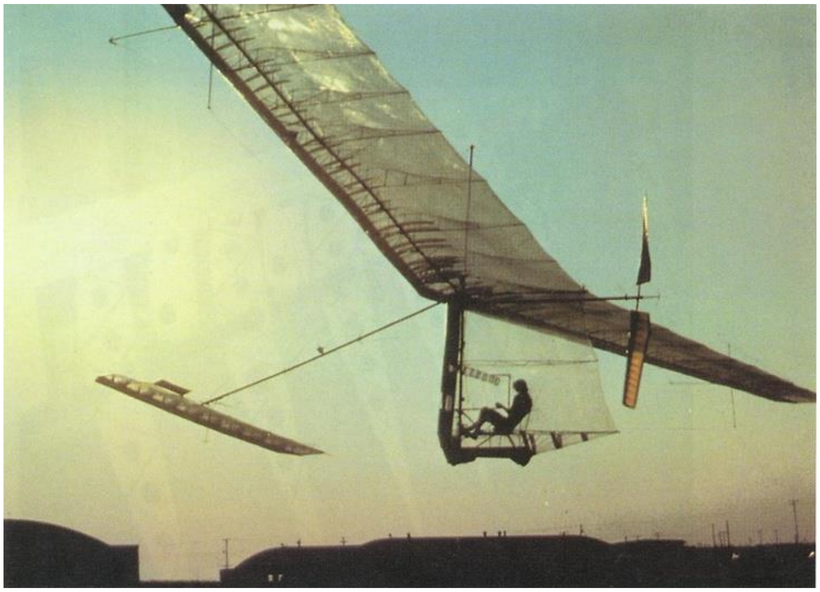


Fig. 17: A photograph of Gossamer Condor taken during its' inaugural flight in 1977

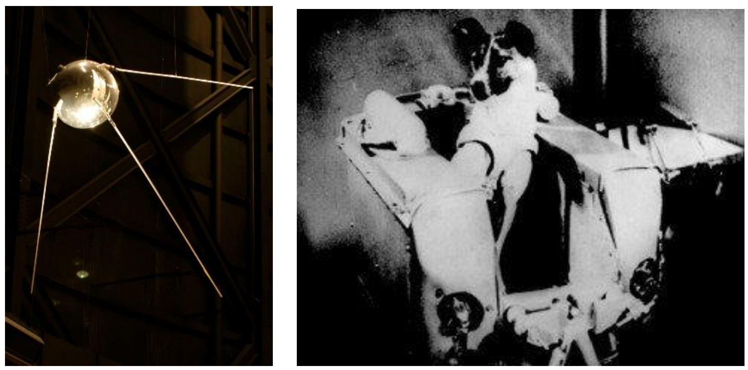
In the later part of the 20th century, aircraft development shifted away from improving speed or stability and more towards digitizing in-flight instruments as computers became more of a reality. Aircraft materials shifted away from metal to highly specialized composite materials such as fiberglass and thermoplastics, which allowed for more refined designs that could achieve even greater stability and make aircraft considerably lighter.[81] Many of these developments are still utilized in commercial, passenger, and military aircraft in today's age. Another development that has achieved considerable attention in the 21st century is the development and more widespread use of Unmanned Aerial Vehicles (UAV's), more colloquially referred to as drones. Technology has reached the point where computerized and automated systems can allow drones to reach a variety of locations that would be inaccessible for most larger aircraft and to make aviation technology more accessible to people in areas where commercial flights are uncommon.

Beyond Gravity: Aerospace and off-Earth Developments

The development of the nuclear bomb launched the United States and the Soviet Union into the Cold War, a period where both powers engaged in accelerated technology development to match one another. As supersonic developments raised the threats of intercontinental ballistic missiles and nuclear annihilation, researchers began to look beyond Earth's atmosphere and to consider space as a possible location for extending their spheres of influence.

Suborbital designs had previously been considered for potential military purposes. During World War II, the Axis powers had proposed a contracting competition for the development of a bomber that could attack the American mainland, and some of the designs involved winged rockets that were meant to travel within Earth's orbit without achieving escape velocity.[82] However, these designs had never been achieved. The next serious consideration of orbital or spaceflight did not resurface until the 1950's. By this time, rocket propulsion technology had progressed to a point where, with the proper trajectories, objects could be launched with the intent of either remaining in Earth's orbit or leaving Earth's orbit entirely.

