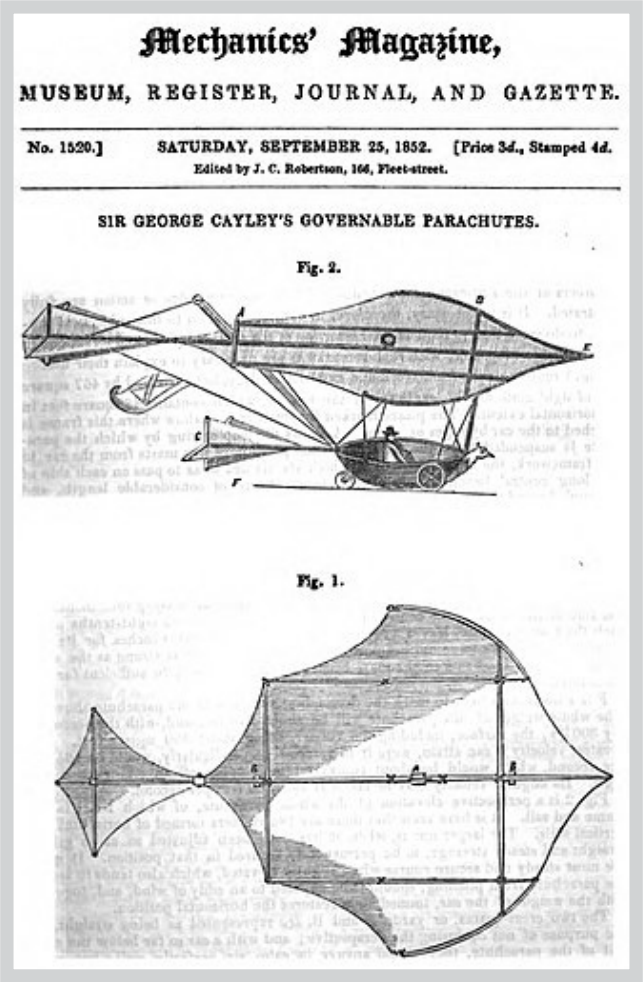
AN INTRODUCTION TO AEROSPACE & AVIATION

The following article is the first in a series of four extracts concerning the above taken from a much larger publication prepared by Dr Michael Smith in early 2020. This extract covers the very early days up to the beginning of the jet age. The series has been released as an informative and historical industry foundation to The Schools' Aerospace Careers Programme. Since then, of course, the aerospace and aviation industries have moved on, including weathering Covid-19 which severely impacted aviation, the customer of aerospace, but both are recovering and, indeed, developing fast with an increasing range of applications and innovations fueled by the new technologies of the fourth industrial revolution. But what *is* aerospace, and how did it all start?



Mechanics' Magazine,

MUSEUM, REGISTER, JOURNAL, AND GAZETTE.

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SIR GEORGE CAYLEY'S GOVERNABLE PARACHUTES.

Fig. 2.

Fig. 1.

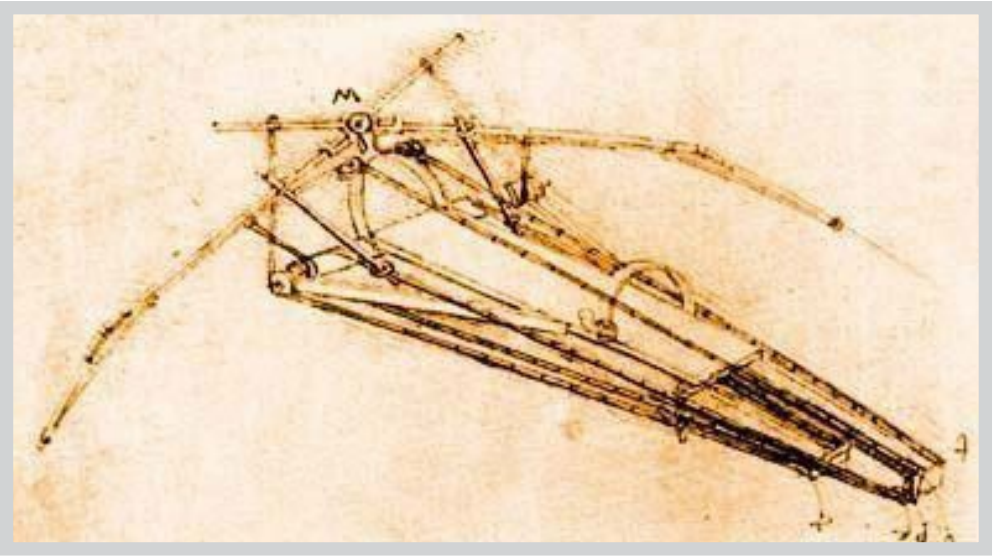
Modern aerospace began with Sir George Cayley in 1799. Cayley proposed an aircraft with a 'fixed wing and a horizontal and vertical tail', defining characteristics of the modern airplane.

Aerospace is the human effort in science, engineering, and business to fly in the atmosphere of the Earth (aeronautics) and surrounding space (astronautics).

Aerospace organizations research, design, manufacture, operate or maintain aircraft or spacecraft. Aerospace is not the same as airspace, which is the physical airspace directly above a location on the ground. The beginning of space and the ending of the air is considered as 100 km above the ground according to the physical explanation that the air pressure is too low for a lifting body to generate meaningful lift force without exceeding orbital velocity.

Aviation (the term was introduced in 1863 by French pioneer Guillaume Joseph Gabriel de La Landelle) traces its history well over two millennia. Invented by the Chinese, the kite may have been the first form of man-made aircraft, possibly as far back as the 5th century BC. Ancient and medieval Chinese sources describe kites being used to measure distances, test the wind, lift men, signal and communicate. Furthermore, since the 3rd century BC the Chinese have applied the principle of hot air rising to a type of hot air balloon, the sky lantern.

Ibn Firnas (809 – 887) was an Andalusian polymath: an inventor; physician; chemist; engineer; musician and poet. He built the first human carrying glider. The crater Ibn Firnas on the Moon is named in his honour. But it was not until the 15th century in Europe that some of the basics of rational aircraft design began to be defined. Most notable amongst those involved was Leonardo da Vinci (1452 – 1519), probably the best know polymath in the western world who, from the last years of the 15th century until 1505 wrote about and sketched many designs for flying machines including ornithopters, gliders and parachutes. However, while his designs for man-powered ornithopters and rotorcraft were rational, they underestimated the amount of power needed. He realised this in time and turned his attention to controlled gliding flight; that said, he was centuries ahead of his time.



A Leonardo da Vinci design for an ornithopter

THE PIONEERS

1783 was a most important year for aviation, specifically ballooning, and was dominated by the Montgolfier brothers on the one hand, and Jacques Charles and the Robert brothers on the other.

Both launched unmanned and then manned balloons, the former using hot air and the latter using hydrogen which had been discovered 17 years earlier by Henry Cavendish. Various theories in mechanics by physicists during the same period of time, in particular fluid dynamics and Newton's laws of motion, led to the foundation of modern aerodynamics, most notably by Sir George Cayley. Balloons, both free-flying and tethered, began to be used for military as well as private purposes from the end of the 18th century and provided the first detailed understanding of the relationship between altitude and the atmosphere.

Airships were originally called 'dirigible balloons'. Work on developing a steerable (or dirigible) balloon continued sporadically throughout the 19th century with the first fully controllable free-flight being made in a French Army electric powered airship 'La France'. However, these aircraft were slow, short-lived and extremely fragile. Routine controlled flights did not occur until the advent of the internal combustion engine, and it was the Brazilian Alberto Santos-Dumont who effectively combined these two technologies into a non-rigid airship. At the same time the rigid airships were also being developed led by their pioneer, Ferdinand von Zeppelin, with a first flight in July 1900 by LZ1.

These craft were used extensively by Germany in WWI; and then, following the lifting of airship building restrictions imposed on Germany by the Treaty of Versailles, in 1926 work commenced on LZ127 (Graf Zeppelin) and in the early 1930s on LZ129 (Hindenburg) which both operated regular trans-Atlantic flights from Germany to the USA and Brazil. As an aside, the Art Deco spire of the Empire State Building in New York was originally designed as a mooring mast for Zeppelins and other airships, although it was found that high winds made this impossible and the plan was abandoned.