Both the United States and the Soviet Union kicked off their respective research into space-related technology with satellite programs. The Soviet Union had better success with this part of the race, and launched the first man-made satellite (*Sputnik I*) into orbit in 1957.[83] The R-7 rocket which carried *Sputnik I* into orbit was modified from an existing intercontinental ballistic missile design, which had the rocket power necessary to overcome the gravitational force of the earth and atmospheric drag.[83] The Soviet Union would go on to achieve another milestone when they sent the dog Laika into orbit on *Sputnik II*, proving that mammals could at least survive the ascent.[83] Unfortunately, Laika's demise during her fourth orbit around the Earth demonstrated that the technology available to return safely back to Earth's surface had yet to be developed.[83] Other satellite missions continued, mostly under top secret conditions, and focus began to shift to sending things beyond Earth's orbit and towards the next nearest milestone: the moon.



Figs. 18 and 19: A recreation of Sputnik (left) and a photograph of Laika inside the compartment of Sputnik II (right)

In order for an object to leave Earth's surface, it has to first be propelled to a significant velocity such that the forces lifting the object exceed the gravitational force of the Earth.[84] The minimum speed needed to achieve this is generally referred to as "escape velocity," and the first craft to exceed Earth's escape velocity was the *Luna I* satellite launched by the Soviet Union in 1959.[84, 85] This would accelerate further satellite developments, and a variety of firsts would follow in the next decade. These included the first successful recovery of a satellite, the return of living animals from space, and multiple planetary flybys of the Moon, Venus, and Mars.[86] This also included the first successful dockings between spacecraft in orbit.[86] On April 12, 1961, Yuri Gagarin would achieve the first manned orbital spaceflight, and on July 20, 1969, the crew of the

Apollo 11 would become the first humans to walk on the surface of another celestial body on the Moon.[86]

The great majority of the rockets which carried satellites, people, and research equipment into space were only designed for single uses, as the extreme heat of reentry into Earth's atmosphere tended to burn up rocket stages or equipment. With the incredible costs associated with space programs, it was not long before designs for a reusable spacecraft were being proposed. The idea would be realized in the Space Shuttle, which was designed to be carried up into Earth's orbit by a rocket and to return to the surface on its own, landing in almost exactly the same fashion as a modern airplane. The Space Shuttles were never designed to leave Earth's orbit, but completed a number of influential missions that would significantly improve mankind's understanding of space and how sustained space flight could affect humans. In addition, the research devoted to the continual recovery of the Space Shuttle's systems has inspired technologies used commonly in modern rockets, such as SpaceX's lower stage rocket recoveries.[87]

Fig. 20: A photograph of the Space Shuttle Columbia landing

Towards the end of the twentieth century and into the twenty-first, rocket technology improved to the point where rockets were not only able to send objects flying by the surface of Mars, but also onto Mars' surface. The National Aeronautics and Space Administration (NASA) sent a series of rovers to Mars' surface to collect various geological and meteorological data on the planet.[88] One of these rovers, *Perseverance*, came with a small helicopter named *Ingenuity*. On April 19, 2021, Ingenuity became the first aircraft to make an unmanned controlled, powered flight on a planet other than Earth, and it continues to make research flights up to the present day.[88]

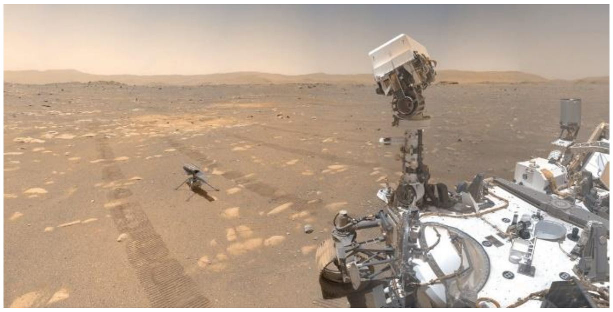


Fig. 21: One of the "selfies" taken by the Perseverance rover on Mars (Ingenuity can be seen in the background)

Conclusions

In examining the vast discoveries relating to the field of aviation, the incredible speed at which advancements were made is apparent. In a period of time which equates to only a little more than one percent of human history, mankind transitioned from jumping from high places to remotely piloting aircraft on other planets. The continued rise in computer-driven instrumentation is likely to improve the autonomy of both existing aircraft and aircraft developed for as-yet uncharted territories like the surface of Mars or other planets in the solar system. Fortunately, the future of aviation science both on Earth and elsewhere remains promising, although it remains to be seen what will fuel interest in these advancements. Aviation progressed as a field not only through the desire for human betterment, but also through the desire to maintain military power, the search for notoriety associated with innovation, and the gain of the economic benefits of novel success. As aviation adapts to the future, it can be hoped that the struggles, mistakes, and inspirations of the pioneers who came before will continue to be remembered.