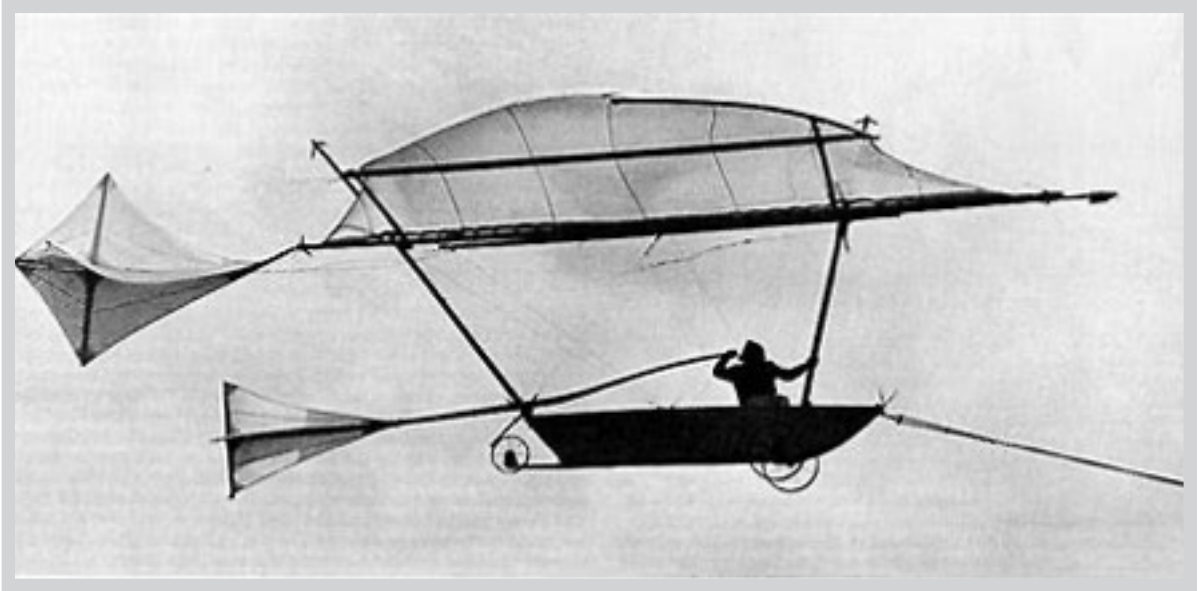
The Montgolfier balloon

The Hindenburg Disaster

The *Hindenburg* disaster in 1937, along with political and economic issues, hastened the demise of Zeppelins, although airships are still used today, albeit filled with Helium rather than the much more combustible Hydrogen used in pre-war days. For a while the long-distance capability of the airship was then taken over by the flying boat which had been developing during WW1 and during the inter-war years. Used extensively by the Allies and Axis powers during WWII their use rapidly declined thereafter for several reasons. The ability to land on water became less of an advantage owing to the considerable increase in the number and length of land based runways during World War II; and as the reliability, speed, and range of land-based aircraft increased, the commercial competitiveness of flying boats diminished.

Boeing 34 Clipper

Sir George Cayley (1773 – 1857), who introduced this section, was first called 'the father of the aeroplane' in 1846. In 1799 he set down the concept of the modern aeroplane as a fixed-wing flying machine with separate systems for lift, propulsion and control. In 1809 he began the publication of a landmark three-part treatise "On Arial Navigation" in which he identified the four vector forces that influence an aircraft: thrust, lift, weight and drag. In 1848 he had progressed far enough to construct a glider large and safe enough to carry a child, and in 1852 he published the design for full-size manned glider which he called a "governable parachute", the next year constructing a version capable of launching from the top of a hill which it did, across Brompton Dale, thereby carrying the first adult aviator.



The 'Governable Parachute'

The second half of the 19th century was a period of intense study, characterized by the 'gentlemen scientists' who represented most research projects until the 20th century. Significant amongst them was Jean-Marie Le Bris who, in 1856 with a glider named 'L'Albatros artificiel' pulled by a horse made the first flight higher than his point of departure; Félix du Temple who, in 1857 proposed a monoplane with a tail plane and retractable undercarriage; and Matthew Piers Watt Boulton who studied lateral flight control and in 1868 patented the aileron.

Furthermore, in 1871 Francis Wenham and John Browning probably constructed the world's first wind tunnel and demonstrated that high aspect ratio wings, long & narrow, had a better lift to drag ratio that short stubby wings with the same lifting area; and the same year Alphonse Pénaud flew the first aerodynamically stable fixed-wing aeroplane called the 'Planophore'. In 1879, using compressed air, Victor Tatin flew the first model to take off under its own power; and that same year Gaston Biot, assisted by Comte de Massia constructed and briefly flew a bird-like glider which is claimed to be the earliest man-carrying flying machine still in existence.

The Biot-Massia glider

In 1890 Clément Ader completed the first of three steam driven flying machines, and in 1890 made an uncontrolled hop of around 50 meters; this was the first manned airplane to take off under its own power. And in 1891 Otto Lilienthal became the first person to make controlled untethered glides routinely, and the first to be photographed flying a heavier than air machine so stimulating interest around the world. He made over 2,000 flights and rigorously documented his work. In 1896 Octave Chanute, having funded the development of several gliders, his team flew several of their designs eventually deciding that the best was a biplane. Additionally, the invention of the box kite during this period by Lawrence Hargrave lead to the development of a practical biplane.