References

NOTE: Sources are listed by order of appearance in the report.

1. Dutt, M. N. (1891-1894). *Ramayana* (translation). Calcutta, India: Deva Press. Retrieved from https://archive.org/details/Valmiki_Ramayana_English_Prose_Translation_7_volumes_by_ Manmatha_Nath_Dutt_1891_to_1894/Valmiki%20Ramayana%20-%20MN%20Dutt%20-%20Volume%201%20%26%202%20-%20Bala%20%26%20Ayodhya%20Kandas%201891/page/n7/mode/2up

2. Burton, R. (1885-1888). *The Thousand Nights and a Night* (translation). Retrieved from https://burtoniana.org/books/1885-Arabian%20Nights/

3. Atkinson, J. (1832). *The Shahnameh* (translation). London, England: The Oriental Translation Fund of Great Britain and Ireland. Retrieved from ttps://archive.org/details/theshahname/page/n7/mode/2up

4. Kline, A. S. *Metamorphoses 8, the Ovid Collection.* University of Virginia Libraries. Retrieved from: https://ovid.lib.virginia.edu/trans/Metamorph8.htm

5. Aristotle (translated by Stocks, J.L.). *De Caelo (On the Heavens)* (Vol. 2). Retrieved from: http://classics.mit.edu/Aristotle/heavens.html

6. Sachau, E. C. (1910). *Alberuni's India* (Vol. 1). London, England: Kagan Paul, Trench, Trubner & Co. Retrieved from http://www.columbia.edu/cu/lweb/digital/collections/cul/texts/ldpd_5949073_001/pages/ldpd_5949073_001_00000007.html?toggle=image&menu=maximize&top=&left=

7. National Aviation Academy. (2023). *Airfoil design 101: What is an airfoil?* Retrieved from https://www.naa.edu/airfoil-design/

8. Beaumont, F., Murer, S., Bogard, F., & Polidori, G. (2021). Aerodynamics of a flapping wing as a function of altitude: New insights into the flight strategy of migratory birds. *Physics of Fluids*, *33*(12), 1–10. https://doi-org.libproxy.unl.edu/10.1063/5.0071910

9. P. Henningsson & A. Hedenström (2011). Aerodynamics of gliding flight in common swifts. *J Exp Biol*, 214 (3): 382–393. https://doi.org/10.1242/jeb.050609

10. Han Shu. *Book of Han: Biography of Wang Mang.* Retrieved from https://ctext.org/han-shu/wang-mang-zhuan

11. White Jr, L. T. (1961). Eilmer of malmesbury, an eleventh century aviator: a case study of technological innovation, its context and tradition. *Technology and Culture,* 2(2): 97-111.

12. Needham, J. (1965). *Science and Civilisation in China*. 5(1)

13. American Kitefliers Association (2021). *Kite Origins.* Retrieved from https://www.kite.org/about-kites/history-of-kites/#:~:text=The%20earliest%20written%20account%20of%20kite%20flying%20is,style%20of%20kite%20and%20cultural%20purpose%20for%20

14. Temple, R. (1986) *The Genius of China.* New York: Simon & Schuster.

15. Bate, J. (1634). *The Mysteryes of Nature and Art.* London, England: Harper and Jackson, 94-96. Retrieved from https://www.loc.gov/resource/rbc0001.2009rosen1480/?sp=5&st=image

16. Stamp, J. (2013, February). The history of rocket science. *Smithsonian.* Retrieved from https://www.smithsonianmag.com/innovation/the-history-of-rocket-science-4078981/

17. Leishman, J. G. (2000). *Principles of Helicopter Aerodynamics*. Cambridge: Cambridge University Press. 18, 7–9. ISBN 978-0-521-85860-1 Retrieved from https://web.archive.org/web/20140713201846/http:/terpconnect.umd.edu/~leishman/Aero/history.html

18. National Aeronautics and Space Administration (2021, May). *Brief history of rockets.* Retrieved from https://www.grc.nasa.gov/www/k-12/TRC/Rockets/history_of_rockets.html