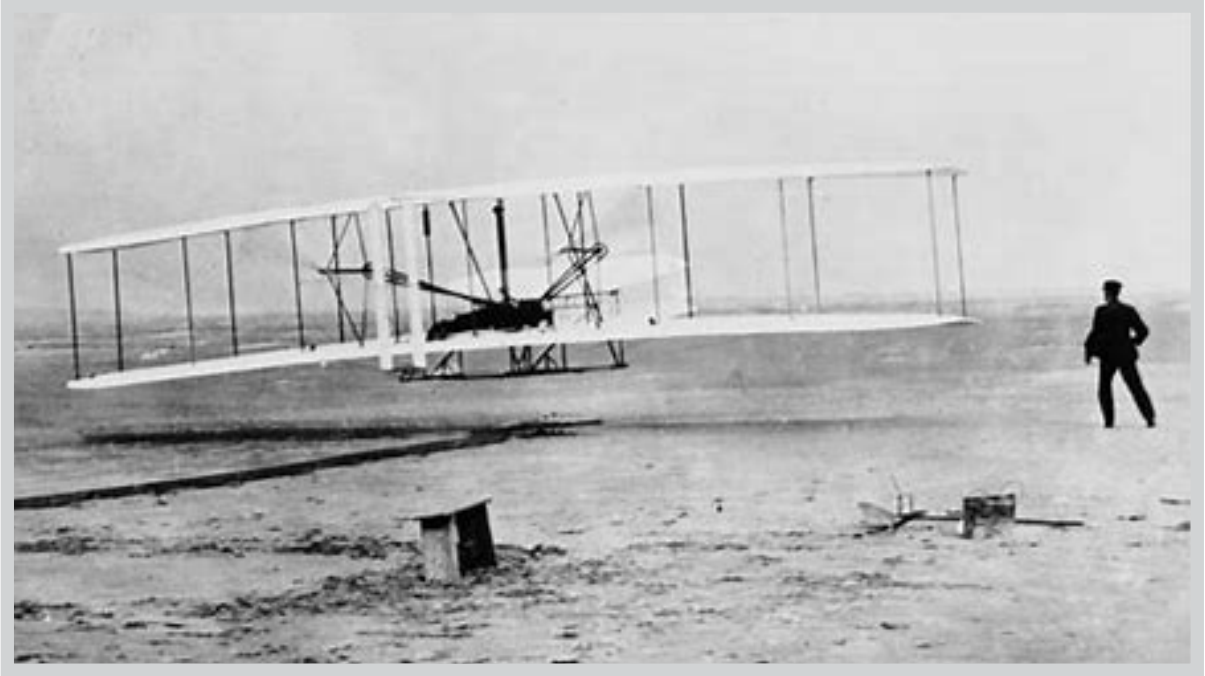
Otto Lilienthal

Also in 1896 Samuel Pierpont Langley made the first successful sustained flight of an unpiloted, engine driven, heavier-than-air craft of substantial size. With the success of his earlier, increasingly improved designs, and funded by the US Government, he then built a scaled-up version which flew twice in 1901 and then, with a more powerful engine, in 1903. Furthermore, believing his basic design was successfully tested he then matched it with a much more powerful engine designed by Stephen Balzer, but the resulting craft was too fragile. Simply scaling up the original small models resulted in a design that was too weak to hold itself together. Two launches in late 1903 resulted in the craft, named *Aerodrome*, immediately crashing. Nine days after the second launch the Wright brothers successfully flew their *Flyer*.

That said, in 1914 Glenn Curtiss made 93 modifications to *Aerodrome* and flew this very different aircraft leading to the Smithsonian Institute, without acknowledging the modifications, asserting that Langley's *Aerodrome* was the first machine "capable of flight."

The heavily modified Langley's 'Aerodrome'

Another contemporary of, and challenger to, the Wright brothers was Gustave Weißhopf who changed his name to Whitehead on emigrating to the US. Between 1897 and 1915 he designed and built early flying machines and engines. On 14 August 1901, two and half years before the Wright brothers' flight, he claimed to have carried out a controlled powered flight in his Number 21 monoplane at Fairfield Connecticut. Who made this world-changing first flight, Whitehead or the Wright brothers, remains a contested subject to this day. That said, it is generally agreed to be Orville Wright in The Wight Flyer on 17 December 1903 at Kill Devil Hills, North Carolina, four miles south of Kitty Hawk. He flew 120 feet in 12 seconds and was recorded in the famous photograph below.



The 'Wright Flyer'

To do so they had to solve simultaneously the problems of control and power. They did the former by inventing wing warping for roll control combined with yaw control using a steerable rear rudder. At the same time they designed and built a low powered internal combustion engine, and designed and carved wooden propellers that were more efficient than any before. Although wing warping was only used very briefly during the history of aviation, the principle of combining lateral control with a rudder was a key advance in aircraft control. The fourth flight of The Wright Flyer took place on the same day as the first, and Wilbur was at the controls. He flew 852 feet in 59 seconds.

During the next two years the Wright brothers continued to develop their aircraft making many important design changes, including disconnecting the rudder from wing warping, this made an immediate improvement. A redesigned Flyer III became the first practical aircraft (albeit without wheels and needing a launching device) flying consistently under full control and bringing its pilot back to the starting point landing without damage. On 5 October 1905 Wilbur flew 24 miles in 39 minutes.

There were many other pioneers during this period, but perhaps the most notable was Louis Blériot who, on 25 July 1909, won world-wide fame by flying across the English Channel in his Bleriot XI.

The Bleriot XI

Finally, one other pioneer should be mentioned. Paul Cornu, who designed and built a helicopter (below); it made the first rotary wing free flight at Lisenux, France. However, the design proved impracticable, so the first successful rotorcraft was an autogyro invented by Juan de la Cierva and first flown in 1919.

Alcock & Brown and their trans-Atlantic Vickers Vimy in 1919

THE 'MODERN' AEROPLANE

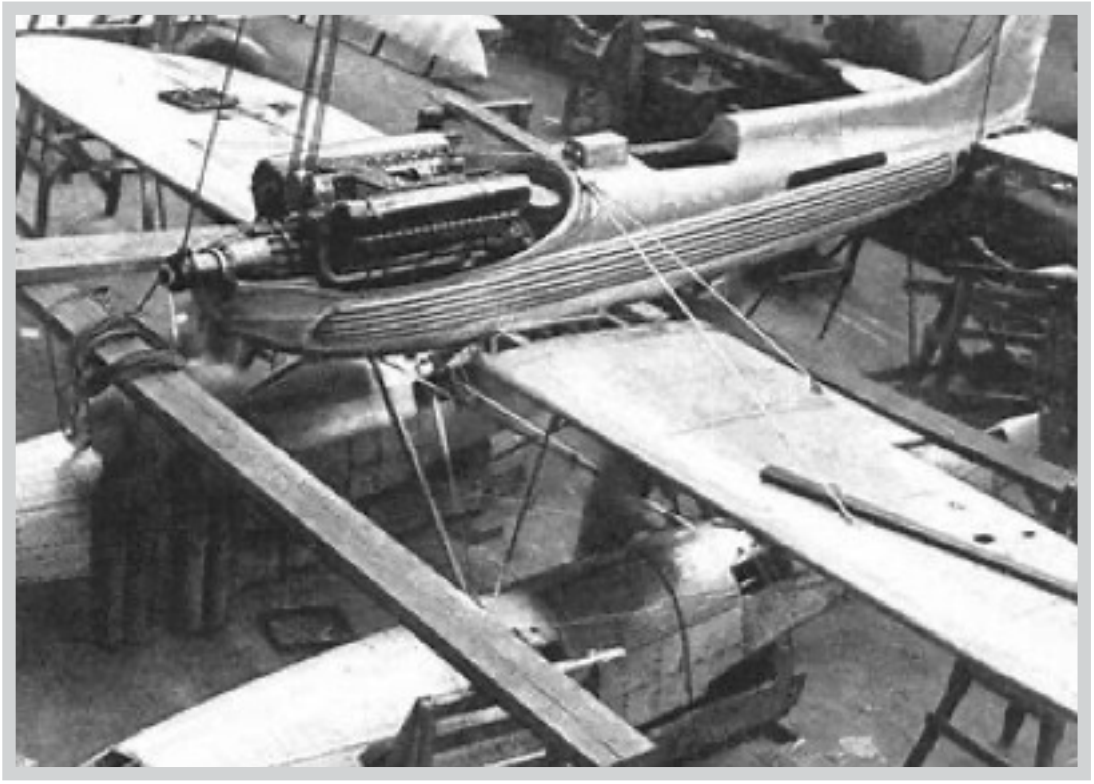
The world was moving from the first to the second industrial revolution, and as is often the case, sadly it was war that accelerated technological advancement. The concept of the airplane as an offensive weapon was generally discounted before WWI, but the idea of its use for reconnaissance was quickly taken up, especially with the development of radiotelephones so enabling communication between pilots and ground commanders. Thereafter it was only a short space of time before pilots were shooting at each other. France, Britain, Germany and Italy were the leading manufacturers of fighter planes at that time.

The inter-war years of 1918 – 1939 saw great advances in aircraft technology as airplanes evolved from low-powered wood and fabric bi-planes to high-powered monoplanes made of aluminium. Such names as Hugo Junkers, William Stout and Andrei Tupolev stand out. Furthermore, air races, and prizes for distance and speed records, continued to drive development. For example, on 14 June 1919 John Alcock and Arthur Brown made the first non-stop flight across the North Atlantic in a Vickers Vimy; and in 1922 Gago Coutinho and Sacadura Cabral made both the first flight cross the South Atlantic and one using astronomical navigation. Five years later Charles Lindbergh made the first solo non-stop flight cross the Atlantic; and in 1928 Charles Kingsford Smith made the first trans-Pacific flight. In 1929, Kingsford Smith and Charles Ulm were the first aviators to circumnavigate the world crossing the equator twice. Also in 1929 Jimmy Doolittle developed instrument flight; and Dornier built the largest plane ever built at that time, the Do X which, on 21 October, carried 169 people, a record not broken for 20 years.

And then there was the Schneider Trophy and an aircraft designer called RJ Mitchell. Both, together, and the resulting Supermarine Spitfire are, of course, fundamental to the ACP story.

The *Coupe d'Aviation Maritime Jacques Schneider* was a trophy awarded annually (and later biennially) to the winner of a race for seaplanes and flying boats. Announced in 1912 with the first race in 1913, it continued on until 1931. Initially it was intended to encourage technical advances in civil aviation, but soon became a contest for pure speed with laps over a triangular course of, eventually, 350 km. The contests were staged as time trials with aircraft setting off individually at pre-agreed times, usually 15 minutes apart. They were extremely popular. If an aero club won three races in five years they would retain the trophy. Each race was hosted by the previous winning country, and each club could enter up to three competitors. The symbolism of the trophy, which is sculptured in silver and bronze, represents speed conquering the elements of sea and air.