19. Stamp, J. (2013, May). A brief history of robot birds. *Smithsonian.* Retrieved from https://www.smithsonianmag.com/arts-culture/a-brief-history-of-robot-birds-77235415/

20. Jakab, P. (2013, August). Leonardo da Vinci and flight. *National Air and Space Museum.* Retrieved from https://airandspace.si.edu/stories/editorial/leonardo-da-vinci-and-flight

21. National Aeronautics and Space Administration (1996, August). *Buoyancy: Archimedes principle.* Retrieved from https://www.grc.nasa.gov/WWW/k-12/WindTunnel/Activities/buoy_Archimedes.html

22. Encyclopedia Britannica, T. Editors of (2023, January 6). Boyle's law. *Encyclopedia Britannica*. Retrieved from https://www.britannica.com/science/Boyles-law

23. Slavec, G. (1971-1972). History of Aviation - Bartolomeu Lourenco de Gusmao (Translated from the Brazilian Air Force Website). Retrieved from https://www.fai.org/sites/default/files/documents/cia-hof-gusmao-bartholomeu-de.pdf

24. Gillispie, C. C. (1983). Aloft with the Montgolfiers. *Sciences*, *23*(4), 46. https://doi-org.libproxy.unl.edu/10.1002/j.2326-1951.1983.tb02635.x

25. Encyclopedia Britannica (1911). The Montgolfier and Charles balloons. Excerpt from *Aeronautics - Encyclopedia Britannica.* Retrieved from https://www.todayinsci.com/M/Montgolfier_Brothers/MontgolfierBalloon-EB1911.htm

26. Rumerman, J. (2003) Early Balloon Flight in Europe. *U.S. Centennial of Flight Commission.* Retrieved from https://www.centennialofflight.net/essay/Lighter_than_air/Early_Balloon_Flight_in_Europe/LTA1.htm

27. Piccard, D. L. (2023, February 7). Balloon flight. *Encyclopedia Britannica*. Retrieved from https://www.britannica.com/technology/balloon-flight

28. Offaly, (2007, September 1). The Tullamore balloon fire - first air disaster in history. *Offaly Historical and Archeological Society.* Retrieved from https://web.archive.org/web/20141216152553/https:/www.offalyhistory.com/reading-resources/history/tullamore-history/the-tullamore-balloon-fire-first-air-disaster-in-history

29. Vergano, D. (2011, June 10). 150 years ago, Army intel got off the ground - Union forces deployed a balloon to view battlefield for first time. *USA TODAY (Arlington, VA)*, p. 4A. Available from NewsBank: Access World News – Historical and Current: Retrieved from https://infoweb-newsbank-com.libproxy.unl.edu/apps/news/document-view?p=WORLDNEWS&docref=news/137C746524455AC8

30. Naval History and Heritage Command (2015, July 13). George Washington Parke Custis. Dictionary of American Naval Fighting Ships (DNAFS). Retrieved from https://www.history.navy.mil/content/history/nhhc/research/histories/ship-histories/danfs/g/george-washington-parke-custis.html

31. Tarsaidze, A. (1942). The Air Blitz of 1812. *The Russian Review*, *2*(1), 89–101. https://doi.org/10.2307/125276

32. Green, A. (2013). A brief history of the airship. *Popular Mechanics*, *190*(9), 124.

33. Encyclopedia Britannica, T. Editors of (2023, February 11). *airship*. Encyclopedia Britannica. Retrieved from https://www.britannica.com/technology/airship

34. Judkins, P. (2016). Sound and fury: sound and vision in early U.K. air defence. *History & Technology*, *32*(3), 227–244. https://doi-org.libproxy.unl.edu/10.1080/07341512.2016.1236526

35. National Museums Scotland (2023). Airship R.34. *National Museums Scotland.* Retrieved from https://www.nms.ac.uk/explore-our-collections/stories/science-and-technology/airship/

36. McGrogan, D. (2022) USS Los Angeles. *NavSource Online: Rigid Airships Photo Archive.* Retrieved from https://www.navsource.org/archives/02/99/029903.htm

37. McGrogan, D. (2022) USS Shenandoah. *NavSource Online: Rigid Airships Photo Archive.* Retrieved from https://www.navsource.org/archives/02/99/029901.htm

38. Heydt, B. (2003). timeline 5th October 1930: The R101 Airship Disaster. *British Heritage*, *24*(7), 16

39. DiLisi, G. A. (2017). The Hindenburg Disaster: Combining Physics and History in the Laboratory. *Physics Teacher*, *55*(5), 268–273. https://doi-org.libproxy.unl.edu/10.1119/1.4981031

40. Encyclopedia Britannica, T. Editors of (2022, July 25). Steve Fossett. *Encyclopedia Britannica*. Retrieved from https://www.britannica.com/biography/Steve-Fossett

41. White, L. (1968). The Invention of the Parachute. *Technology and Culture*, *9*(3), 462–467. https://doi.org/10.2307/3101655

42. Encyclopedia Britannica, T. Editors of (2023, January 1). *Louis-Sebastien Lenormand*. *Encyclopedia Britannica*. https://www.britannica.com/biography/Louis-Sebastien-Lenormand

43. Hart, C. (1979). Burattini's flying dragon. *The Aeronautical Journal, 83*(823), 269-273. doi:10.1017/S0001924000031754

44. Giovanni Alfonso Borelli. *Oxford Reference.* Retrieved from https://www.oxfordreference.com/view/10.1093/oi/authority.20110803095518913

45. Botham, C. J. (2019, December) Emanuel Swedenborg's glider sketch. *On Verticality.* Retrieved from https://www.onverticality.com/blog/emanuel-swedenborg-glider

46. Karwatka, D. (2007). George Cayley--The founder of Modern Aeronautics. *Tech Directions, 67*(4), 10–11.

47. Cayley, G. (1809-1810) On aerial navigation. *Nicholson's Journal of Natural Philosophy,* 1, 2 & 3. Retrieved from *https://web.archive.org/web/20130511052409/http:/www.aeronautics.nasa.gov/fap/OnAerialNavigationPt3.pdf*

48. Royal Aeronautical Society (2021). William Samuel Henson. *Royal Aeronautical Society Heritage Collections.* Retrieved from https://aerosocietyheritage.com/biographies/william-samuel-henson

49. D'alto, N. (2004). Victorian Dreams of FLIGHT. *Aviation History, 14*(3), 42.

50. Boulton, M. P. (1864) On aerial locomotion. Retrieved from https://upload.wikimedia.org/wikipedia/commons/8/8f/On_A%C3%ABrial_Locomotion_Full_Text.pdf

51. Scott, P. (2001). What Where They Thinking? *Air & Space Smithsonian*, *15*(6), 62. Retrieved from https://www.smithsonianmag.com/air-space-magazine/what-were-they-thinking-1965721/

52. Gibbs-Smith, C.H. (2000). *Aviation*. London: NMSI. p. 56. ISBN 1900747529.

53. Raffel, M., Wienke, F., & Dillmann, A. (2021). Flying Qualities of Otto Lilienthal's Large Biplane. *Journal of Aircraft*, *58*(2), 413–419. https://doi-org.libproxy.unl.edu/10.2514/1.C036022

54. Anderson, J. D. (2004). Inventing flight: the Wright brothers & their predecessors. *JHU Press.* p. 145. ISBN 0-8018-6875-0.

55. Worrel, R. K. (1979). The Wright Brothers' Pioneer Patent. *American Bar Association Journal*, *65*(10), 1512.

56. National Air and Space Museum (2023). Researching the wright way. *Smithsonian Institution.* Retrieved from https://airandspace.si.edu/explore/stories/researching-wright-way

57. National Air and Space Museum (2009). Bleriot's cross-channel flight. *Smithsonian Institution.* Retrieved from https://airandspace.si.edu/stories/editorial/bl%C3%A9riots-cross-channel-flight

58. Jordan, D. (2003). Wrights and Wrongs? *History Today*, *53*(12), 4–5.

59. National Air and Space Museum (2022). The roar of the crowd. *Smithsonian Institution.* Retrieved from https://airandspace.si.edu/stories/editorial/roar-crowd

60. Randle, A. (2021, July 9). History of flight: breakthroughs, disasters and more. *History*. Retrieved from https://www.history.com/news/history-flight-aviation-timeline

61. Crouch, T. (2013, September). Yes, the wright brothers really were the first to fly. *Smithsonian Magazine.* Retrieved from https://www.smithsonianmag.com/air-space-magazine/who-flew-first-290750/

62. MacIsaac, D. (2016, July 18). Air warfare. *Encyclopedia Britannica*. Retrieved from https://www.britannica.com/topic/air-warfare