The importance of these races was significant in advancing aeroplane design, particularly in the fields of aerodynamics and engine design, and would show its results in the best fighters of WWII. The streamlined shape and the low drag, and the liquid cooled engine, pioneered by Schneider Trophy designs are exemplified in the American P-51 Mustang, the Italian Macchi C.202 and, of course, the British Supermarine Spitfire, the latter of which traces its heritage back to the Supermarine S5, S6 and S6B designed by RJ Mitchell which won the Trophy in 1927, 1929 and 1931 respectively, the last three races. During the 11 races over the years from 1913 to 1931 the winning speed rose from 48 mph to 340 mph; and then, shortly after the last race a Supermarine S6B flown by Flt Lt George Stainforth set a new world record of 404 mph.

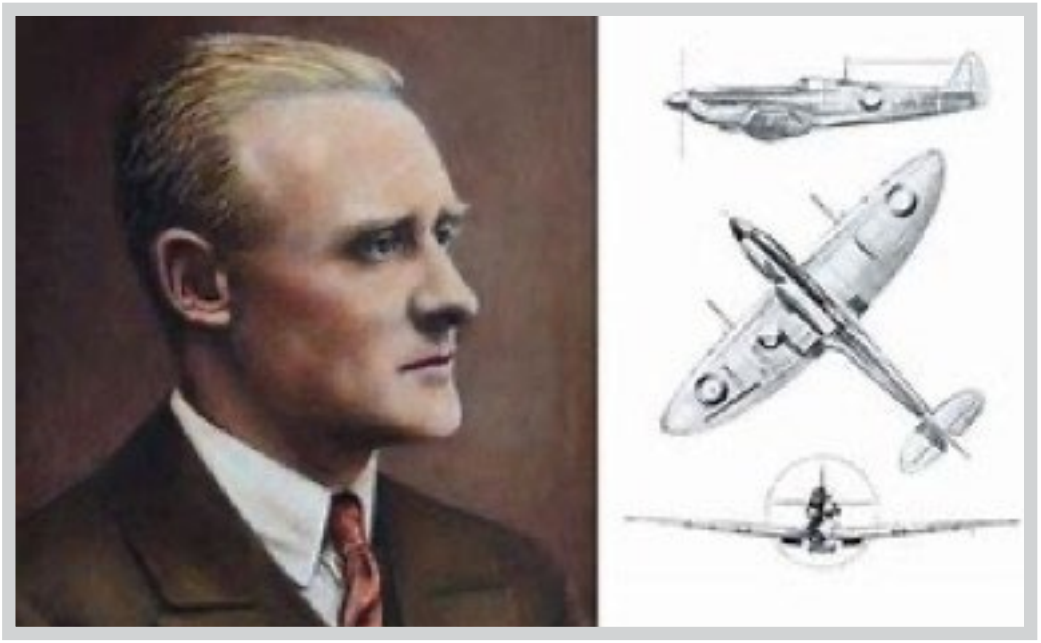


Supermarine S6B showing the new Rolls-Royce R engine.

Some significant aircraft manufacturers in WWII were as follows:

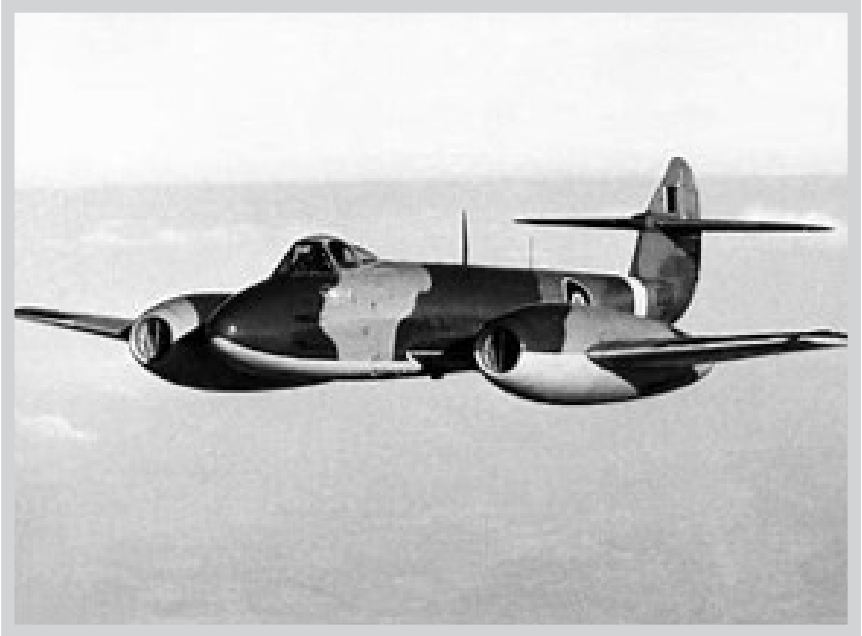
Armstrong Whitworth (UK)	Gloster (UK)	Mitsubishi (Japan)
Avro (UK)	Grumman (US)	Nakajima (Japan)
Bell (US)	Handley Page (UK)	North American Aviation
Boeing (US)	Hawker (UK)	Polikarpov (USSR)
Curtiss (US)	Heinkel (Germany)	Reggiane (Italy)
De Havilland (UK)	Ilyushin (USSR)	Short Brothers (UK)
Dornier (Germany)	Junkers (Germany)	Sikorsky (US)
Douglas (US)	Kawasaki (Japan)	Supermarine (UK)
Fairey (UK)	Lavochkin (USSR)	Tupolev (USSR)
Fiat (Italy)	Lockheed (US)	Vickers (UK)
Focke-Wulf (Germany)	Macchi (Italy)	Vought (US)
Fokker (Germany)	Messerschmitt (Germany)	Yakovlev (USSR)