63. Mortimer, G. (2013). Giving the Machine Gun Wings. *Aviation History*, *23*(6), 50–55.

64. Karwatka, D. (2011). Hugo Junkers and All-Metal Monoplanes. *Tech Directions, 70*(7), 12.

65. Herbert A. Johnson, The Wright Patent Wars and Early American Aviation, 69 J. Air L. & Com. 21 (2004) https://scholar.smu.edu/jalc/vol69/iss1/3

66. Canas, A. C., Marabujo, M. R., & Sousa, T. (2020). Coutinho's Method for the Altitude. *Journal of Navigation, 73*(4), 861–873. https://doi-org.libproxy.unl.edu/10.1017/S0373463319000961

67. Mody, C. C. M. (2000). "A New Way of Flying": Différance, Rhetoric and the Autogiro in Interwar Aviation. *Social Studies of Science (Sage Publications, Ltd.), 30*(4), 513–543. https://doi-org.libproxy.unl.edu/10.1177/030631200030004002

68. Siegel, N. (2004). Legacy of Flight. *Aviation History, 14*(4), 82.

69. Zupp, O. (2010). The "Old Bus" Endures. *Aviation History, 20*(3), 16–17.

70. Beer, T. (2003). Amelia Earhart. *Biography, 7*(11), 120

71. Mahoney, M. (2013). Flying Blind. *MIT Technology Review, 116*(1), 11.

72. Winter, F. H. (2021, April 30) A century before Elon Musk, there was Fritz von Opel. *Smithsonian Magazine.* Retrieved from https://www.smithsonianmag.com/air-space-magazine/century-elon-musk-there-was-fritz-von-opel-180977634/

73. Corum, J. S. (2004). The Luftwaffe and Its allied air forces in world war II: parallel war and the failure of strategic and economic cooperation. *Air Power History*. 51(2).

74. Pushkar, R. G. (2002, June). Comet's tale. *Smithsonian Magazine.* Retrieved from https://www.smithsonianmag.com/history/comets-tale-63573615/

75. HARRIS, S. E. (2020). Dawn of the Soviet Jet Age: Aeroflot Passengers and Aviation Culture under Nikita Khrushchev. *Kritika: Explorations in Russian & Eurasian History, 21*(3), 591–626. https://doi-org.libproxy.unl.edu/10.1353/kri.2020.0029

76. MacGregor, J. (2022). How the Bell X-1 ushered in the supersonic age: the speeding-bullet design propelled Chuck Yeager into history. *Smithsonian*, 1.

77. Prisco, J. (2019, July 10). Tupolev Tu-144: the soviets' doomed rival to Concorde. *CNN Style.* Retrieved from https://www.cnn.com/style/article/tupolev-tu-144-concordski/index.html

78. Prince, A. R. (2018). Supersonic gamble. *Aviation History, 28*(4), 64–71.

79. Khol, R. (1999). Quick-and-dirty structural design put the Gossamer Condor in the air. *Machine Design*, *71*(16), 70.

80. Gossamer Albatross to take the high road. (1979). *Science News*, *116*(19), 327. https://doi-org.libproxy.unl.edu/10.2307/3964425

81. Tavvala, V. (2014). COMPOSITE MATERIALS IN AIRCRAFT.

82. Roblin, S. (2021). Hitler's "amerikabomber" project: bombing New York from Germany. *The National Interest.* Retrieved from https://nationalinterest.org/blog/reboot/hitlers-amerikabomber-project-bombing-new-york-germany-185050

83. Sagdeev, R. (2007). Sputnik and the Soviets. *Science*, *318*(5847), 51–52. https://doi-org.libproxy.unl.edu/10.1126/science.1149240

84. Encyclopedia Britannica, T. Editors of (2022, December 30). escape velocity. *Encyclopedia Britannica*. https://www.britannica.com/science/escape-velocity

85. National Aeronautics and Space Administration (2022, October 28). Luna 1 spacecraft. *USA.gov.* Retrieved from https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1959-012A

86. National Aeronautics and Space Administration (2023). Moon missions: exploration. *NASA Science.* Retrieved from https://moon.nasa.gov/exploration/moon-missions/

87. Baiocco, P. (2021). Overview of reusable space systems with a look to technology aspects. *Acta Astronautica*, *189*, 10–25. https://doiorg.libproxy.unl.edu/10.1016/j.actaastro.2021.07.039

88. National Aeronautics and Space Administration (2023). Mars Helicopter. *NASA Science.* Retrieved from https://mars.nasa.gov/technology/helicopter/#Overview