And so we turn to the iconic aircraft that is at the heart of the ACP, RJ Mitchell's Spitfire.



"If anybody ever tells you anything about an aeroplane which is so bloody complicated you can't understand it, take it from me, it's all bollocks."

Advice given by RJ Mitchell about his engineering staff to test pilot Jeffrey Quill during prototype trials.



Gloster Meteor

The Spitfire was originally going to be called the 'Shrew', allegedly named after one of the design team's daughters who was called a spitfire because of her temperament. Mitchell commented *"That's just the bloody silly sort of name they would choose."*

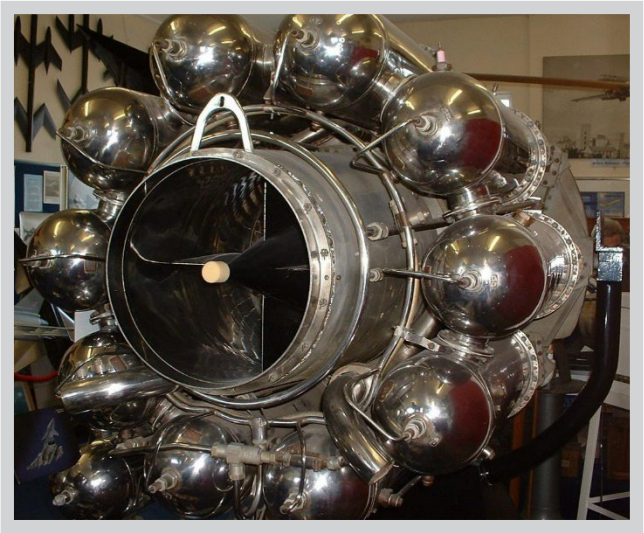
And so an aeronautical legend was born. The Spitfire was designed as a short-range, high-performance interceptor aircraft by Mitchell when he was chief designer at Supermarine Aviation Works, which operated as a subsidiary of Vickers-Armstrong from 1928. Mitchell pushed the Spitfire's distinctive elliptical wing with cutting-edge sunken rivets (designed by Beverley Shenstone) to have the thinnest possible cross-section, helping give the aircraft a higher top speed than several contemporary fighters, including Sydney Camm's magnificent Hawker Hurricane. Mitchell continued to refine the design until his death in 1937, whereupon his colleague Joseph Smith took over as chief designer, overseeing the Spitfire's development throughout its multitude of variants.

During the Battle of Britain, from July to October 1940, the public perceived the Spitfire to be the main RAF fighter, though the more numerous Hurricane shouldered a greater proportion of the burden against Germany's air force, the Luftwaffe. However, Spitfire units had a lower attrition rate and a higher victory-to-loss ratio than those flying Hurricanes because of the Spitfire's higher performance. During the battle, Spitfires were generally tasked with engaging Luftwaffe fighters, mainly the Messerschmitt Bf 109E, which was a close match for them.

After the Battle of Britain, the Spitfire superseded the Hurricane to become the backbone of RAF Fighter Command, and saw action in the European, Mediterranean, Pacific, and South-East Asian theatres. Much loved by its pilots, the Spitfire served in several roles, including interceptor, photo-reconnaissance, fighter-bomber, and trainer, and it continued to serve in some of these roles until the 1950s. The Seafire was a carrier-based adaptation of the Spitfire that served in the Fleet Air Arm from 1942 through to the mid-1950s. Although the original airframe was designed to be powered by a Rolls-Royce Merlin engine producing 1,030 hp it was strong enough and adaptable enough to use increasingly powerful Merlins and, in later marks, Rolls-Royce Griffon engines producing up to 2,340 hp. As a result, the Spitfire's performance and capabilities improved over the course of its service life. As a UK front-line fighter aircraft it was superseded by the Gloster Meteor, the RAF's first operational jet fighter which entered service in very limited numbers during 1944.

THE DAWN OF THE JET AGE

Based on a seminal paper published in 1926 (An Aerodynamic Theory of Turbine Design) in 1928 a young RAF College Cranwell cadet called Frank Whittle submitted his ideas for a turbo-jet to his superiors, and after further development submitted his first patent in 1930 (which was granted in 1932). A new aviation age had been born.



The W2/700. The first British production jet engine which powered earlier models of the Gloster Meteor.

Wing Commander Frank Whittle whilst at the Ministry of Aircraft Production.

Air Commodore Sir Frank Whittle, OM, KBE, CB, FRS, FRAeS as he became (1 June 1907 – 9 August 1996) single-handedly invented the turbojet engine. A patent was submitted by Maxime Guillaume in 1921 for a similar invention; however, this was technically unfeasible at the time. Despite considerable Government indifference and lack of funding Whittle's jet engine was developed some years earlier than that of Germany's Hans von Ohain who was the designer of the first *operational* turbojet engine and admitted later in life that he had, in fact, seen Whittle's patent five years before submitting his own.

The world's first aircraft to fly purely on turbojet power was the privately produced Heinkel HE 178 in 1939; but the first operational jet fighter was the Messerschmitt 262 in 1944 followed by the Heinkel He 162 in 1945. Additionally, in 1944 the first jet powered bomber went into service, the Arado Ar 234. That said, for many reasons, such as fuel shortages, lack of experienced pilots and the declining German war industry, their entry to service was delayed too long for this new technology to have a material effect on the outcome of WWII.

Two other concepts were tried. The motorjet, which was a combination of piston engine and turbojet, development of which was ceased at the end of WWII because the turbojet became regarded as a more practical solution to jet power; and rocket power, the first such aircraft being the Heinkel He 176, but the only one that went into operational service was the Messerschmitt Me 163. There was no jet on jet combat in WWII.

The Me 262. Design work started before WWII, but problems with engines, metallurgy and top-level interference kept the aircraft from operational status with the Luftwaffe until mid-1944. The Me 262 was faster and more heavily armed than any Allied fighter, including the British Gloster Meteor. Me 262 pilots claimed a total of 542 Allied aircraft shot down. The Allies countered its effectiveness in the air by attacking the aircraft on the ground and during take-off and landing. Materials shortages and design compromises on the Junkers Jumo 004 axial-flow turbojet engines led to reliability problems. Attacks by Allied forces on fuel supplies during the deteriorating late-war situation also reduced the effectiveness of the aircraft as a fighting force. In the end, the Me 262 had a negligible impact on the war as a result of its late introduction and the consequently small numbers put into operational service.

NAZI GERMANY'S AMAZING PLANS

There were several other important aerospace developments during WWII, especially in Germany.

One was helicopters with the introduction of the Focke Achgelis Fa 223 and the smaller Flettner Fl 282, and the Sikorsky R-4 in the USA.

Also: the experimental wire guided Ruhrstahl X-4 air-to-air rocket powered missile; the V1 - an early pulsejet cruise missile, the best counters to which were the Mosquito, Spitfire XIV and Mustang; an experimental SAM, the Rheintochter R1; and the V2, the first long-range guided ballistic missile.

Focke Achgelis Fa 223

Ruhrstahl X-4

Rheintochter R1

V1 Flying Bomb

V2 guided ballistic missile

Additionally in Germany: the first jet powered 'flying wing', the Gotha Go 229; the experimental delta wing Lippisch 13a powered by a granulated coal fuelled ramjet which was proved after the war by the USA could have outpaced and outmanoeuvred the most agile fighters of the day; the Heinkel Wespe, a project study into a tail-sitting VTOL interceptor; the successful push-pull piston engine heavy fighter, Dornier Do 335; and the four and six engined swept-forward wing jet powered bomber, the Junkers Ju 287.

Finally, for this document, the proposed 'Amerika Bomber' the Silbervogel, the design of which was a significant one as it incorporated new rocket technology and the principle of the lifting body, foreshadowing future development of winged spacecraft such as the X-20 Dyna-Soar of the 1960s and the Space Shuttle of the 1970s. In the end, it was considered too complex and expensive to produce. The design never went beyond mock-up test.

Gotha Go 229

Lippisch 13a

Heinkel Wespe

Dornier Do 335

Junkers Ju 287

Silbervogel Bomber

POST-WAR COMMERCIAL AVIATION

After World War II, commercial aviation grew rapidly, using mostly ex-military aircraft to transport people and cargo.

This growth was accelerated by the large number of heavy and super-heavy bomber airframes like the B-29 and Lancaster that could be converted into commercial aircraft. The DC-3 also made for easier and longer commercial flights. Two typical long-haul airliners of the early post-war period were the Lockheed Constellation and, later, the Bristol Britannia, both being turboprop powered.

Lockheed L-1049 Super Constellation

Bristol 175 Britannia

That said, by the time the Britannia flew the first commercial jet airliner was about to do so as well, the British de Havilland Comet. By 1952, the British state airline BOAC had introduced the Comet into scheduled service. While a technical achievement, the plane suffered a series of highly public failures, as the shape of the windows led to cracks due to metal fatigue. The fatigue was caused by cycles of pressurization and depressurization of the cabin and eventually led to a catastrophic failure of the plane's fuselage. By the time the problems were overcome, other jet airliner designs had already taken to the skies, in particular the Boeing 707 in 1957 and the DC-8 in 1959 which established new levels of comfort, safety and passenger expectations.

De Havilland DH106 Comet

Boeing 707